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Infrastructures of Aggression: Military Expenditure during the British Industrial and American Informational Mode of Development Shifts

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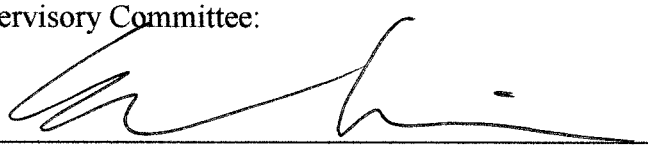
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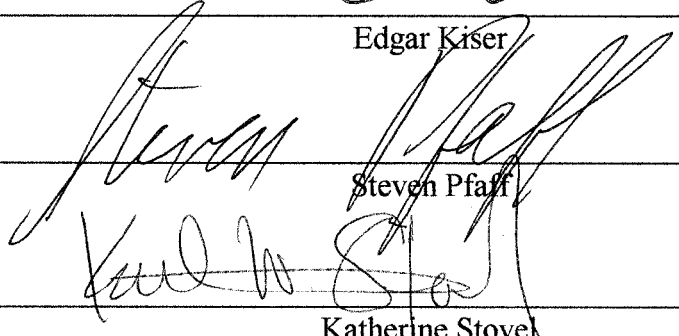


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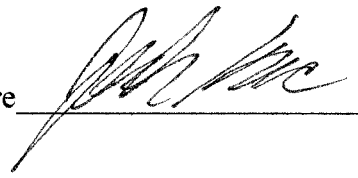


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Abstract

Infrastructures of Aggression: Military Expenditure during the British Industrial and American Informational Mode of Development Shifts

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Nearly a decade into the 21st century it is evident that the post-WWII American economy unleashed a global socio-technological transformation as profound as any experienced since the early days of the British Industrial Revolution. Surprisingly however, few social theorists have attempted to specify causal mechanisms that are common to both the British Industrial and American Informational 'Mode of Development Shifts.' A mode of development shift entails a pervasive transformation in the technological infrastructure through which productivity gains are derived. This comparative historical study demonstrates that long-term large-scale military expenditure acted as an effective agent of infrastructural transmogrification in both Britain (1689-1784) and the United States (1940-1999) owing to an interacting set of conjunctional causal variables including: capitalistic defense contracting, efficient tax administration, sound public deficit finance, the institutional prerequisites to economic development, and insulation from attack. Consequently, defense expenditure and its vicissitudes fomented a cyclical pattern of radical technological evolution in advanced infrastructural sectors followed by rapid commercial diffusion thus initiating the Industrial and Informational Mode of Development Shifts.

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CHAPTER 1: THE THEORY AND THE LITERATURE

Nearly a decade into the 21st century it is evident that the post WWII American economy unleashed a global socio-technological transformation as profound as any experienced since the early days of the British Industrial Revolution (Mokyr, 1997; Castells, 1996, 1998; Greenspan, 2000; Cortada, 2002; Gilder, 2005; Ruttan, 2006). Surprisingly however, few social theorists have attempted to specify causal mechanisms that are common to both the British Industrial Revolution and the American Information Technologies Revolution, and yet distinctive from the mechanisms that typically operate during periods of more regular technical change (Castells, 1996, 1998; Mokyr, 1997).[1] In this dissertation comparative historical methods will be utilized to assess whether large-scale military expenditure, conducted through a sound public deficit finance system and interjected into the economy via an institutionalized market-based competitive contracting mechanism, initiated similar and significant causal processes contributing to both the Industrial and Informational 'Mode of Development Shifts.'

Prior to and during the emergence of 'industrialism' as a comprehensive system of capital accumulation and economic growth, 18th century England was

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[1] Precisely delineating temporal boundaries for these two technological revolutions can be tricky, as will be discussed below. There is consensus that the British Industrial Revolution brought the world 'industrialism' – a novel framework for economic growth and capital accumulation first evident in the 1780s (Crafts, 1987; Mokyr, 1993; Crouzet, 2001); and that the American Information Technologies Revolution brought the world 'informationalism', alternatively termed flexible specialization or flexible volume production – a novel framework for economic growth and capital accumulation first evident in the 1980s (Piore and Sabel, 1984; Castells, 1996; Cortada, 2002; Beniger, 1986; Harvey, 1990; Harrison, 1994; Borrus and Zysman, 1992).

engaged in successive decades of expensive capital intensive hostilities.[2] Similarly, prior to and during the emergence of 'informationalism' as a comprehensive system of capital accumulation and economic growth, the 20th century United States of America was engaged in successive decades of expensive capital intensive military competition.[3] In order to wage capital intensive warfare, both 18th century Britain and the latter 20th century United States enacted a series of military expenditure packages that far exceeded in cost those that had ever come previously (Kennedy, 1987). In both these states military expenditure was carried out through analogous structural mechanisms and institutional configurations: The state, making use of efficient bureaucratic taxation and public deficit finance, amassed considerable capital. The state then spent this capital in an effort to meet specific, and many times complex, objectives arising from defense efforts. The state itself, however, did not produce the goods and materials that were required to fulfill these objectives. Capitalistic firms competing in an institutionalized market for defense contracts met the production goals set by autonomous state defense departments.

In the following, it will be argued that the state-guided competitive capitalistic contracting marketplace for defense expenditures drove commercial contracting firms in 18th century Britain and the latter 20th century US to expand,

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[2] England was embroiled in heavy battle for over half of the years between 1689 and 1784.
[3] WWII from 1941 to 1945, and then of course the Cold War from 1949 to 1989, which comprised the hot conflicts in Korea and Vietnam, along with other simmering third world cauldrons. In short, America was embroiled in costly capital intensive defense efforts in nearly every year between 1941 and 1989.

improve, rationalize, and innovate. Indeed, over the long course of their respective capital intensive battles, the technologies and production processes fomented by the synergistic interaction between defense departments and defense contractors generated, in both nations, the infrastructural foundations for entirely novel 'modes of development.'

All such theoretical claims will be tested below via an extensive application of comparative historical methods. I will be assessing and comparing the positive cases of Britain (1689-1784) and the United States (1940-1999), and the negative cases of France (1689-1784) and Japan (1945-1999).[4] The main hypothesis being analyzed can be reduced to the following: The crucial infrastructural technologies that compose the foundations for new 'modes of development' are innovated by capitalistic defense contracting firms profiting from public deficit funds directed to them by autonomous bureaucratic state agencies in a great power[5] nation-state confronting a grave national security threat. The national security threat motivates the massive accrual of public deficit funds, while a competitive institutionalized marketplace for defense contracts confers efficiency in the spending of these funds. Over an extended period of hostilities (multiple decades), potent, and heavily

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[4] The temporal parameters of the British and French cases are marked by the initiation of the Nine Years War and the close of the War of American Independence. This study avers that Britain's industrial mode of development formed within this interval (Deane, 1965; Ashton, 1968b; Mokyr, 1993; Crouzet, 2001). The temporal parameters of the American and Japanese cases are marked by the initiation of American involvement in WWII, the close of the Showa Era in Japan, and the end of the 20th century (in order to capture the first post Cold War decade). This study avers that America's informational mode of development formed within this interval (Castells, 1996; Bell, 1973; Harvey, 1990; Cortada, 2002).

[5] The term 'great power' simply denotes a nation with a GNP larger than that of most contemporaneous nations (Kennedy, 1987).

capitalized (i.e. approximately 6%-15% of GDP per annum), 'defense contractor–defense department' synergies interact with commercial markets more generally to generate an observable and measurable discontinuity and evolution in the warring nation-state's 'mode of development.'

WHAT IS A MODE OF DEVELOPMENT?

A mode of development indicates 'the technological arrangements through which labor works on matter to generate product and productivity gains' (Castells, 1996). A mode of development is categorized by the technical factor primarily being applied to production processes in order to yield progressively amplified productivity gains. Historically, there have been three modes of development: agrarianism, industrialism, and informationalism. In an agrarian mode of development incremental productivity gains are realized through the use of varying combinations of natural elements (land, labor, fertilizer). In an industrial mode of development productivity gains arise from the introduction of new energy sources into the production process (i.e. the conversion of heat into motion), and the ability to decentralize the use of energy throughout manufacturing via motors and machines (Forbes, 1958; Goldstone, 2000; Mokyr, 1993). In an informational mode of development information generation, processing, and transmission become the 'fuel' for productivity gain (Bell, 1973; Castells, 1996, 1998; Cortada, 2002).

Hence, up to the present, there have been two mode of development shifts – one towards industrialism and one towards informationalism. Both shifts occurred

within the capitalist mode of production, and both have qualitatively differed from the typically continuous augmentations of productive forces inherent in any capitalist mode of production.[6] Put simply, a shift in modes of development denotes a discontinuity in the developmental processes of capitalism itself (Castells, 1996; 1998).

The first transition to a new mode of development occurred when technologies that converted heat to motion, such as the steam engine, were widely applied to production processes, thus enabling extensive use of machine-based factory organization. An industrial mode of development can be defined by this conversion of energy to motion for use in machine-based production. In an industrial system productivity gains are primarily derived through the use of cheaper and more efficient energy sources (steam, oil, gas, and later electricity) generated by ever more portable engines powering increasingly complex machines. Notice that defining industrialism in this way creates continuity in western capitalist production from c.1780-c.1970 (Forbes, 1958; Bell, 1973; Castells, 1996; Goldstone, 2000).

Industrial production, by its very nature, entails heavy sunk costs in fixed and inflexible capital. This is because energy use is most rationalized in large standardized production systems (Taylor, 1911; Chandler, 1977). Factory based

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[6] A mode of development is quite distinct from a mode of production, and the two should not be confused. A mode of production refers to a specific gelling of class structures and the resultant productive and distributive relationships that emerge. Feudalism and capitalism are of course examples. A mode of development on the other hand refers to "the technological arrangements through which labor works on matter to generate the product, ultimately determining the level and quality of surplus" in a capitalist system (Castells, 1996, 16).

mass production then, and the economies of scale that developed from it, were direct outcomes of the industrial method of deriving productivity gains. Market saturation, however, was a dire consequence for the inflexible industrial corporation. In response to market saturation industrial corporations vertically integrated – one firm oversaw and completed the total production process from the stage of raw materials right through to the final consumer purchase; this decreased costs, thus increasing market size and market-share.[7] Indeed, over time the search for new markets for large batches of standardized goods, and cheaper resources with which to manufacture them, propelled the modern vertically integrated industrial corporation to the farthest corners of the globe (Taylor, 1911; Bell, 1973; Chandler, 1977; Piore and Sabel, 1984; Harvey, 1990; Castells, 1996).

The advent of semiconductors transformed the industrial corporation and the industrial mode of development along with it. The application of the microprocessor to manufacturing marks a discontinuity in the development of capitalism; with the computer was born the informational mode of development (Castells, 1996). In the informational mode of development production processes are no longer rigid and standardized; they are flexible, variegated, and ephemeral. Corporations are no longer vertically integrated; they are horizontally networked to other corporations in impermanent chains of supply and production. Information technologies power these supply and production chains by providing the real-time linkages that connect one corporation and its informational databases to another

[7] In America, the first industrialists to vertically integrate "did so because existing marketers were unable to sell and distribute products in the volume they were produced" (Chandler, 1977, 287).

corporation and its informational databases. Goods are assembled within these world-spanning networks of interdependent yet independently managed firms. Any one specific combination of firms and products is expected to persist in the short run only. Short-run batches of commodities are manufactured for specific purposes and specific markets; when the purpose is filled or the market is saturated the network changes. A network of a different geometry composed of varied firms capable of fulfilling new market niches then arises (Bell, 1973; Chandler, 1977; Piore and Sabel, 1984; Beniger, 1986; Harvey, 1990; Harrison, 1994; Castells, 1996).

This new regime of capital accumulation has been widely termed flexible volume production.[8] Since markets are naturally in a state of flux, output, productivity, profit, and capital accumulation are enhanced if production is flexible. Information technologies, and the attendant ability to instantaneously apply new reams of information to production, allow it to be so. Utilizing reprogrammable software attached to fixed capital hardware, firms immediately transform market signals into commodities. As market demand alters, new products and processes quickly appear. Information technologies enabling massive 'just in time' inventory

[8] The terms flexible volume production, flexible automation, flexible mass production, lean production, etc., all describe large-scale implementations of old time flexible specialization production techniques through the application of informational technologies. For the sake of simplicity all the types and methods of flexible specialization that mark informationalism as a unique mode of development are subsumed under the label flexible volume production here. One important rationale for doing so is that flexible volume production indicates flexible inter-firm mass production on a global scale empowered and enabled by information technologies, while the term flexible specialization is often applied in a more local sense and tends to focus upon intra-firm managerial techniques (Piore and Sabel, 1984; Borrus and Zysman, 1992, 20-1; Castells, 1996, 1998).

systems are crucial to this method of production, as are direct and flexible linkages between buyers and sellers. In fact, the more powerful information technologies become (the faster they can process larger amounts of data), the greater the possibilities for combining productive and reprogrammable corporate capital, market indicators, inventory, and innovative scientific knowledge in novel ways. This is especially true if information is accessible globally, and it is. Digitalization has provided the world with a common language enabling database interaction on an international scale. As a result, knowledge centers around the world have become interconnected, and they are interacting with corporate production networks, thus facilitating the innovation of new products and manufacturing processes. As production and innovation accelerates, market flux is augmented, and supply is immediately brought into line with the augmented market flux. Within the informational mode of development, productivity gains emerge from this virtuous interactive circle composed of producers, buyers, and innovators all linked by information technologies (Piore and Sabel, 1984; Beniger, 1986; Harvey, 1990; Borrus and Zysman, 1992, 20-1; Harrison, 1994; Castells, 1996; Harris, 1998; Greenspan, 2000).

Additionally, information technologies have radically transformed global finance, thus broadening and quickening capital flows, thereby enhancing productivity further. IT powered financial markets have become the nerve center directing the rise and fall of new firms and network geometries in the pursuit of ever greater accumulation at the global level. Funds are quickly drawn to, or

withdrawn from, horizontally integrated global production chains as required in order to maintain flexibility and amplify profits. This occurs via a dense 24 hour global real-time instantaneous electronic trading complex capable of swiftly erecting or destroying entire domains of production. Moreover, advanced information processing devices, many times handheld by traders on floors or in offices, have enabled the rise of increasingly exotic investment vehicles, such as derivatives, collateralized debt and loan obligations, and 'quant funds', which allow speculative gains to multiply while infinitesimally distributing, and thus limiting, risk. The result has been a nearly continuous creation of expanding liquidity, which, when applied to flexible methods of consumption and production, extensively augments productivity in the informational mode of development (Harvey, 1990; Castells, 1998, 360-5; Greenspan, 2000; Cortada, 2002; Dearnley, 2001).

If it is true that informationalism, industrialism, and agrarianism are in fact three distinct modes of capitalist development, what distinguishes the periods of transition in between them from more regular periods of technological change? Separate modes of development should not be conceived of as discrete dichotomous variables. Owing to the coordination requirements of productive processes all successful technical change necessarily exhibits a good deal of historical continuity. In other words, technological change is largely path dependent (David, 1985, 1990; Ruttan, 2001, 2006). However, as Nelson and Winter (1982) make clear in their seminal work, *An Evolutionary Theory of*

Economic Change, at any one juncture in the evolutionary chain of technical development there are numerous potential directions that technological trajectories can take. Nelson and Winter argue that the path that is actually taken is an outcome of complex organizational selection processes (in a manner akin to biological natural selection). Regardless of selection mechanism, Nelson and Winter view "organizations as being typically much better at the tasks of self-maintenance in a constant environment than they are at major change, and much better at changing in the direction of 'more of the same' than they are at any other kind of change" (9-10).

Transitioning to a new mode of development, by definition, is not 'more of the same.' This then is one way to understand a mode of development shift as distinct from regular periods of technological change – it is not change in the direction of more of the same – it is change towards radically new ways of producing and engendering productivity gains. In neo-classical economics, technological advance is measured by shifts in production functions. "The production function specifies a quantitative relation between inputs and outputs: given the quantities of various inputs, a certain amount of final product will be generated" (Elster, 1983, 96). Regular technical progress causes production functions to gradually shift outward – equal values of input generate incrementally increased values of output. During such normal periods of technical development the established pattern of economic activity is enhanced and extended (Castells, 1996). A shift in mode of development, on the other hand, significantly transforms

economic activities and processes of production. A mode of development shift manifests as a cluster of interrelated radical[9] innovations that rapidly alter production functions and rates of productivity. Momentous structural changes are effected in an economy; economic differentiation advances and capital investments deepen. The extent of technological change involved in a transition to a new mode of development can therefore be distinguished from periods of more regular technical change by measuring the pace and quality of 1) increasing economic differentiation, 2) deepening levels of capital investment, and 3) positive augmentations and discontinuities in productivity and economic production functions (Castells, 1996, 1998; Mathias, 1969; Elster, 1983; Mokyr, 1993).

Of these indicators, increased economic differentiation is perhaps the most palpable manifestation of a mode of development shift. For a mode of development shift is marked by the emergence of technologies that allow productivity gains to be derived from production processes in greater quantities, but more importantly, in novel ways. Hence, there is a clear qualitative difference between a rapid deepening of the current mode of development and an actual shift in modes of development. Modes of developments can and do evolve without shifting (Castells, 1996; 1998). For example, in the 17th century new methods of fertilization and crop rotation caused British agricultural productivity to rise. Some have termed this an agricultural revolution (John, 1967). An agricultural revolution

[9] "An innovation is incremental if it is an improvement to an existing technology and radical if it could not have evolved through incremental improvements in the technology that it challenges in some particular use" (Lipsey et al, 1998, 36).

it may have been, a mode of development shift it was not. Any productivity gains that occur in an agrarian mode of development, by definition, arise from new combinations of natural elements (land, labor, fertilizer, animal power, etc.). Thus the 17th century 'agricultural revolution' in Britain was a perfecting or deepening of the extant mode of development. By the 19th century productivity gains in the British economy were being derived primarily from the increased application of motors and machines to production – a transition from one mode of development to another had occurred. Of course, the shift did not occur overnight. The temporal boundaries of a mode of development shift are fluid and therefore difficult to precisely specify.[10] Moreover, just as historians of technological trajectories would predict, there was initially much continuity between the agrarian and industrial modes of development (Nelson and Winter, 1982; Elster, 1983). Nevertheless, it is clear that the 'technological arrangements through which labor works on matter to generate product and productivity gains' went through an observable and measurable transformation away from agrarian methods and towards industrial methods during the mid to late 18th century (Landes, 1969; Deane, 1965; Ashton, 1968b; Crafts, 1987; Castells, 1996; Mokyr, 1993).

Much as the agrarian mode of development deepened and was perfected over time, the industrial mode of development too deepened and was perfected – sometimes quite quickly. Most notably, at the inception of the twentieth century there was what has been termed the 'Second Industrial Revolution' (Landes, 1969).

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[10] See the long standing debate amongst economic historians regarding the dating of the Industrial Revolution (Rostow, 1960; Mathias, 1972; Crafts, 1987; Rule, 1992; Mokyr, 1993).

The Second Industrial Revolution was marked by advances in electrical power, electrical motors, the internal combustion engine, automotive devices, and standardized assembly line production. As indicated by its very moniker the Second Industrial Revolution was a deepening of the extant mode of development – productivity gains were being derived in greater quantities through ever better methods of converting energy into motion (Castells, 1996; Landes, 1969; Taylor, 1911).

In the literature on technological change one is hard pressed to find a serious scholar dubbing the Information Technologies Revolution the 'Third Industrial Revolution.' And there is good reason for that – production today is less and less industrial and more and more informational in nature. As discussed above, information technologies and concomitant flexible volume production have replaced the engine and associated assembly line production as the main motors of economic growth and productivity gain in the developed world. Again, this change did not occur over night. In fact we are currently and undoubtedly still in the midst of it (Bell, 1999; Castells, 1996; Cortada, 2002). Being in the midst of it, one merely has to look to manufacturing today – from the automotive to the apparel to the mining industries – to see that informational technologies many times interact with and help coordinate industrial methods of production. Nevertheless, it is quite clear, that in the past thirty years, the 'technological arrangements through which labor works on matter to generate product and productivity gains' have been radically transformed – they are drastically more informational (Bell, 1973; Piore

and Sabel, 1984; Beniger, 1986; Harvey, 1990; Harrison, 1994; Castells, 1996; Dearnley, 2001; Cortada, 2002).

Was this change inevitable? Is the application of information technologies to industrial production simply a natural progression of industrialism itself? Is the developed world merely perfecting and deepening the industrial mode of development yet again? Daniel Bell (1973; 1999), James Beniger (1986), David Harvey (1990), Bennett Harrison (1994), Manuel Castells (1996; 1998), and James Cortada (2002), along with a whole host of other social theorists studying the issue, all say, unequivocally, no. Something more is going on; there has been an unambiguous break with industrialism, and this it seems was not an inevitable occurrence.

No work points to this fact better than Piore and Sabel's *The Second Industrial Divide* (1984). At the time the book was written, Piore and Sabel identified two alternative paths for industrial production. One, 'International Keynesianism', was a relatively simple international expansion of the vertically integrated system of mass production. In the language of Manuel Castells (1996: 154), this trajectory involved a 'deepening of the current industrial mode of development.' The second alternative path that Piore and Sabel identified, 'Flexible Specialization', entailed the widespread application of information technologies to corporate production processes and a corresponding transition to horizontally integrated corporate organizational modes. It is now clear that the second path was taken. The late twentieth century witnessed a shift away from the

industrial mode of development and towards an informational mode of development (Castells, 1996; 1998).

The rise of 'informationalism' begs the question; what in late twentieth century capitalist society caused the general framework for capital accumulation and economic development to transform? In answering this important question social scientists have tended to focus upon the emergence of increased economic competition in mass-produced industrial spheres that occurred throughout the 1960s and 1970s. Subsequent margin pressures led transnational corporations to convert their inflexible vertically based modes of integration, organization, and production into flexible horizontally networked modes of integration, organization, and production. This transition, as discussed above, required information technologies. When information technologies were applied to transnational corporate production processes, profits increased and a new regime of accumulation emerged (Piore and Sabel, 1984; Harvey, 1990; Borrus and Zysman, 1992; Harrison, 1994; Castells, 1996).

Given that organizations are better at changing in the direction of 'more of the same' than they are at any other kind of change (Nelson and Winter, 1982), why didn't OECD corporations and governments resolve the 1970s global profit recession through an internationally coordinated expansion of Keynesian demand policies? Piore and Sabel (1984) opine that the political wherewithal for such policies had waned by the late 1970s, in part due to the 1970s oil shocks and inflation (increasing profit through demand stimulation would have required

global-wide amplified energy consumption and likely would have exacerbated systemic inflation). Moreover, the development of information technologies had made feasible a new mode of streamlined and more profitable production not requiring extra energy consumption. Therefore, in the 1970s and 1980s the rational economizing micro-economic choice was one towards the application of information technologies to manufacturing thus causing a shift in macro-economic organizational forms (Piore and Sabel, 1984; Harvey, 1990; Harrison, 1994). Flexible volume production (i.e. flexible specialization techniques applied globally and empowered by infrastructural information technologies) was born and the industrial world's mode of development began to shift (Castells, 1996, 1998; Cortada, 2002).

MODE OF DEVELOPMENT SHIFTS AND MILITARY EXPENDITURES:

Another important question, especially germane to this dissertation, arises from the above explications: Specifically, where did the information technologies that enabled corporate transitions to horizontally networked and flexible modes of integration come from? In the *Second Industrial Divide* Piore and Sabel (1984) outline the technological requirements of flexible volume production and make clear that the requisite technologies existed as of the 1970s. However, the emergence and innovation of the information technologies necessary to the mass implementation of the new regime of accumulation is left as an exogenous and unexplained factor in Piore and Sable's model. To be sure, the pace of corporate

technological change in the 1970s, like most other times, was conditioned by profits (or lack thereof). However, profit cycles alone cannot explain why the late 1970s profit recession in particular was overcome through the adoption and adaptation of information technologies. Information technologies were applied to production processes because they were there, but why were they there?

Oddly, discussions of Cold War military expenditure are typically absent from causal analyses of flexible volume production and informational 'take-off' (Bell, 1973; Piore and Sabel, 1984; Harvey 1990; Harrison, 1994; Castells, 1996). This is surprising, mainly because many of the informational infrastructural innovations that facilitated the new regime of accumulation were developed by the American Department of Defense, or related agencies such as the National Aeronautics Space Administration (NASA) and the Defense Advanced Research Project Agency (DARPA), in alliance with independent labs and privately owned defense contractors. Semiconductors, computers, the Internet, satellites, and fiber optic communications are only a few technological innovations in a myriad of examples that benefited from state defense department – market contractor synergies during the Cold War (Galbraith, 1978; Botkin and Dimanecescu, 1984; Martin, 1996; Hecht, 1999; Ruttan, 2006: DeLanda, 1991; NRC, 1999; Gavaghan, 1998).

I believe a similar argument can be made for the British Industrial Revolution; privately owned and independently managed firms in the iron, steam, mining, shipbuilding, and transport sectors of the British economy profited from

large-scale military expenditures as the 18th century British productive infrastructure transitioned from agrarian to industrial. Whether 18th century British military expenditures facilitated or hindered the Industrial Revolution has been a matter of some debate. As will be discussed in more detail during the formal treatment of the British Case, most mainstream economic historians have argued that, if 18th century British military spending had any affect on British development at all, it was probably a negative one (Ashton, 1968; Landes, 1969; Mathias, 1979; Rule, 1992). Two quotes from the famous TS Ashton serve to summarize this view:

> "Advocacy of the thesis that the claims of war and the weakening of foreign competition by tariff barriers and high freights were stimulating to the iron trade must not be taken to imply the heresy that war may be productive of national wealth. What the ironmaster gained at this time the British consumer, in large measure, lost" (Ashton, 1968b, 152). "If there had been no wars to force up prices, raise rates of interest, and turn resources to destruction, the course of the industrial revolution would have been smoother, and its consequences would not have been, as they are, in dispute" (Ashton, 1968, 126).

There are two main problems with such classically liberal and conventional analyses. First, they tend to be motivated by a political stance of pacifism. Second, the arguments typically rest upon largely unsubstantiated counterfactuals. Perhaps 18th century military spending contributed to the long-run growth prospects of the British economy by switching gains from consumers to ironmasters. Perhaps war had other indispensable stimulatory effects that more than made up for rising prices and interest rates.

This is precisely the position that William McNeill (1982) takes in his opus, *The Pursuit of Power*:

> "Most historians of the Industrial Revolution pay little attention to war. Those who do notice it usually argue that the war hindered rather than promoted industrial development. This is a questionable proposition. The vast increases in governmental expenditures, nearly all for war purposes, surely affected supply and demand for every article exchanged in the British economy. Only if one assumes that some other stimulus would have put the entire labor force to work and endowed the formerly underemployed portion of the British public with an effective purchasing power equivalent to that exercised by the British army and navy, does it seem plausible to assume that in the absence of war the pace of British industrialization would have equaled or exceeded that which actually occurred" (McNeill, 1982, 210).

It is McNeill's contention that great power rivalry with France positively altered effective demand in 18th century Britain, displacing it from items of personal consumption towards items requiring large fixed capital expenditures and developed infrastructure for their production. Unfortunately, this line of thought is tangential to McNeill's overall weapons development theses in the *Pursuit of Power*, and he thus departs from the debate leaving the question unsettled and in need of further empirical support.

McNeill is not alone in challenging the conventional historical doctrine that regards military spending as a hindrance to British industrialization. A.H. John (1955) asserts that in the years prior to 1763 war opened markets and stimulated the introduction of innovations in the iron sector without causing inflation. Phyllis Deane (1975) echoes John's view, but she opines that by the time of the Napoleonic Wars, war induced inflation extinguished the previous positive effects of military spending. Patrick O'Brien (1989), on the other hand, is uncertain whether Deane's relatively one-dimensional take on the Napoleonic Wars accurately depicts the complicated dynamics between military spending and

economic growth in late 18th century Britain. In "The Impact of The Revolutionary and Napoleonic Wars on the Long-Run Growth of the British Economy" O'Brien composes an empirically based 'balance sheet' weighing the positive and negative effects of British military spending during the years 1793-1815. His findings are quite detailed and thus too lengthy to recount here. However, his final conclusion summarizes his article and the current state of the literature quite well: "At present there seems to be no basis for arguing that wars with France either seriously retarded or actively stimulated the progress of British industry" (380).

In short, few if any modern economic historians have been so bold as to claim that British military expenditure was a necessary and indispensable causal variable in the economic processes leading to British industrialization. However, none have empirically established the opposite. Why, some two hundred years after the 18th century, does such uncertainty concerning the role of military expenditures in the Industrial Revolution still exist? The problem lies in the necessarily counterfactual nature of the debate. The historical circumstances are such that, for better or for worse, Britain did spend heavily to fight the long 18th century French wars. Whether the long run growth prospects for Britain would have been lessened, or improved, were it not for military spending is therefore a difficult question to answer.

A comparative historical analysis of mode of development shifts that incorporates both positive and negative cases offers a method for circumventing

this counterfactual conundrum. In order to formulate a resolute assertion concerning the role of military expenditure during the genesis of the Industrial Revolution, one need not look at Britain in isolation. One can study the outcome in cases that resemble 18th century Britain on the important measures (e.g. the latter 20th century United States). One can also search for cases similar to 18th century Britain, but where critical variables of interest, such as military spending, are absent. Of course, owing to the necessarily small n of cases and the large number of potential causal variables no one comparative historical study could entirely solve the counterfactual conundrum involved in analyzing the role of military expenditure during the Industrial or Information Technologies Revolutions. Nevertheless, a comparative historical project carefully constructed in regards to case selection and theory should illuminate the causal processes related to military expenditure during a mode of development shift better than the typical one case studies that have previously sought to address the question. A four case comparative historical study is being undertaken here. Its methodology and case choice will be detailed below. Before a comprehensive methodological discussion can be taken up though, the dissertation's theory must first be precisely delineated.

A CAUSAL THEORY OF THE MILITARY EXPENDITURE IMPETUS TO MODE OF DEVELOPMENT SHIFTS:

The causal variables in the abstracted theory pertaining to the impetus of military expenditures during the transition from one mode of development to another are:

1) *Long-term large scale military expenditure and purchasing aimed at the procurement of capital intensive, technically advanced, heavy weaponry.* Long-term (multiple consecutive decades) large-scale (6%-15% of GDP per annum) military spending and purchasing aimed at the procurement of high cost heavy weaponry (typically associated with naval / and or aerospace weapons systems) displaces effective demand in a capitalist nation from consumables towards capital intensive technically complex goods which require advanced infrastructure for their manufacture (McNeill, 1982). Over time this alteration of effective demand profoundly modifies the technological character of production in the economic sectors directly implicated in national defense; from these sectors spring innovative, state of the art, and radically new infrastructurally oriented products and processes (Galbraith, 1978; Varynen, 1992, 15; Smith, 1985, 18). Such sophisticated and innovative infrastructural goods and techniques can elicit fresh new ways of organizing commercial production and generating productivity gain, thus creating the potential for a mode of development shift.

2) *A competitive capitalistic marketplace for defense contracts with formally institutionalized bidding and purchasing procedures, composed of independent private contracting firms, and directed by autonomous state defense departments.* Contractual purchasing arrangements between defense departments and competitive market-based defense contracting firms institutes a set of legal, bureaucratic, and social ties connecting autonomous state agencies to innovative domestic capitalists. These institutional ties provide a mechanism enabling

directed military spending and state-supported innovation without requiring the state to centralize control. Centralized state control precludes the operation of the 'military expenditure impetus to mode of development shifts theory' because states lack diverse sources of intelligence for innovation, and there are few greater motivators to innovate than individualized profit potential (Evans, 1995). In an effective market-based defense contracting system, bureaucratically managed autonomous state agencies direct private capitalistic firms to meet complex, and many times previously unattainable, objectives arising from urgent and emergent national security needs. Concurrently, competition for defense funds amongst contractors provides a potent force compelling process rationalization and radical innovation. Hence, state-directed military spending aimed at the procurement of high cost state of the art weaponry, when undertaken in coordination with a competitive capitalistic marketplace for military contracts, can over time create powerful synergies steering economic, infrastructural, and technological change (Galbraith, 1978; Varynen, 1992, 15; Yudken and Black, 1991, 180-81; Smith, 1985, 18; Misa, 1985, 287; Hooks, 1990, 391; Kovacic, 1990b, 106).

3) *A sound public deficit finance system.* Sound public deficit finance provides the economic 'fuel' that powers the defense department – defense contractor synergies described above. Public deficit finance involves the issuance of interest bearing transferable debt securities by the government. It allows a capitalist state to pool surplus capital (savings from the private marketplace) and direct it towards a desired goal. Public deficit finance can be used to marshal considerable amounts of

capital; amounts unthinkable absent public deficit finance. In general, only grave national security threats have provided sufficient justification for massive public indebtedness; that indebtedness in turn assures that the defense department–defense contractor synergies that lie at the crux of the 'military expenditure impetus to mode of development shifts theory' are copiously capitalized (Dickson, 1967; Galbraith, 1978; Brewer, 1988). However, if capital goods improvements are to materialize during war amidst massive public indebtedness, public deficit finance must proceed on a sound basis. Otherwise the investment climate would be unsuitable for increased capital expenditures (due to destabilizing factors such as hyper-inflation). As will be detailed extensively below, the crucial elements required for sound public deficit finance include a modern bureaucratically managed treasury, a central bank with regulatory control over currency issue and debt monetization, a large pool of domestic and international creditors, along with other various organizational structures and institutional minutiae (Dickson, 1967; Malkin, 1987; Brewer, 1988; Carruthers, 1996; Gordon, 1997; Sturm and Muller, 1999).

4) *Efficient systems of taxation typically bureaucratic in nature*. Efficient taxation[11] is crucial to both long-term large-scale military expenditure and sound public deficit finance. In modern bureaucratic states over 50% of military expenditure is usually covered by yearly tax revenues (Dickson, 1967; Kennedy, 1987). Nevertheless, because of the slow pace of tax collection, modern

[11] Efficiency will be measured below by looking at the ratio of aggregate revenue as compared with the costs of collection (Brewer, 1988; Ishi, 1993).

bureaucratic states tend to spend well ahead of the actual receipt of revenue by issuing short and long-term public debt instruments. The regularly scheduled payments of interest on these and all public debt instruments are necessarily funded directly out of tax revenue. Thus public deficit finance cannot be operative and useful unless tax receipts are specifically earmarked to service particular debts; otherwise few would ever purchase a public bond. Therefore efficient taxation and predictable revenue estimation are essential preconditions to sound public deficit finance. Bureaucratic tax collection is typically the most effective way of assuring earmarking.[12] As long as tax revenue is collected in an efficient and predictable manner earmarking will be reliable. The gross amount of taxation collected and the per capita tax burdens imposed are important in so far as they enable increased military expenditure and allow the earmarking of ever greater volumes of public debt (Brewer, 1988; Tilly, 1990; Carruthers, 1996; Gordon, 1997). In addition to enabling sound public deficit finance, taxation can be viewed as a causal factor in the 'military expenditure impetus to mode of development shifts' processes if it effectively redistributes income towards defense contractors that are innovating state of the art weapons and technologies, and / or towards investors who are capitalizing the subsequent commercialization of said innovations.

5) *The Institutional Prerequisites to Economic Development: parliamentary (or*

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[12] Monitoring capacity is the key variable determining whether bureaucratic tax collection will be efficient. Bureaucratic taxation is therefore most effective in states with developed transportation networks. In some structural environments (for example those with poor transportation networks), non-bureaucratic tax collection is most effective (Kiser and Kane, 2001). The key variable here then is not bureaucracy, but efficiency and predictability.

electoral) governance, secure property rights, and low transaction costs. These institutional factors are grouped together as one independent variable because they are structurally necessary in order for any sort of significant market-generated economic development to occur (North, 1990; North and Weingast, 1989; North and Thomas, 1973); whether regular incremental progress, rapid continuous progress, or a discontinuous mode of development shift. Parliamentary (or electoral) governance is especially important in this study not only because such governance guarantees secure property rights by couching rulers in a codified system of checks and balances preventing arbitrary confiscation of gains and thus maintaining incentives to exchange, but also because parliamentary governance insures that public credit instruments oblige the entire nation rather than just a single monarch or ruling faction. This greatly widens the pool of capital and credit available to the state by lowering risks to investment (North and Weingast, 1989; Dickson, 1967). Additionally, secure property rights, especially those involved in knowledge protection (i.e. patent laws), are crucial to the functioning of the 'military expenditure impetus to mode of development shifts theory' because in a capitalist market technological innovation will not occur without them (North, 1990; North and Thomas, 1973). A shift in mode of development of course involves innovation, but also relies on new and widening markets for trade and credit, increased productivity, and deeper economic differentiation and penetration into the social milieu (Castells, 1996; 1998). All of these things require heightened integration of factor, capital, and credit markets; and therefore also necessitate low

transaction costs, especially at the macroeconomic level of interregional exchange (North, 1990).

6) *Insulation from attack.* Market oriented technological progress and growth in fixed capital investment is implausible if infrastructure is likely to be destroyed or if security of rule is low. Therefore, if the citizenry deems the domestic market to be insufficiently protected, the mechanisms driving the 'military expenditure impetus to mode of development shifts theory' will not obtain.

When put into action, the theoretical model generally works like this: A clear and present national security threat confronts a modern bureaucratic capitalistic state. The state pools its nation's surplus capital through the mechanisms of public deficit finance and bureaucratic taxation. The state then directs this continually amassing capital, by way of bureaucratic agencies that are institutionally embedded in and also autonomous from the nation's indigenous capitalist market, to capitalistic firms engaged in the production of war materials. If the war materials desired by the state's purchasing boards are intended for use in advanced capital intensive naval or aerospace type combat, then the capitalist firms, which are vigorously competing to obtain the nation's pooled purchasing power, will necessarily be producing goods that require increased fixed capital expenditures and expanded or innovative capital infrastructure for their manufacture. Continued war continually reinforces these competitive firms' capital goods investments and innovations; for battle (or an arms race) is a 'black hole' into which the materials of war are inescapably thrown. The longer the state is at

war, the more demand there is for innovative infrastructurally based productivity enhancing developments. As military expenditures continue, capital expenditures in defense industries are continually augmented. The ranks of the engineering community also multiply. In time, numerous technological, infrastructural, and human capital advances that aid in the production of war materials emerge.

Ironically though, the actual transition from one mode of development to the next tends to take place during the characteristically short-lived intervals of peace following periods of intense rivalry over the entire multi-decadal span of long-term great power military competition; such as the interval of peace between 1763 and 1775 during the 'Second Hundred Years War', or the 1970s détente that occurred during the Cold War. An active phase of great power military competition creates tremendous over capacity in defense industries – both in output capabilities and in human capital. When peace ensues, either intermittently or permanently, engineers and capitalists who had been engaged in war production are released back into the commercial economy. If the economy is sufficiently capitalist (i.e. patent, contract, and investment laws), these profit seekers immediately search for ways to apply their newly innovated capital facilities and talents to the products of peace. They are often (although not always) successful for military production mirrors market production in numerous ways.[13] After a brief period of economic adjustment, the human and fixed capital enhancements

[13] The importance of turnover time, the need for precision, portability and resource efficiency as essential, standardization is required, and separate parts must be coordinated to work as an organic whole (DeLanda, 1991; Ruttan, 2006).

gained through defense efforts result in abundant direct and indirect commercial applications during peace. As intense conflict alternates with relative peace over the protracted span of a momentous great power rivalry, progressive infrastructural innovations arise within the modern capitalistic state, interact with the underlying commercial economy, and eventually coalesce into the foundational framework for a novel mode of development.

An important corollary to the above abstracted theoretical process states that: *The form the mode of development takes is to a significant extent dependent upon the type of conflict that contributed to its evolution.* In other words, the informational mode of development is 'informational', in part, because the nuclear arms race was in many ways informational – the US military was interested in developing a communications infrastructure that would immediately discern a pending Soviet first strike through rapid remote data retrieval and informational analysis. The infrastructural technologies that emerged (integrated circuits, computers, the Internet, satellites, etc.) now provide the framework for the informational mode of development (DeLanda, 1991; Botkin and Dimanecescu, 1984; Martin, 1996; Castells, 1998; Hecht, 1999; Gavaghan, 1998).

Similarly, 18th century warfare made great use of heavy cast iron materials and mass-produced capital goods such as immense cannons, ordnance, naval ships and all their associated wares (McNeill, 1982). Hence iron foundries, shipbuilders, the mining industry, and later the burgeoning steam engine sector, were all stimulated during 18th century war. Additionally, increased production in these

sectors encouraged canal and road construction in Britain as budding industrialists sought better and cheaper ways to transport their heavy wares (Ashton, 1968b; John, 1955; Deane, 1975). Advances in cast iron production, steam-power, and transport infrastructure in essence define British industrialization (Rule, 1992; Landes, 1969; Mokyr, 1993; Deane, 1965). It is thus fair to posit that the means of 18th century warfare significantly molded the Industrial Revolution (John, 1955; Deane, 1975; McNeill, 1982; O'Brien, 1991; Crouzet, 2001).

Three caveats concerning this important corollary must be noted. First, the form the mode of development takes is not entirely or solely dependent upon the type of conflict that contributed to its development. To begin with, styles of war do not develop in a vacuum. They are fundamentally related to the nature of the combatants' economies. Nonetheless, wars have often caused economies to alter in ways primarily attributable to the needs of battle. For example, cast iron was not popular in early 18th century Britain – iron from the forge had more ductility and was more tensile. Iron from the foundry (cast iron) however produced better and cheaper cannons, ordnance, anchors, and guns. The rapid growth and improvement of foundries and foundry techniques in Britain throughout the 18th century was, I will argue, directly attributable to war. And it is foundry iron that was later used for rails, engines, machinery, bridges, canals, and buildings; in short, the foundry drove the Industrial Revolution (Anderson, 1972; John, 1955; Ashton, 1968b; Deane, 1975, 1965). Thus, cast iron had existed, but it was entirely transformed by

war, and subsequently became a crucial infrastructural technology capable of fomenting a mode of development shift.

The second and related caveat to the above corollary arises from an argument that has previously been mentioned – the actual 'mode of development shift' tends to take place during the intervals of peace following periods of active conflict – therefore, extant productive processes significantly mold modes of development along with evolving methods of conflict. Perhaps an example will clarify this point: in the aftermath of the Seven Years War (1756-1763),

> "Ironmasters in particular had to face the fact that some of their markets had, for a time at least, ceased to exist, and that new outlets must be found if production were to be continued. Hence it was in 1767 that Coalbrookdale Company used its surplus metal to make rails of iron to replace those of wood on its wagon ways. This was done partly in order to keep the men in employment, and with the knowledge that if iron again rose in price the rails could be taken up and sold, but also, no doubt, in the hope of creating a commodity of general use" (Ashton, 1968b, 134-5).

In other words, cast iron rails replaced wooden wagon ways because the Seven Years War left ironmasters with overcapacity for production of cast iron, but wooden wagon ways had long existed in iron enterprises, well before the Seven Years War. Similarly, after the Seven Years War, John Wilkinson converted his newly invented canon boring machine into a device designed for the boring of steam engine cylinders. Inefficient atmospheric steam engines had been used to pump water from mines for decades prior to the 1760s. However, it was Wilkinson's application of the canon borer that made Watt's two chamber steam engine an efficient converter of energy capable of theretofore unimaginable feats of mechanically propelled perpetual motion (Forward, 1924, 36; Musson and

Robinson, 1969, 445; Tann, 1974, 84). Combined, these two defense-related improvements of already existing commercial devices eventually yielded a radically new mode of industrial transportation; the railroad (Ashton, 1968b, 56; Mokyr, 1993, 56). Thus it becomes clear that both the evolving nature of conflict and extant productive methods impact the forms that radical invention takes as war born fixed and human capital are released back into the commercial economy during those intervals of peace when mode of development shifts progressively take hold.

The two caveats to the corollary thus far mentioned can be summarized in one statement: Although methods of conflict are initially a function of the economies of the combatants, the form the new mode of development takes is significantly conditioned by evolving methods of conflict, in conjunction with extant productive processes. This statement is concerned with causal process; the coming analyses will avoid tautology. As will be shown, during transitions to new modes of development, heightened conflict and military expenditure do measurably and independently affect the infrastructural nature of the underlying commercial economy. The new economic infrastructure then reacts back upon methods of war, which in turn prompts further alteration of commercial technological trajectories. Over protracted decades of intense, albeit somewhat intermittent, great power rivalry, the consequences of this 'feedback loop' can be quite profound, creating an obvious discontinuity in a nation's capitalist mode of development.

Feedback loops such as these are notoriously difficult to deal with

methodologically. A feedback loop emerges when the development and change of two interacting systems becomes interdependent – changes to one system prompts alterations in the interacting system, and the loop is completed when these secondary alterations react back upon the initial system, causing changes there, which of course starts the process over again. The feedback facilitating the syncing of modifications in two interdependent systems comes in three main, often interrelated, forms: informational feedback (envision the sequenced alterations taking place between a mainstream news conglomerate and the alternative 'blogosphere'), electronic or wave-based feedback (envision the sequenced alterations taking place between Hendrix's guitar and his amplifier), and economic feedback (envision the sequenced alterations taking place between a company's profits and its stock price). Feedback can be positive, which means that feedback between the two systems increases the output of each; or negative, which means that feedback between the two systems reduces the output of each until either the systems themselves or their interconnections dissolve (Johnson, 2001).

In the case of the theoretical statement at hand, the productive infrastructure for war can be said to be interacting with the underlying commercial economy in a positive economic feedback loop leading, over time, to an aggregate mode of development shift. Driving the interdependent change of the two systems is large-scale military expenditures injected into the economy owing to a sustained arms race between two or more great powers.

> "An arms race, in natural evolution or in human history, forms what is called a self-sustained feedback loop. In this sense an arms race resembles physical processes such as runaway explosions, or chemical processes like cross catalytic reactions, in which the product of the reaction stimulates the production of a second substance which in turn accelerates the rate of production of the first substance. While natural processes, following the laws of thermodynamics, always tend to seek a point of equilibrium, self sustained feedback loops push natural processes away from equilibrium, toward critical points. Points that often inflect towards the onset of new evolutionary processes of development" (DeLanda, 1991, 49).

A number of positive economic feedback loops will be analyzed in this study; notably those relating to military expenditure, iron, and economic development as the British economy transitioned from agrarianism to industrialism, and those relating to military expenditure, information technologies, and economic development as the American economy transitioned from industrialism to informationalism. More concretely, the claim will be made that war became somewhat industrial before the British economy did; cast iron was needed for Britain's style of capital intensive naval warfare before it became the infrastructural backbone of industrialism (Deane, 1965; 1975). Thus, in a significant way, the need for heavy cast iron cannons, and the way in which Britain funded their construction, kicked off the complex feedback loop leading to the British Industrial Revolution. The same can be said of the positive economic feedback loop leading to the American Information Technologies Revolution – war turned informational first; mid 20th century America required information technologies in order to prepare for potential nuclear war prior to information technologies becoming the infrastructural backbone for enhanced commercial development (DeLanda, 1991).

Although the mid-late 20th century advent of electronic feedback has changed the terminology somewhat, it is clear that comparative history has long been the methodology that sociologists have relied upon in order to unravel causality in such positive economic 'feedback loops.' In this methodology, the proposed causal mechanism presumed to be propelling the feedback loop is derived from an analysis of one or two positive cases, and then tested against negative cases or further positive cases exhibiting a background environment that facilitates the isolation of the key causal mechanism (Weber, 1978; Stinchcombe, 1978; Tilly, 1984; Ragin, 1987; Mann, 1993; Kiser and Hechter, 1991). To what qualitative or quantifiable extent, then, does military expenditure cause a new mode of development to come into being and settle on a particular infrastructural constellation is an empirical question that I will be attempting to address below through the use of comparative historical methods.

One final caveat to the original theoretical corollary above (*the form the mode of development takes is to a significant extent dependent upon the type of conflict that contributed to its evolution*) is an acknowledgement that American military spending during the Cold War affected technological trajectories in a much more direct, intense, intentional, and rapid fashion than did British military spending during the 18th century. Increased capital expenditure by defense contractors on advanced capital intensive infrastructure was clearly an *unintended* consequence of British war finance. Contrariwise, during the Cold War the American Defense Department quite *intentionally* guided technological

trajectories.[14] Nevertheless, I believe that in both the British and American cases, extremely outsized military expenditures, actualized through sound public deficit finance and activated via market-based contracting, over the long-run, induced technological and infrastructural changes indispensable to the formation of novel modes of development. The mechanisms are simply more direct and formalized in the American case, as will be shown.

WHY INFRASTRUCTURES OF AGGRESSION?

Much has already been said of infrastructure, and of course, the overarching definition being employed here refers to a set of interconnected techno-structural elements providing the framework supporting a system, such as a mode of development. In economic terms, "when a sector exhibits massive spillover effects and the knowledge is tacit and passed through community institutions along with diverse markets the sector could be considered part of the economic infrastructure" (Conca, 1992, 246). An economic sector also must be ubiquitously applied and generate broad externalities (social gains that are not fully capturable by private firms) if it is to be deemed infrastructural (Borrus and Zysman, 1992, 213-4).

Taken together these definitional concepts mark the technologies studied

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[14] This is not surprising, for in the twentieth century all great power states took a direct hand in steering scientists and researchers towards complex technological advances in defense weaponry (Galbraith, 1978; McNeill, 1982). And yet only the US domestically generated an informational mode of development shift. Whether production of defense weaponry in 20th century great power states had transformative redounding effects upon the underlying domestic economy was primarily determined, I would argue, by the variables in the 'military expenditure impetus to mode of development shifts theory'; i.e. the nature and scale of procurement, the soundness of the fiscal variables, the quality of economic institutions, and the level of insulation from attack.

here (mainly cast iron capital goods, the steam engine, semiconductors, computers, and the Internet) as key techno-economic infrastructures (Harris, 1998; Helpman, 1998; Lipsey et al, 1998; Helpman and Trajtenberg, 1998; Bresnahan and Gambardella, 1998, 255). For example, 'Computers and semiconductors have long ago ceased to be valued as artifacts unto themselves. Like the steam engine or electricity before it, they have become a part of modern technical infrastructure.' They are valued for their ability to seamlessly integrate into and improve nearly every contemporaneous technologically oriented activity (Akera and Nebeker, 2002, 4).

Going further, this dissertation seeks to establish that the key technological systems that came to compose the infrastructural foundations of the industrial and informational mode of developments would not have developed in the radical, rapid, and coordinated ways in which they did absent the military expenditure impetus. It will be shown that in each respective period military expenditure and its vicissitudes largely determined the pace of the synchronized development and diffusion of the key infrastructural technologies at hand. In each case, the underlying technologies were incredibly expensive to develop, and far different from anything the market was offering prior to the massive reorientation in effective demand brought on by colossal defense expenditure. In fact, the evolution of the critical infrastructural sectors analyzed in this study clearly followed a defense-type logic where military need took precedence over expense, rather than a market-type logic where cost and profit trumped all. The data in this study will

plainly indicate that the crucial industrial and informational infrastructural technologies did not evolve out of endogenous economic processes alone; rather, their primary forms crystallized in response to exogenous defense needs. After decades of feedback loop interaction with commercial markets, these initially defense-oriented, and thus radically new, sectors engendered entirely novel technological trajectories and methods of deriving productivity gain; trajectories and methods that almost certainly would not have formed in the same extraordinary way, or at a synchronized pace, if they had resulted from endogenous market processes only (Ruttan, 2006; DeLanda, 1991).

Of course, this comparative project has been designed in order to first support, and then to test, these bold, and at times counterfactual, claims. We will return to this point subsequently, but before we do it is important to differentiate the 'military expenditure impetus to mode of development shifts theory' from other theories of coalesced innovation. The idea that exogenous defense-related forces fundamentally determined the development and diffusion of the key technological sectors that came to compose the infrastructural foundations of the industrial and informational modes of development sets the 'military expenditure impetus to mode of development shifts theory' apart from already established theories of coalesced innovation. Since the time of Joseph Schumpeter (1934), scholars have noted the periodic coalescence of major innovations into what has been termed 'techno-economic paradigms.' "A techno-economic paradigm embodies a relatively stable cluster of core technologies, around which innovation and

economic activity takes place" (Conceicao and Heitor, 2006). According to world systems and K-wave theorists, techno-economic paradigms arise every forty to sixty years (or so) owing to a cycle that is as endogenous and natural to capitalism as the shorter business cycle. These longer forty to sixty year cycles are termed K-waves, which have two phases: a twenty to thirty year A-phase wherein new innovations arise and coalesce into a techno-economic paradigm, and a twenty to thirty year B-phase wherein the techno-economic paradigm diffuses throughout the world. The endogenous market mechanism driving the periodic K-wave cycle relates to profit rates on the key techno-economic paradigm technologies – they descend during the B-phase as the central technologies and techniques diffuse thus initiating a new A-phase period of innovation (Freeman and Louca, 2001; Modelski and Thompson, 1996; Boswell, 1991; Hopkins and Wallerstein, 1982).

As should be apparent from the 40-60 year temporality of K-waves, techno-economic paradigms shift far more often than modes of development do. For example, Freeman and Louca (2001) assert that the industrial age, starting in 1770, exhibited four separate techno-economic paradigms, and that since 1970 there has been one 'information and communications' techno-economic paradigm. Assuredly then, there must be something rather unique about the initial discontinuous transition to an industrial, and later to an informational, techno-economic paradigm. As has been discussed above, Manuel Castells (1996; 1998) has persuasively argued that these two techno-economic paradigm shifts are historically unique because they alone are marked by severe discontinuity in the

technical methods through which labor works on matter to generate productivity gains. This dissertation asserts that these more rare discontinuous shifts in 'productivity paradigms' (i.e. modes of development) arose as a consequence of a powerful exogenous extra-market force: multiple decades of massive defense expenditure amassed via sound public deficit finance and interjected into the economy through a market-based contracting mechanism. The causal importance of this exogenous force to both mode of development shifts can be understood most simply and directly by apprehending the actuality that each mode of development shift was preceded by a multi-decadal span wherein nearly continuous conflict came to be predominated by the same factors that ultimately transmogrified into the infrastructural bases for the new modes of development. In other words, as has been asserted above and will be detailed below, battle in the period preceding industrialization became cast-iron capital goods centric; similarly battle became information-centric decades prior to the emergence of informationalism as a systemic framework for capital accumulation and productivity gain. Thus military expenditure can be viewed as the exogenous disturbance to regular endogenous market processes that caused productivity paradigms to shift in an exceptionally radical discontinuous manner during the two mode of development shifts heretofore witnessed.[15] Hence this dissertation avers that both the industrial

[15] What technical problems are to be solved, and the kinds of solutions that become acceptable, is determined not only by those who hold social power, but also by the problems that they face. As a consequence, national security exigencies can widen the selection alternatives in the evolutionary process of technological change and help adjudicate between them, thus significantly biasing the direction of technical change. Over time, the effect can be quite great (Varynen, 1992, 15; Yudken

techno-economic infrastructure and the informational techno-economic infrastructure are properly considered infrastructures born of militaristic aggression.[16]

SITUATING THE THEORY IN THE LITERATURE ON WAR AND DEVELOPMENT:

How does the above multifaceted theory fit into the broad literature on war and economic development? The modern literature on war and economic development can be traced back to Werner Sombart, an early twentieth century Professor of Sociology and National Economy working at the University of Berlin. In *Krieg und Kapitalismus (War and Capitalism)*, published on the eve of WWI, Sombart argued that war, and preparation for it, spawned capitalism in Europe. He asserted that the union of the warlord and the capitalist led to large scale enterprises designed to meet the increasing pressure of demands for food, clothing, and munitions arising from combat. He also claimed that all of the great advances in metallurgy, machinery, and standardized production issued from battle. Eighteenth century war, in particular he said, forced the rationalization of production and exchange while also enlarging the shipbuilding industries. Sombart did admit that

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and Black, 1991, 180-81; Smith, 1985, 18; Misa, 1985, 287; Hooks, 1990, 391). Indeed, defense expenditures have "frequently influenced the rate and direction of inventive activity in the economy as a whole" for decades at a time (Kovacic, 1990b, 106).

[16] As conflict between Great Powers extends in time and range, strategy morphs from domestic defense to an aggression bound provision of 'national security', which entails protection of 'economic, political, and military interests throughout the world, wherein virtually every development in the world, in times of both peace and war, is perceived to be potentially crucial' (Hooks, 1990, 366). Such a description certainly applies to both 18th century British and latter 20th century American military posture, thus the term 'aggression' seems more apropos than 'defense' in regards to these two cases.

taxation during war impoverished many, but he believed that nascent capitalists in heavy industry benefited greatly. In short, it was Sombart's view that war and only war was able to fulfill many preconditions of capitalist development in Europe; "War was not the offspring of economic structures, but rather their progenitor" (Sombart quoted in Winter, 1975, 5; Smith, 1985).

Sombart's views were controversial even in his own day. Many authors at the time complained that his theses were overstated and rather one sided, failing to take into full account either the many negatives of war or the overwhelming importance of progress in the peaceful spheres of business during Europe's transition to capitalism. *Krieg und Kapitalismus* also lacked rigorous definition of key concepts and sufficient evidence to support Sombart's weighty claims. As time passed, Sombart's views became all the more controversial, for, not surprisingly, Adolf Hitler adored the work of Werner Sombart. And as Hitler rose to power in Germany, Werner Sombart became an eminent member of the Nazi Party. By the end of WWII Sombart's theses had been entirely rejected by more 'civilized' scholars (Trebilcock, 1969; Winter, 1975; Smith, 1985).

Professors in the United States did not address questions concerning war and economic development in any great detail until after WWII. Of course, at this time, much of the American interest in the debate was driven by a blind, albeit understandable, hatred of Nazism. In *Western Civilization Since the Renaissance*, John Nef (1963), the foremost American expert on the subject, summarized his career-long findings; "Wars contributed less than nothing while the preparation for

war contributed relatively little to economic progress" (cited in Trebilcock, 1969, 475). Walt Rostow, also a famous American theorist interested in the question, tended to agree with Nef. In fact, by foreshadowing the 'crowding out thesis,' Rostow (1942) unwittingly laid the foundations for mainstream American views on the debate:

> "Similar volumes of new investment for war materials and cotton factories may, within a given period, have precisely the same income and employment multiplier effects, and they may yield precisely the same secondary increases in new investment. But in the first case society is left with a number of cannon, and in the second case with enlarged facilities for production: that is, lower long run cost curves" (Rostow, 1942; quoted in Anderson, 1972, 3).

Rostow and Nef's basic arguments remained mainstream through at least the 1980s (really right up to the present). Indeed, the 1980s can be characterized as a decade in which questions of 'economic development and war' received far more attention than questions of 'war and economic development.' Paul Kennedy's famous and widely read opus, *The Rise and Fall of the Great Powers* (1987), is representative. In the book, Kennedy delineates the complex history of great power war (extended conflicts amongst the globe's leading nations). He asserts that great power wars are the site where the uneven economic development of states becomes an international hierarchy of power. "There is detectable a causal relationship between the shifts that have occurred over time in the general economic and productive balances and the position occupied by individual powers in the interstate system" (xxvii). Kennedy, however, does not address whether great power war itself can positively affect processes of economic development. In fact, it is

Kennedy's view that an economy can easily become overburdened by military expenditures, thus leading to industrial decline.

World systems theorists, such as Albert Bergesen (1985), Christopher Chase-Dunn (1989), Terry Boswell (1991), George Modelski and William Thompson (1996), and Terence Hopkins and Immanuel Wallerstein (1982), emphatically agree with the tenor of Mr. Kennedy's arguments concerning 'imperial overstretch.'[17] Going further, world-systems theorists have spent an extraordinary amount of time and effort attempting to link intervals of imperial overstretch with concomitant global war and incidences of K-waves. In their estimation K-waves trigger war; however, wars cannot produce K-waves. Indeed, much like Paul Kennedy, world-systems theorists believe that military expenditure is far more likely to cause national overextension and economic decline than economic progress of any sort.

World Systems Theory as a field was enormously popular during the early-mid 1980s; Ronald Reagan was in power and American Cold War military expenditures were soaring once again. Simultaneously, the United States began losing its technological supremacy in the world-economy to a rapidly emergent Japan. Is it no wonder that academics of the day were concerned with the potential destabilizing effects of military expenditures? This general concern came to be

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[17] Imperial overstretch is a condition wherein a polity's power commitments require military expenditures beyond what its economy can handle. For a discussion of the imperial overstretch thesis as applied to the Soviet Union see Randall Collins' "The Future Decline of the Russian Empire: An Application of Geopolitical Theory," a 1980 lecture later published in *Weberian Sociological Theory* (1986).

embodied in the 'crowding out thesis'; an idea that continues to enjoy widespread currency. "The idea of crowding out is simply that under full employment, an increase in the difference between the amount of resources used by the government and the resources released by reducing private consumption through taxation or inflation has to come from investment." Decreased private sector investment means less private sector innovation; less private sector innovation means diminished economic growth, or so the theory goes (Mokyr, 1987, 294). This preoccupation with the harmful effects of military spending, and its negative affects on technological development, still endures. Even though the strict scope condition on the crowding out thesis – full employment – is rarely satisfied (McNeill, 1982; Mintz, 1992; Ruttan, 2006).

One famous historian stood against the grain of the literature in the 1980s – the aforementioned William McNeill. In *The Pursuit of Power* (1982), McNeill documents the role that states have played in initiating processes of technological development as a consequence of warfare. He also records the effects that such processes have had on the development of technology: 18th century British military spending drove the 18th century revolutions in iron production and steam use; military spending during the Crimean War brought Bessemer steel; state spending in WWI enormously increased industrial capacity for mass production; microwave, nuclear, and rocket technologies were an outcome of state military R&D expenditure during WWII; and state spending during the Cold War produced spaceships and satellite technologies. As McNeill outlines the history of these

weapons developments, he also illuminates an historical trend towards ever greater state involvement in weapons innovations. He terms this trend one of 'command technological development', wherein states increasingly command producers to innovate certain things that are needed for successful military endeavors. In McNeill's view, all great power states adopted systems of command technological development in the period directly before WWI, and have since commanded producers during times of war. Thus, McNeill makes no distinction between the post 1945 American market-based contracting system of military technological development and that of the entirely socialistic USSR.

McNeill is an historian, and although his historical narrative is detailed and compelling, it is not scientific in a sociological manner; his theories are incompletely stated and loosely applied, his comparisons are not methodologically sound, and there is no systematic discussion or specification of the variables necessary to generating successful command processes of technological development. Thus McNeill's conclusions are somewhat unsatisfying, and they leave one asking many questions. Some of the more interesting broadly sociological questions include: If many key infrastructural technologies spring from states in order that they may fight wars, what caused states themselves to come into being? Is not national security the main chore of the state? Is it not possible then that wars caused states to evolve? Has conflict therefore initiated processes leading to both the development of the state and the development of the technological infrastructures of production that states utilize?

In recent years a large literature has arisen which addresses the origins of the 'European nation-state model' – a model that eventually proliferated throughout the world. Most authors in this literature have identified war as a (if not the) prime driver of state formations and transformations (Bean, 1973; Hintze, 1975; Mann, 1986; Tilly, 1975, 1985, 1990; Ertman, 1997). In fact, "The general argument that wars were the main causes of the growth of states has now been widely accepted" (Kiser and Linton, 2001, 411). Charles Tilly's seminal work, *Coercion, Capital and European States* (1990) clearly articulates this general argument: "Far more than other activities, war and preparation for war produced the major components of European states" (28). Conflict caused the structurally diverse 10th century European states to eventually converge on one form – that of the capitalistic bureaucratic tax state. As technologies of war became ever more complex throughout the second millennia (driven to complexity by increasingly fierce competition in the anarchic European interstate system) only states which had taken the 'capitalized coercion' path to development could muster the mounting costs of war. The capitalistic growth dynamic was unique in its capacity to generate the resources required in order to meet spiraling combat expenses. By the eighteenth century, warfare costs were met mostly through borrowing, and Tilly makes clear that the capitalist bureaucratic tax state had an undeniable advantage over other types of states in the fiscal realm as well. The pools of capital necessary to capitalize public deficit finance were deeper in states containing a vibrant capitalist class. Furthermore, bureaucratic taxation allowed certain taxes to be earmarked for

future debt repayment, hence limiting outlay risk. Thus capitalistic states that developed bureaucratic taxation and a sound fiscal system of debt out-competed and extinguished other state forms during inter-European and later extra-European great power war.

Naturally then, detailed historical studies of European fiscal systems have combined with and contributed to the war and state-building literature. Many of these studies have focused on the British system in particular; for the 18th century British state was among the first capitalistic bureaucratic tax states to develop a sound public deficit finance system (Binney, 1958; Dickson, 1967; Brewer, 1988; Carruthers, 1996). In this literature too, war is identified as the key variable driving the development of bureaucratic tax administration and public deficit finance (Brewer, 1988; Carruthers, 1996; Kiser and Linton, 2001). In his seminal work, *The Sinews of Power* (1988), John Brewer makes the argument plain: "Victory in battle relied in the first instance upon an adequate supply of men and munitions, which, in turn, depended on sufficient money and proper organization – what modern military men call logistics and sociologists dub infrastructure" (xv). In tracing the development of this financial infrastructure, Brewer avers that the eighteenth century French wars caused the British state to become the largest single actor in the British economy:

> "The state's military role made it the most important single factor in the (18th century British) domestic economy: the largest borrower and spender, as well as the largest single employer. Public spending, fueled by military costs, rose by leaps and bounds. The civilian administration supporting the military effort burgeoned; taxes and debts increased. Britain acquired a

> standing army and navy. She became, like her main rivals, a fiscal-military state, one dominated by the task of waging war (27)."

To finance large military efforts, 18th century Britain revolutionized its taxation and financial system. By the 19th century, the British model of finance – complete with efficient tax collection, predictable revenue, short and long term publicly funded debt securities, and a central bank – was envied and emulated the world over (Dickson, 1967; Brewer, 1988; Carruthers, 1996).

In today's historical and economic literature the structural components that compose the British model of finance are taken to be necessary requirements to successful national economic development (North, 1990). Conventional doctrine concerning economic development is completed with the addition of institutionalist theory. Institutionalists, such as Ronald Coase (1937), Oliver Williamson (1981), Douglass North (1990), and Walter Powell and Paul DiMaggio (1991) focus on transaction costs – "the cost of measuring the valuable attributes of what is being exchanged and the costs of protecting rights and policing and enforcing agreements" (North, 1990, 27). Institutionalists assert that economic growth can only take place in states where the legal system minimizes the transaction costs involved in exchange and innovation through mechanisms such as non-arbitrary property and patent laws (North and Thomas, 1973; North, 1990).

Hence, conventional economic and historical doctrines commonly cite sound public deficit finance, bureaucratic tax collection, parliamentary (or electoral) political systems, property laws, and low transaction costs as critical ingredients necessary to both regular and swift economic progress (Rostow, 1960;

Landes, 1969; North, 1990). Military spending, on the other hand, is typically excluded from conventional causal discussions of economic development. In fact, as suggested above, long-term large-scale military expenditure is often cited in historical and political-economic literatures as a deterrent to rapid economic growth (Nef, 1950; Rostow, 1960; Ashton, 1968; Mokyr, 1987; DiFilippo, 1990; Mintz, 1992).

Drawing upon the literature, I accept that sound public deficit finance, efficient tax collection, parliamentary (or electoral) governance, property laws, and low transaction costs are key and necessary elements to national economic development of any sort, and therefore also crucial during transitions from one mode of development to the another.[18] However, in this work's theoretical model the above state institutional / structural factors are not considered sufficient for the initiation of the processes propelling mode of development transitions forward. Throughout diverse settings, the presence of sound public deficit finance, bureaucratic tax collection, parliamentary governance, property laws, and low transaction costs have not spontaneously and regularly generated mode of development shifts; there have only been two, and both of these occurred in capitalistic bureaucratic tax states funding large-scale military expenditure during multi-decadal spanned great power rivalries.

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[18] In the theory I disaggregate the economic foundations of modern liberal democratic states into discrete variables because sound public deficit finance, bureaucratic tax collection, and the institutional prerequisites to economic growth did not develop to the same extent or in the same manner in each modern state (Mann, 1986; 1993). Theoretically then, variation in each of these structural / institutional components may in and of itself alter outcomes on the dependent variable.

In this project, the state structural and institutional foundations of 'liberal democracies', which developed over the long history of western political-economic formation, as well as the cumulative private savings of investors that also amassed over this history, are taken to be metaphorical 'uranium.' A long-term large-scale national security effort then can be considered the metaphorical 'Manhattan Project': massive defense spending, when accumulated through public deficit finance and the state structural / institutional variables listed in the theoretical model, and enacted through an institutionalized market-based defense contracting mechanism, effectively coordinates aggregate national savings at sufficient quantities and intensity to create a 'critical mass' for a mode of development shift. Up to the present, only great power rivalry has motivated the pooling of enough metaphorical 'uranium' (i.e. taxation, debt, and savings) to cause a metaphorical 'nuclear explosion' (i.e. a mode of development shift). Without state directed military expenditure acting as 'The Manhattan Project', the detonation of a mode of development shift is viewed here as highly improbable.[19]

Is there sociological justification for specifying military expenditure as a crucial causal factor in mode of development shifts when conventional historical and economic doctrines caution against this? I believe there is. Many political economists and scholars studying economic development contend that states necessarily play a critical role in modern processes of technical innovation and

[19] Perhaps in the future some pressing need not related to great power rivalry, such as environmental devastation, will motivate liberal democratic states to accumulate and direct aggregate national capital in a powerful enough way to propel a mode of development shift.

development (beyond that of providing a suitable institutional framework) (Bell, 1973; Galbraith, 1978; Gereffi, 1990; Evans, 1995; Helpman, 1998). States coordinate and fund research through university systems (Bell, 1973). States can also partially absorb the risks involved in high cost private sector R&D by limiting market uncertainty through demand stimulation (Galbraith, 1978). Perhaps most importantly, state agencies can form umbrella coalitions amongst diverse and competitive domestic capitalists in order to chart a path of technologically driven expansion (Gereffi, 1990; Evans, 1995; Anchordoguy, 2005).

Peter Evans in his seminal study of technological progress in the developing world, *Embedded Autonomy: States and Industrial Transformation* (1995), explains the importance of the state's role as technological 'handmaiden.' With the collapse of the Soviet statist model, Evans takes it as a given that market economies provide the best socio-economic environment for technological innovation. He then poses the question; what types of states are best suited to promoting technological advance in the milieu of a market economy? His answer is a 'developmental state.' Evans argues that developmental states are not command states for those tend to be overly predatory, under-bureaucratic in their organization, and stifling of development. Developmental states are also not Weberian type states entirely insulated from society.

> "To the contrary, (developmental states) are embedded in a concrete set of social ties that binds the state to society and provides institutionalized channels for the continual negotiations and re-negotiations of goals and policies. Either side of the combination by itself would not work. A state that is only autonomous would lack both sources of intelligence and the

> ability to rely on decentralized private implementation. Dense connecting networks without a robust internal structure would leave the state incapable of resolving collective action problems, of transcending the individual interests of its private counterparts. Only when embeddedness and autonomy are joined together can the state be considered developmental" (212).

Evans points to Japan's Ministry of International Trade and Industry (MITI) as "the best starting point for trying to understand the structural features of the developmental state" (48). MITI is an autonomous bureaucratic state agency that has cultivated a set of embedded institutional and social ties with private Japanese firms. MITI, in alliance with these private firms, uses public funds to map a path of technological development for the Japanese economy. They have clearly met with great success.

In the 1980s, American political-economists envied Japan's MITI and lamented the lack of such an agency in the US (Tirman, 1984; DiFilippo, 1990). Gregory Hooks (1990), a Professor of Political Economy at Washington State University, questions this perspective. Does the US truly lack an autarkic planning agency with embedded institutional ties to American corporations? Professor Hooks answer is no, the US does have such an agency. He asserts that

> "The Pentagon is clearly the most powerful and well financed federal bureaucracy, but recent debates over the state have all but ignored it... The Pentagon's budgetary resources and administrative authority have allowed it to pursue its goals in an autarkic fashion, and in the name of national security, the Department of Defense has implemented a de facto industrial planning policy" (358-9).

Hooks defines industrial planning as "the state's effort to shape production and distribution in specific industrial sectors, including interventions and negotiations

with individual firms" (359). He then proceeds to trace the Pentagon's industrial planning in the post WWII aeronautics and microelectronics industries. In the parlance of Peter Evans, Hooks asserts that the Pentagon utilized 'embedded autonomy' in order to map a path of technological development for the American defense sector during the post WWII epoch.

Of course, it is during this epoch that America's mode of development veered away from industrialism and towards informationalism. And it is the technologies created by the Pentagon, the Department of Defense, NASA, and DARPA, in alliance with technologically advanced defense contractors through the mechanism of embedded autonomy, that now provide the infrastructural skeleton for the informational mode of development. Transistors, integrated circuits, computers, the Internet, satellites, wireless networks, laser technologies, and fiber optic communications all benefited from national security related industrial planning during the Cold War (Ruttan, 2006; Galbraith, 1978; Botkin and Dimanecescu, 1984; Hooks, 1990; Castells, 1996; Martin, 1996; Hecht, 1999; DeLanda, 1991; Abbate, 1999). Analogously, in the 18th century, the British Ordnance and Naval Offices, which, as will be shown, were also embedded in and yet autonomous from the underlying competitive defense contracting marketplace, guided defense contractors to produce complex cast iron capital goods, heavy weapons, and immense warships that were widely considered to be technological marvels of their day (Black, 1989; Deane, 1975; Glete, 1993; Lavely, 1987).

Developing any one of these highly multifaceted and capitally intensive technologies was undoubtedly a project of enormous undertaking. Galbraith in the *New Industrial State* (1978) laid bare a further crucial role that defense departments play in initiating and maintaining such projects: They

> "provide contracts of long duration, calling for large investment of capital in areas of advanced technology. There is no risk of price fluctuations. There is full protection against any change in requirements, i.e., any change in demand. Should a contract be canceled, the firm is protected on the investment it has made. For no other products can the technostructure plan with such certainty and assurance" (322).

Here Galbraith points to a central and powerful aspect of technological planning for national security that is absent in any other type of industrial planning, including MITI's: large-scale procurement of technologically advanced capital goods. Galbraith (1978) asserts that no capitalist state has been able to justify the funding of massive long term contracts and extensively guaranteed markets in advanced capitally intensive technological sectors without the impetus of a substantial national security threat. And, as will be demonstrated, in both 18th century Britain and the Cold War United States, a long-term national security threat motivated the financing of large-scale contracts of long duration for technically advanced capital goods, which crystallized into state of the art forms owing to the presence of institutionalized embedded autonomous mechanisms of state guided / market innovated technological development in key defense sectors.

The overarching argument I will be seeking to assess in the dissertation can now be restated as follows: When long-term large-scale procurement of capital intensive goods for national defense is funded by sound public deficit finance in a

modern bureaucratic capitalistic state, and enacted through the economizing and potent innovation-inducing mechanism of state-guided 'embedded autonomous' market-based contracting, a unique economic synergy between defense departments and defense contractors emerges. This synergy can powerfully steer national technological and infrastructural trajectories. During the 18th century, and then again during the latter half of the 20th century, such an economic synergy, over the long term, intermittently interacted with underlying commercial markets in Britain and the United States respectively, consequently fomenting the novel techno-economic infrastructures that girded both the Industrial and Informational Mode of Development Shifts.[20]

Unquestionably, assessing the military expenditure impetus to mode of development shifts in a substantial comparative-historical study contributes to the present state of the literature on war and economic development. To begin with, there is still great uncertainty as to whether British military spending helped or

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[20] Of course, not all of the innovations, consumptive goods, and socio-economic processes associated with the Industrial and Informational Revolutions stem from military spending; it is clear that several do not. I am not attempting to assert some grand meta-theoretical monocausal 'Sombart-esque' type argument here. In the following, I will be attempting to clarify the causal role of military expenditure in mode of development shifts by composing a study that isolates this variable, and the clearly specified structural factors that enable it, out from other historical variables. Of course, 'hermetically isolating' military spending and the structural factors that enable it out from other historical variables is not entirely possible. By their very nature, all large comparative historical projects face this same problem. Hence, the conclusions that can be drawn from comparative historical work are necessarily tentative. Comparative historical theory is therefore best when it is generalizable and falsifiable (Kiser and Hechter, 1991), as it is here. The following study will attempt to assess the precise causal effect (if any) of military spending during the Industrial and Informational Mode of Development Shifts by addressing those economic and structural variables that are 1) directly related to arguments for or against military spending as an important causal factor and / or 2) previously deemed relevant by a majority of eminent scholars interested in macro level structural-economic causal explanations of the industrial and / or informational transformations.

hindered the Industrial Revolution (O'Brien, 1989, 1991; Mokyr, 1993; Crouzet, 2001). By bringing new comparative cases to bear on the subject, I hope to establish that state military expenditures had similar positive causal effects and acted through analogous mechanisms during both the Industrial Revolution and the Information Technologies Revolution.

Moreover, the research on military spending that was conducted in the 1980s, which tended to draw negative conclusions owing to a technologically emergent Japan and a purportedly technologically stagnant America, still resounds in the literature today. Yet much in the real world has changed. With the end of the Cold War, Japan became mired in a lengthy stagnation. And by 1996, the United States had reclaimed its position of technological preeminence in the world economy (NSF, 1996; NSF 2006; US Industrial Outlook, 1995, 2000; Gregory, 1993). It is therefore high time to revisit the crowding out thesis.

Interestingly, and perhaps counterintuitively, I do not believe that my theory is in opposition to the crowding out thesis. I accept that government military expenditures can and do 'crowd out' private market investment and innovations to some extent at certain specifiable junctures. The question becomes whether this is perennially a bad thing. Crowding out may not always be detrimental to an economy. Undoubtedly many times it is (as will be shown), but under certain conditions (as will also be shown), crowding out can cause modifications to economic infrastructure that benefit the long-run growth prospects of an economy. Private markets, when left to their own devices, tend to generate incremental

process oriented innovations meant to improve articles for personal consumption (Ruttan, 2006; Helpman and Trajtenberg, 1998; Markiewicz and Mowery, 2003). Private markets alone cannot guarantee demand for new and risky capitally intensive technologically advanced infrastructural goods in the same way that procurement for national defense can (Galbraith, 1978; McNeill, 1982; Ruttan, 2006). Theoretically then, military expenditure can be an impetus to mode of development shifts because state defense agencies are endowed with the fiscal power of public deficit finance, and in so being, they are in a position to shepherd capitalists towards new radical technological and infrastructural innovations; innovations that the market might not develop otherwise (Ruttan, 2006; Galbraith, 1978). Thus, in specifiable structural environments, a grave national security threat can unleash a unique economic synergy that over time may open up radically novel trajectories for economic development, regardless of, indeed perhaps because of, private sector crowding out.

Is this a far-fetched notion? It is now accepted that long periods of military expenditure occasioned by war stressed early political units to such an extent that the modern fiscal bureaucratic nation-state resulted (Bean, 1973; Hintze, 1975; Mann, 1986; Tilly, 1975, 1985, 1990; Ertman, 1997; Kiser and Linton, 2001). Is it not possible then that long periods of military expenditure occasioned by great power rivalry drastically affected and extensively modified the technological, infrastructural, and developmental trajectories of leading fiscal bureaucratic states?

In essence, this is the question that I pose. What follows is the method that I propose to address it.

METHODOLOGY AND CASE CHOICE:

As previously discussed the object of interest (dependent variable) in my dissertation is a 'mode of development shift.' The concept has been defined above. As also previously stated, the causal variables in my proposed theoretical model are an interacting set of six structural / institutional factors: Long-term large-scale military expenditure; capitalistic defense contracting; sound public deficit finance; efficient systems of taxation; the institutional prerequisites to economic development; and insulation from attack. Comparative historical methods are particularly suited to research projects involving this type of 'multiple conjunctional causation,' especially when the relevant cases of interest are necessarily few in number (Ragin, 1987). In order to elucidate the causal role of military spending in mode of development shifts, I will analyze the appropriate collective causal complex embedded within each selected case. Each case will then be cross-compared. Additionally, in each case, the collective causal complex related to military expenditure will be contrasted with competing structural-economic explanations of the phenomena of interest.

Which brings us to a key and most essential question: Why have I chosen the cases of Britain (1689-1784), France (1689-1784), USA (1940-1999), and Japan (1945-1999)? Positive case choice is necessarily driven by successful

outcome on the dependent variable (a mode of development shift). Owing to the dissertation's focus on state directed military spending, the unit of analysis is of course the nation-state. Given the unit of analysis, object of interest, and definition of mode of development shift being employed here, the historical record reveals only two valid possibilities for positive cases; 18th century Britain, and the latter 20th century USA (Castells, 1996). My goal will be to demonstrate that both these positive cases share a specific set of causal mechanisms relating to large-scale military expenditure, amassed via bureaucratic taxation and a sound public deficit finance system, and enacted through market-based contractual purchasing arrangements and embedded autonomous methods of state-led technological development. Concomitantly, if my theory is accurate then each cluster of interrelated infrastructural innovations that mark the two respective mode of development shifts should be, to some extent, qualitatively dependent on the forms that conflict took during each respective period of great power rivalry.

Owing to the unavoidably small n of positive cases, the comparative project at hand requires carefully thought out selection and inclusion of negative cases. These negative cases will serve to 'test' the conclusions drawn from the positive cases by 'controlling for' specific variables of interest. Why have I chosen the negative cases of France (1689-1784) and Japan (1945-1999)? Ideally, the definition of the set of potential negative cases would not be influenced by knowledge of instances of the hypothesized causes or instances of the hypothesized effects. However, drawing cases from a set that includes all possible negative

instances of a mode of development shift is rather futile. The set is too large and diverse while my object and causal variables of interest are quite exact and narrowly defined. Therefore, the dissertation's proposed theoretical model guides the negative case choice (Kiser and Hechter, 1991).

In order to 'isolate' the effects of military spending, the investigation ought to include a negative case containing each of the state structural / institutional variables present in the theoretical model, sans military spending. In fact, this negative case should hold each of the disaggregated state structural / institutional variables present in the positive cases as constant as possible. Such a case could be labeled a 'near instance of a mode of development shift' – a nation that hypothetically could have had a mode of development shift but did not due to the absence of the main causal variable of interest. The inclusion of a negative case that controls for the political-economic structure common to both positive cases not only isolates military spending, but also facilitates a dialogue between my claims and those of adversarial authors that consider the presence of liberal democratic institutional variables, absent military spending, sufficient cause for any type of improvement in economic production functions.

Clearly, the more that nation A and B structurally differ, the more challenging is the task of isolating military expenditure as a causally relevant factor. Fortuitously, the period of informational transition provides a case that acts as an approximate control experiment. Post WWII Japan adopted a liberal democratic state structure under the watchful eye of the American occupation and

then focused specifically on advanced technological production. Post WWII Japan was also severely constrained in its ability to spend militarily. Therefore, Post WWII Japan is incorporated into the study as a near instance of an informational mode of development shift where political-economic structure is held relatively constant and military spending is largely absent.

It is much harder to locate a nation-state that could be considered a near instance of an industrial mode of development shift wherein military spending was contained. Since this study is not concerned with the determination of the causal mechanisms involved in repeating the steps of an already developed process, the temporal range of negative case choices for the industrial mode of development shift is limited to the period preceding industrialism. However, the problem lies in locating a nation with a liberal democratic political economy and well-defined patent and property laws that was not engaged in large-scale military expenditure previous to or during Britain's mode of development shift; such a nation simply does not exist (North and Thomas, 1973). In thinking about this dilemma, the words of Charles Tilly are quite constructive:

> "We must make sure that the logic of comparison, which guides a search for concomitant variation, fits our aims like a sweatshirt and not like a straightjacket; it should make the exercise more effective, rather than making it impossible. No one should take the rules to require a search for the perfect pair of structures or processes: exquisitely matched on every variable except the purported cause and the supposed effect" (Tilly, 1984, 80).

That being said, it seems logical to include in the study an 18th century case that will control for military spending itself, absent the variables which conjunctionally

interact to make it an effective force of demand. As aforementioned, the dissertation's theoretical model is one of 'multiple conjunctional causation.' Hence, the importance of conjunctional interaction between long-term large-scale military expenditure, market-based contractual purchasing arrangements, and the state structural / institutional variables included in the model, can be displayed by holding military spending constant. Britain's main rival in the period of industrial take-off lacked market-based contracting and the state structural / institutional variables included in the dissertation's theoretical model, but spent approximately as much on war as Britain over the course of the 18th century. Therefore, incorporating the case of France (1689-1784) into the study is both constructive and realistic. In so doing, evidence supporting the claim of multiple conjunctional causation can be marshaled while temporality and scale of military expenditure are controlled for. Moreover, including this case in the study will allow me to draw some tentative conclusions concerning the relative causal weight attributable to each of the discrete state structural / institutional independent variables included in the model; these variables have their own pattern of variation within the French case.

CHAPTER 2: THE THEORY AS APPLIED TO THE BRITISH CASE

As discussed in chapter one, early modern Britain was the first nation-state to generate and then harness the accumulative power of the industrial mode of development. As stated, the thesis being promulgated here is that long-term large-scale military expenditure, raised through a sound public deficit finance system, and activated within a market-based institutionalized competitive system for defense contracts, was an important, significant, and as of yet largely neglected, cause of the British Industrial Revolution. Before historical data is marshaled to support this argument, the theory at hand will be situated in the overall extant literature regarding causality during the British Industrial Revolution.

The first theoretical debates that must be addressed when discussing the British Industrial Revolution are those relating to definition and temporality. Both issues are less clear cut than one might hope. The case for defining industrial production as a vertically integrated, engine, and machine based manufacturing paradigm has already been made and is largely supported in the literature (Crouzet, 2001; Mokyr, 1993; Ashton, 1968b; Deane, 1965; Chandler, 1977; Hobsbawm, 1968; Castells, 1996) As for the term 'revolution', well, this is perhaps a bit of a misnomer. When contemplating the term and its relation to industrialization it is useful to keep the words of Joel Mokyr (1993: 2) in mind: "From a purely ontological point of view, the British Industrial Revolution did not 'happen.' What took place was a series of events, in a certain span of time, in known localities, which subsequent historians found convenient to bless with a name." Historians

have found it necessary and / or convenient to name this period in economic history because by all accounts production experienced profound and sweeping qualitative changes leading to unmistakable shifts in quantitative growth rates and other macroeconomic aggregates (Deane, 1965, 4; Crouzet, 2001, 106; Mokyr, 1993).

Precisely when this shift in aggregates first made itself felt has been a matter of some debate (Mokyr, 1993; Crouzet, 2001). Economic historians have now settled upon the 1780s as the crucial decade in which initial statistical discontinuities can be found (Crouzet, 1990; Brown, 1991; Crafts, 1987; Thompson, 1973; Deane, 1965).[21] If the 1780s are taken to be the statistical pivot, then the qualitative structural transformations ushering in industrial macroeconomic growth can be assumed to have occurred in the preceding decades, for "There is typically a long lag between the occurrence of changes in technology, even those of fundamental importance, and the time they start affecting aggregate statistics such as industrial production and national income per capita" (Mokyr, 1993, 10). Qualitative transformations can, of course, be more difficult to temporally pinpoint. Exactly which temporal interval scholars have chosen to study largely revolves around their object of interest. Those who have concentrated on developments in cotton textiles and iron production, the two most widely accepted leading sectors of the British Industrial Revolution, tend to focus upon the interval 1740-1790 when describing the transformation in methods and

[21] "There is a broad agreement about an acceleration during the 1780s in all manufacturing output, which signifies that Britain had truly entered the Industrial Revolution" (Crouzet, 1990, 24).

organization that led to industrial style economic growth (Crouzet, 2001; Landes, 1993; Mokyr, 1993; Harley, 1993; Brown, 1991; Thompson, 1973; Deane, 1965; Ashton, 1959). Those who argue that industrial growth was an effect of Britain's institutional and market environment tend to reach back further, to as early as the middle 17th century (Brown, 1991; North and Weingast, 1989; North and Thomas, 1973; Landes, 1969).

In accord with the literature, I accept the 1780s as the decade in which the industrial mode of development was first quantifiably specifiable. In searching for the origins of the industrial mode of development shift, and specifically the role that military expenditure played in the transformation, I will venture as far back as 1688. Thus, in regards to temporality, the view espoused here is decidedly gradualist. The relative discontinuity of the 1780s is seen as the outcome of a long process of the coming together of various disparate but progressively fusing threads, including: modernizing economic institutions, improving credit channels, slow developments in iron, steam, and coal production, quicker progress in cotton textiles, and bettering transportation infrastructure. These factors converged somewhere around the 1780s when national output took a sustained turn upwards. In the subsequent chapters of the British Case, data will be marshaled in support of the dissertation's overarching argument that military expenditure was a crucial impetus in the gelling of these factors. In the remainder of this chapter the discussion will focus upon the ways in which the causal variables highlighted by other authors interact with, contribute to, and / or argue against the 'military

expenditure impetus to mode of development shifts theory' as applied to the British Case.

In reviewing the myriad of contributory causal variables put forth for initial British industrialization, the following dialogue will adhere to the contours of Joel Mokyr's (1993) useful typology regarding 'Industrial Revolution Schools of Literature.' The first causal school of thought identified by Professor Mokyr is 'The Social Change School.' Here, economic transactions, and the political institutions and market structures which govern them, are the focus.[22] Mokyr terms the second causal school of thought 'The Technological School.' Authors in this group consider changes in technology to be primary to all other changes, and thus concentrate on the invention and diffusion of new technical knowledge when constructing causal arguments.[23] The third group of scholars can be said to hail from 'The Macroeconomic School.' Here the emphasis is on quantitative statistics measuring exports, imports, and aggregate variables such as national income, fixed capital formation, and savings ratios.[24] The final causal school identified by Mokyr is 'The Industrial Organization School.' Here authors highlight the organizational

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[22] Notable authors in this causal school include Douglass North (1990) along with Barry Weingast (1989) and Robert Thomas (1973), P.G.M. Dickson (1967), Karl Polanyi (1944), and Arnold Toynbee (1884).

[23] Notable scholars in this school include Francois Crouzet (2001), Joel Mokyr (1993), Richard Sullivan (1989), and David Landes (1969).

[24] Important authors in this causal school include Charles Feinstein (1988), C. Knick Harley (1993), N.F.R. Crafts (1987), Jeffrey Williamson (1984), Phyllis Deane (1965), and Walt Rostow (1960).

changes inherent in the shift to industrialization; the focal point is therefore the emergence of large firms and factories (Mokyr, 1993, 6).[25]

THE SOCIAL CHANGE SCHOOL / NEO-INSTITUTIONALISM:

Let's commence with a discussion of the Social Change School focusing upon the political-economic institutions which underpinned the British shift to industrialism as espoused by the 'new institutionalists.' New institutionalists are primarily concerned with the question; what institutional features create an environment conducive to modern economic growth? "Growth will simply not occur unless the existing economic organization is efficient. Individuals must be lured by incentives to undertake the socially desirable activities... mechanisms must be devised to bring social and private rates of return into close parity" (North and Thomas, 1973, 2). New institutionalists argue that governments are responsible for creating and maintaining such mechanisms, and the way they do so is through the gradual and path dependent development of institutions (constraints that human beings devise to shape human interaction) which reduce the costs of transacting through protections of various private property rights. The key aspects of this school of thought that are specifically germane to the theory under consideration here involve parliamentary governance (along with its associated independent judiciary), secure property rights (especially in regards to knowledge property), and unified economic markets (low interregional transaction costs).

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[25] Notable authors in this school include Rick Szostack (1989), Maxine Berg (1985), Alfred Chandler (1977), Franklin Mendels (1972), and Sydney Pollard (1965).

These political-economic institutions were not only necessary components of the British economic miracle, but are also integral prerequisites to 'the military expenditure impetus to mode of development shifts theory' as expounded in the introductory chapter.

The reasons why parliamentary governance was crucial to English economic development were also explained in chapter one; parliamentary governance and the associated emergence of an independent judiciary in England couched rulers in a series of codified limitations described in the common law preventing arbitrary confiscation of gains thereby aligning private rates of return with social rates of return through the existence of secure property rights (North and Weingast, 1989). Moreover, parliamentary governance in England assured that public debts obliged the entire nation rather than just the sovereign thus amplifying the capital made available to the state for military expenditure (Dickson, 1967; Brewer, 1988; Carruthers, 1996).

The ascendancy of Parliament and the rise of a completely independent judiciary guided by common law obtained in England only after a protracted struggle aimed at limiting the power of the sovereign dating back to 1485. The struggle was resolved in favor of the economically preferable institutional structure with "the Glorious Revolution of 1688 and its fundamental redesign of the fiscal and governmental institutions" (North and Weingast, 1989, 803-804). From this same struggle emerged England's uniquely effective patent laws. In 1624 the English House of Commons, to the chagrin of the Tudor King, succeeded in

passing the Statute of Monopolies, which proscribed royal monopolies and also embodied a patent system to encourage true innovation, thus establishing for the first time secure property rights to knowledge (North and Thomas, 1973, 154-155).[26]

The third aspect of the institutional environment that can be said to be fundamental to British economic growth, and the dissertation's theory, entails unified economic markets, i.e. the lack of domestic barriers to interregional exchange. Domestic barriers to trade raise transaction costs thereby surrendering the gains that intrinsically devolve from trade between regions. Since economic development is largely curtailed by internal barriers to trade, any potentially positive developmental effects stemming from military expenditure cannot be expected to materialize if national markets are not unified. Integrated regional economic markets in England also evolved during the protracted c. 16th century struggle to limit the power of the English sovereign. With the advent of the Glorious Revolution (and by way of the long standing decay of the English guild system as well), the English state abandoned any real attempts to regulate trade and industry (Crouzet, 1990, 27; Mokyr, 1993, 29; North and Thomas, 1973).

So by the late 17th century royal prerogative in England was constrained, Parliament was providing private wealth holders with voice, an independent judiciary was adjudicating disputes through evolving common law, patent laws were internalizing the externalities previously associated with innovation, and

[26] For a more full history see North and Weingast (1989) and North and Thomas (1973).

burgeoning unified markets were yielding ever lower transaction costs. In other words, the institutional framework of late 17th century England provided an overwhelmingly hospitable environment for secure property rights and economic growth (Minton, 1975, 100; North and Weingast, 1989; North and Thomas, 1973).

New institutionalists tend to end the causal story of the British economic miracle there, some 100 years before the Industrial Revolution appears in macroeconomic aggregates (North and Thomas, 1973, 156-157; North, 1990; Crafts, 1987; Mokyr, 1993). But *should* the story end there? Can the Industrial Revolution rightly be considered the outcome of events that took place over a century before? This dissertation emphatically argues that the new institutionalist interpretation, although incredibly important, is decidedly incomplete. There are significant intervening variables that work their influence over that 100 year period between the Glorious Revolution and the onset of industrial growth; most notably, large-scale military expenditure, raised through a sound public deficit finance system, and activated within a market-based institutionalized competitive system for defense contracts. In comparative history the best causal theories are those that involve the least temporal duration between cause and effect (Kiser and Hechter, 1991). So if it can be demonstrated that military expenditures between 1689 and 1784 had influential causal effects on the genesis of the British industrial mode of development then temporal proximity will favor the explanatory force of military spending over that of economic institutions.

The Glorious Revolution not only ushered in the age of parliamentary supremacy and secure property rights in England, but also kicked off what would become a century long military struggle between Britain and France for hegemony in the global trading system, termed by some the 'Second Hundred Years War' (Kennedy, 1987; Dickson, 1967). For 50 of the 96 years encompassing the span 1689 through 1784, Britain was engaged in hostile capital intensive combat against France. During this struggle military expenditure reached successively superior heights, thus testing the capacity of each nation to raise funds (Wallerstein, 1973; Kennedy, 1987; Arrighi, 1994; Crouzet, 2001). From the first conflict to the final, per annum military expenditure in Britain increased by nearly 500%; and in each of the 50 years of active combat, military expenditure in Britain was between 9% and 16% of national income (Mitchell and Deane, 1962, 387-389; O'Brien, 1991; Brewer, 1988). Indeed, Britain spent approximately a cumulative £564.84 million on war during the hot years of the 1689-1784 French rivalry, or £11.3 million per war year; an annual figure that equates to nearly a quarter of gross national income in England at the start of the 'Second Hundred Years War' (Mitchell and Deane, 1962).[27] It is my contention that such immense expenditure packages raised by the state and released back into the British economy during the interval 1689-1784 materially altered the infrastructural nature of the British economy thus substantially contributing to the British industrial mode of development shift.

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[27] Such expenditure obviously meets the characterization of long-term large-scale military expenditure as laid out in chapter one (6%-15% of national income in a great power nation over a contiguous span of multiple decades).

As asserted in chapter one, this effect could not have obtained if Britain had not developed sound public deficit finance, for during those 50 years of war, deficits ran to between 35% and 50% of total tax revenue (Brewer, 1988). Interestingly, North and Weingast (1989) in their seminal neo-institutionalist paper *Constitutions and Commitment: the Evolution of Institutions Governing Public Choice in Seventeenth Century England*, point to the rise of the capital market for public debt as proof for their thesis regarding the link between institutions and economic growth in Britain.

> "In just nine years (following the Glorious Revolution), government borrowing increased by more than an order of magnitude… (Additionally) large-scale trading in private securities dates from this period… In the early 1690s the volume of securities averaged 300,000 per year. Ten years later, volume averaged 3,400,000 per year, and by the early 1710s, 11,000,000 per year… While underlying economic conditions were surely an important component of the large increase in debt (and trading), they alone can not explain the suddenness with which the debt increased, nor its magnitude" (North and Weingast, 1989, 805; 824).

To be sure, North and Weingast are correct, and I concur, there was incredibly rapid growth in both national debt and tradable securities in the years immediately following the Glorious Revolution. However, institutions and underlying economic conditions together also do not fully account for the 'suddenness' of this occurrence, as North and Weingast suggest. Clearly, the causal variable most directly associated with the swift accumulation of public debt, and not incidentally the rise of a public stock market for privately traded shares, in Britain after the Glorious Revolution is the onset of the Nine Years War (1689-1697) (Brewer, 1988; Carruthers, 1996; Dickson, 1967).

The point then is as follows: the development of an institutional environment conducive to modern economic growth was a necessary pre-condition to the development of sound public deficit finance in Britain, and sound public deficit finance enabled the meteoric rise of the British stock exchange where privately owned public debt securities were traded. However, neither the British institutional environment, nor the advent of sound public deficit finance, nor the rise of the British stock exchange for that matter, can be adequately explained without making military conflict, and the expenditures arising there from, an endogenous and integral part of germane causal theories. As Tilly (1990) makes clear and North continually accedes (North and Thomas, 1973; North and Weingast, 1989), it was the search for revenue to fight wars that drove the English state to accept the institutional 'balance of powers' structure it settled on in the 17th century. This institutional structure enabled the English state to raise unprecedented amounts after the Glorious Revolution, but the story is far from over there. As the narrative chapters of the British Case will demonstrate, successively larger wars with France drove public deficit finance, capital markets, the stock exchange, and credit in Britain to evolve until at least 1757 – the year that Dickson (1967) in his magnum opus *The Financial Revolution in England*, declares the English Financial Revolution fully complete. The years 1689-1757 encompassed the Nine Years War (1689-1697), the War of the Spanish Succession (1702-1713), the War of the Austrian Succession (1739-1748), and the start of the Seven Years War (1756-1763). During each of these extensive conflicts, financial elements that

were integral to sound public deficit finance, and in turn became integral to the formation of industrial economic growth, evolved. Such as: the development and expansion of the capital market for the exchange of assignable equities, the advent of reliable earmarking in anticipation of tax revenue, the introduction of funded long-term public loans, the origination of reliable short-term debt instruments such as exchequer bills, the creation of sinking funds designated for interest payments on public debt, the associated rise of non-date specified redeemability of public loans, conversions on the national debt to lower interest rates, and most importantly, the introduction and evolution of the Bank of England as an institutionalized presence and discounter of last resort in the British economy.[28] These are the complete elements of the English Financial Revolution, entirely present only in 1757, nearly seventy years after the Glorious Revolution. Each of these aspects of the English Financial Revolution will be explored in the following pages, and what will emerge clearly is that it is simply impossible to account for the English Financial Revolution without making military expenditure the central variable in the narrative.

But this is hardly news; although interesting, it is not unique. Economic historians and sociologists such as Dickson (1967), Brewer (1988), and Carruthers (1996) have long maintained that the evolution of sound public deficit finance and capital markets in Britain was driven by war. What is more unique in this study then is directly linking the English Financial Revolution to the British Industrial

[28] Discounting means providing cash at the present value rate for debt coming due in the future.

Revolution by highlighting the injection of military expenditures into the English economy via a capitalistically based competitive defense contracting mechanism. As will be shown, war driven finance and expenditure directly and indirectly contributed to the rise of industrial production in three main ways: 1) By developing and expanding circulating credit and the money supply 2) By driving down the rate of interest throughout Britain on capital of all sorts, most notably in the 1740s and 1750s – crucial decades in the formation of the infrastructural framework for industrial accumulation. 3) By channeling large quantities of capital to privately owned contracting enterprises working in crucial sectors of the emerging industrial economy. These are not entirely uncontroversial propositions, so some theoretical justification for each will now be provided.

The English Financial Revolution can be linked to the British Industrial Revolution via the intervening variable of war finance through an analysis of circulating capital. Circulating or working capital, as opposed to fixed, is capital used in day to day business dealings. Although the shift towards industrialism is commonly viewed as entailing "an increase in the range and variety of fixed capital" (Crouzet, 1972, 39), it is the credit market for circulating capital that enabled 18th century British entrepreneurs to expand their fixed capital outlays. Budding industrialists obtained their needs for circulating capital by entering into the matrix, or web, of credit established by and founded upon public deficit finance related military expenditures. By realizing large accumulations of circulating capital via cheap credit, entrepreneurs' personal capital was freed for investment in

fixed plant. This was particularly crucial in industries where fixed costs were relatively high, such as iron. Thus Britain's credit matrix was absolutely central to the early processes of industrial accumulation (Mokyr, 1993, 100; Rule, 1992, 164; Crouzet, 1990, 163; Brown, 1991, 197).

There can be little doubt that the British matrix of credit formed, in large part, as a consequence of military expenditures over the years 1689 to 1784. Prior to 1689, there were disjointed pools of capital and savings in England, and the conduits linking them to industry were very few and weak (Crouzet, 1972, 5; Brown, 1991, 196). Slowly but surely, gaining pace with each successive war, these disjointed pools were driven together and in turn made available to emerging industrialists by way of the wide variety of credit instruments created by public deficit financed military expenditures (Mokyr, 1993; Dickson, 1967; Deane, 1965). In his aforementioned opus, *The Financial Revolution in England* (1967), Dickson demonstrates that 'government funds constituted the basis of the pyramid of commercial credit' in 18th century Britain (Crouzet, 1990, 165). Public borrowing from 1689 to 1784, all of which was related to defense spending in some way, created an assortment of easily transferable securities which became ever more risk free and reliable as the 18th century progressed. The entire business edifice of 18th century Britain came to rely on these low risk credit instruments which could be invested in or disinvested from at a moments notice. Thus, by funding mushrooming military expenditures, the private sector received in return readily saleable paper assets ranging from exchequer and naval bills at the short end to 3%

and 4% consols at the long. Absent these, there would have been significantly less circulating capital, and what did circulate would have been entirely less secure (Dickson, 1967; Deane, 1965; Pressnell, 1960). Hence, it is eminently reasonable to assume that if war driven public deficit finance had not risen, improved, and expanded over the years 1689 to 1784, British industrialization would have been impeded; according to Dickson (1967, 11-12) it may never have occurred at all.

Furthermore, the growth of an integrated national paper money market in Britain can also be viewed as an unintended consequence of war related public deficit finance (Mathias, 1979, 94-98). Facilitating this expansion in the nation's money supply was the Bank of England, whose existence and evolution owes directly to British military expenditure (as will be shown). The Bank not only forged links between disparate pools of capital, private savers, and the state, it also forged indirect links between savers and industrial entrepreneurs. As the 18th century progressed, the Bank increasingly attracted deposits from the state and private investors, and issued risk free promissory notes, exchanged at face value, to entrepreneurial borrowers against those deposits (Deane, 1965; Dickson, 1967; Mathias, 1979; North and Weingast, 1989). In short, "In response to the government's borrowing needs, banking and stock and security exchanging developed into a mechanism capable of serving the needs of the developing economy as well as the state" (Rule, 1992, 277).

One astonishing miracle of this integrating monetary and credit system born out of military necessity was that it did not cause heightened inflation or rising

interest rates until the 1760s, and even then, the rise in inflation and interest was muted. This is likely because savings were an underutilized aspect of the British economy made active only through public deficit finance. In other words, there was plenty of 'slack' in the British economy allowing for extreme military expenditure and money supply growth without the associated effects of stimulated inflation and augmented interest rates (Dickson, 1967, 245; O'Brien, 1991, 32). In fact, during the 18th century England experienced a large secular decline in interest rates as a result of the evolving national debt; "at the same time as governmental borrowing increased, the interest rate fell" (North and Weingast, 1989, 823; Pressnell, 1960, 181; Brown,1991, 198).

This leads to the second proposition regarding the effects that war finance had upon the genesis of the industrial mode of development between the Glorious Revolution and the 1780s; namely that six decades worth of successfully managed deficit financed military expenditure drove interest rates down throughout Britain, especially in the crucial transitional decades of the 1740s, 1750s, and into the 1760s. Such an argument centers upon the mid-century conversion of rates on public debt from an average around 4% to an average around 3% which was seen as a necessary measure to control interest charges following the extraordinary spending associated with the War of the Austrian Succession (1739-1748). This conversion coincided with a secular decline in private interest rates throughout Britain. The thesis that the public conversion caused the secular decline in private interest rates thus driving a 1750s and 1760s capital goods explosion, which was

crucial to incipient industrial development, was first proposed by T.S. Ashton in 1959. It has remained somewhat controversial ever since (Brown, 1991, 198). Arguments that have been leveled against the view include the idea that private rates did not precisely follow public rates in the 18th century, and the notion that rates experienced a similar decline throughout Europe at this time (Crouzet, 1990). In the data section of the British Case evidence will be provided that not only counters these two assertions, but also demonstrates that it indeed was the mid-century conversion from 4% to 3% on the national debt that drove the decline in private interest rates experienced in Britain during the mid 18th century. And that this decline was an essential factor propelling the 1750s and 1760s capital goods explosion which paved the way for future industrial growth. Briefly, it will be shown that prior to the conversion private rates of interest throughout Britain and Europe were stubbornly higher than rates on public debt and above 4% (Pressnell, 1960; Dickson, 1967). In fact the market mounted great resistance to the conversion which was achieved only through the shrewd political maneuvering of the First Lord Treasurer of the time, Henry Pelham. The conversion forced rates on public debt well below going market private rates for at least a decade, thus releasing investment capital in search of long-term higher returns into the private sector (Pressnell, 1960, 184; Dickson, 1967; Thompson, 1973, 118). This capital in turn drove fixed goods investments, most notably in the iron and transport sectors, thus greatly affecting the infrastructural character of the British economy (Ashton, 1959; 1968; Landes, 1969, 64). Moreover, the two major mid-century wars further

stimulated fixed capital investment while also bringing European foreign capital flooding into the British credit system (Pressnell, 1960, 164; Dickson, 1967), thereby increasing the flow of circulating capital and supporting the secular decline in British interest rates. "It can be argued that the import of foreign capital released English funds, which otherwise might have been tied up in government loans, for industrial development" (Dickson, 1967, 337).

In addition to driving down interest rates and increasing circulating capital, sound public deficit finance enabled military expenditure to be an effective force of demand in key infrastructural sectors, most notably, the iron sector. This leads to the final theoretical argument regarding the crucial effects military expenditure had upon the formation of the industrial mode of development between the Glorious Revolution (1688) to the onset of industrial growth in the 1780s; namely that capital was funneled to capitalistic contractors working in a competitive marketplace via sound public deficit finance, and that these funds encouraged several of the innovations which came to compose the infrastructural foundations of the industrial mode of development.

As alluded to in chapter one, economic historians have typically viewed 18th century war expenditures through the lens of the crowding out thesis. This view is aptly expressed by Richard Brown (1991: 197) "Unlike private investment, government borrowing (in the 18th century) was largely unproductive… The increase in the national debt and debt repayments represented drainage of capital from more productive investment. It was from the point of view of economic

growth, capital lost." I reject this analysis for a number of reasons. First, crowding out mainly operates through mechanisms relating to rising interest rates and inflation and is unlikely to take place if there is a good deal of slack (underutilized resources) in the economy (Harley, 1993; Crafts, 1987; Cavanaugh, 1996, 38). As aforementioned, from 1689 to 1760 the secular trend in British interest rates and inflation was down, and from 1760 to 1780 the rise in both was muted, owing to various forms of slack (e.g. high unemployment and low utilization of savings) in the British economy (Dickson, 1967, 12; Crafts, 1987).

Moreover, public expenditures crowding out private investment should not be considered detrimental to an economy if it can be shown that private industry put public expenditures to effective uses in regards to economic development (Parkin, 1995). Perhaps the most interesting and unique aspect of the theory guiding this dissertation is the notion that military contracts spurred private contractors in the capitalistic marketplace to invest in fixed capital goods innovations that likely would not have emerged in a coordinated temporally synchronized fashion were it not for the stimulus of public funds and the heady profits that derived there from. To be certain, much 18th century military expenditure was spent on goods and services which had little if any effects on the origination of the industrial mode of development; goods and services such as soldiers' wages, soldiers' meals, wool clothing, leather boots, and foreign subsidies. Nevertheless, as will be supported with data in subsequent British case chapters, contractors in key infrastructural sectors (especially those involved in

naval iron production) had direct access to the large torrent of public funds unleashed by military expenditures, and did in fact use these funds to enlarge operations in ways that were fundamental to the formation of industrial production.

It is manifestly true that the main purpose of the extensive public credit system Britain developed in the 18th century was to enable the British way of warfare, which, for the time, was astonishingly capital intensive and market-based (Dickson, 1967, 393; Kennedy, 1987). A crucial statistic that must be understood, one which will be stressed over and over again, is the sheer size of state military expenditures in relation to everyday enterprise in 18th century Britain. For example, influential government contracting firms in the iron sector circa 1748 and 1763 had total capitals averaging somewhere around £1000, and this was exceptionally large for the time (Rule, 1992, 168). Yet in these years, the final years of the War of the Austrian Succession and the Seven Years War respectively, the government spent approximately £8,400,000 and £16,000,000 on military endeavors. The amount of capital flowing from the Navy into the iron sector for ordnance, cannon, anchors and the like can be roughly estimated at £120,000 per annum during the wars of the middle century, and only grew in later wars.[29] Sure, in terms of overall military expenditure this was an infinitesimal proportion, but in

[29] This figure is derived by estimating that naval expenditure accounted for 21% of the British domestic pig iron industry during the wars of the middle 18th century. Total pig iron production was about 35,000 tons in 1763, and price was about £6.50 per ton. Value added for working the pig into naval quality products is estimated at £10 per ton. It is important to realize that all 18th century British iron output figures and aggregate prices are necessarily crude estimates. The data and justification backing these estimates will be precisely detailed in later chapters of the British Case. The estimates are calculated by using price, output, and naval demand figures found in Hyde, 1973; Harris, 1988; Pritchard, 1987; and Glete, 1993.

relation to the size of the emerging and soon to be all important iron sector, this level of per annum capital injection was simply tremendous; and it definitely did drive ironmasters to rationalize, invest in, and innovate upon their production processes. "Government contracts came in large blocks and had to be filled on time. It was worth a businessman's while to introduce revolutionary methods to supply them. Time and again we find some inventor or entrepreneur stimulated by so lucrative a prospect" (Hobsbawm, 1968, 28).

Indeed, the economist J.L. Anderson (1972: 14) persuasively argues that without the inflated demand for iron occasioned by military expenditures there would not have been the same level of technological development in the British iron industry.[30] Fuel economizing in the competitive defense contracting environment presented ironmasters with a permanent incentive to technological improvement, while successive 18th century wars gave them powerful, although intermittent, markets. Due to relatively high sunk costs, closing shop or curtailing production were simply not realistic options in the 18th century iron industry, even

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[30] "Price and quantity figures show demand for iron in the 18th century was inelastic... Also, iron was unproven if not untried for many uses, and consumer conservatism is likely to have retarded its rate of acceptance despite any practicable price reduction. Increasing demand for iron would then be roughly proportional to the rate of economic growth. In these circumstances there would be no incentive as far as the industry was concerned to cut prices, increase supply, or to innovate technologically... The response to change in demand would more likely lie in lengthening order books and price increases. This would tend to retard the growth of the manufacturing sector generally, providing a negative feedback mechanism rather than the beneficial feedback associated with industrial growth where elasticities are higher. Clearly, the impact of war on demand for the industry's products would be such as to overcome the problem illustrated in the model, calling into use new resources rather than merely transferring those already in existence, and causing supply curves to shift bodily and irreversibly to the right, achieving economies of scale and growth and the incorporation of new technology. This analysis is consistent with the observed progress of the iron industry in the 18th century, when high rates of growth coincided with major shifts in the demand curve occasioned by wars."

during severe downturns. Peacetime intervals therefore prompted ironmasters to develop commercial applications for their capitally intensive wares, thereby transforming the infrastructural nature of British production (Hobsbawm, 1968; Ashton, 1968; Deane, 1965). And as will be shown, by the end of the Seven Years War (1963), iron clearly stood out as a central, if not the decisive, industrial leading sector. After the war, the entire British economy felt the 'animating' effects of cheap iron, as too eventually did the whole globe (Deane, 1965, 97; Ashton, 1968). In short, the in depth historical analysis of the British iron sector that will be undertaken in the narrative sections of the British Case will clearly indicate that institutional analysis alone is insufficient to explain the 18th century transformation of the British iron sector from international laggard to revolutionary leader. Causal primacy in this crucial infrastructural sector unmistakably weighs heavily in favor of military expenditure.

Interestingly, there are those who argue that the importance of iron in the initial phases of British industrialization has been overstated. Such authors maintain that the only important industrial leading sector in the 18th century was cotton textiles (Brown, 1991; Rule, 1992); "Not in number of men employed, nor capital invested, nor value of output, nor rate of growth could iron be compared with cotton in this period" (Landes, 1969, 89). This sort of vulgar statistical argument devolves from faulty logic in a number of different ways. In terms of numbers of men employed, capital invested, and value of output, agriculture far outdistances both cotton and iron combined for the entire 18th century and much of

the 19th. So these particular statistical aggregates are actually poor indicators of initial industrial accumulation. Leading transformative sectors by their very nature initially compose a small proportion of the overall economy, but exhibit a certain kind of rapid growth that ultimately excites growth throughout the entire economy (Mokyr, 1993, 1; 12). In terms of growth rates, Modelski and Thompson (1996) assert that the expansion of pig iron production in Britain after 1760 qualifies iron as a crucial leading sector of the Industrial Revolution. Moreover, it is simply incorrect to mechanically compare growth rates in the iron industry to those in the cotton industry, for the capital goods heavy iron industry developed throughout the 18th century while the cotton industry grew up suddenly in the last quarter of the century.[31]

In fact, there is ample reason to designate iron goods production as the most vital leading sector of the British Industrial Revolution, over and above cotton textile manufacture. A central way to measure the strength of a leading transformative sector is by looking at its potential for multiplier or spillover effects (Modelski and Thompson, 1996; Deane, 1965). In other words, a leading sector should have measurable growth and technical repercussions upon the economy as a whole. This is certainly true of the 18th and 19th century British iron industry: Heavy capital intensive iron is a producers' good, expansion of the sector is

[31] Iron had fast late century growth rates considering it came from a higher base, 3.79% per annum from 1780 to 1790, and 7.75% per annum from 1801 to 1811. Cotton textile output grew at a blistering 12.76% per annum pace from 1780 to 1790, but only grew at a 4.49% clip from its higher base during the 1801-1811 interval (Rule, 1992, 107). In any case, "demand for pig iron grew at about 50% per decade between 1750 and 1820", which is sufficiently rapid to merit the leading sector label (Brown, 1991, 94; Modelski and Thompson, 1996).

therefore driven by growth in demand for goods that are being manufactured by enterprises using iron in their fixed capital infrastructure. The early 18th century British iron market was naturally inelastic (Anderson, 1972; Pressnell, 1960, 57), so ironmasters had to create elasticity in the marketplace by adapting their product to widening sectors of production. In turn these adaptations caused growth in various manufacturing industries by lowering their productive costs while increasing the quality of their output. As these industries grew, so too did their consumption of capital intensive iron, thus completing a feedback loop which led to growth not only in the iron industry but throughout the entire British economy (Deane, 1965, 105; Mathias, 1979, 19). This is a common process in leading sector stimulated economic growth, especially when growth is led by a sector that affects the infrastructural foundations of production. Goods that can be used to augment productive infrastructure inherently produce greater multiplier effects, for economic infrastructure affects business in all its aspects (Modelski and Thompson, 1996; Borrus and Zysman, 1992, 213-4). Because of its forward and backward linkages with the rest of the economy, its improvement of capital and transport facilities throughout the economy, and its reduction of production costs for a wide range of manufactured goods, the capital goods iron industry should be viewed as having played 'a more powerful and pervasive role in the process of British industrialization than did cotton consumables' (Deane, 1965, 106; Brown, 1991,

93; Church, 1994).[32]

Going further, the narrative chapters of the British case will establish that each of the critical 18th century innovations in the iron sector (advanced casting, coke smelting, the boring machine, the separate condensing chamber steam engine, puddling and rolling, etc.) can be traced in some way, often in a very direct manner, to British military expenditures. "The adoption of a metal-using technology employing decentralized sources of power, which the inventions (listed in parentheses above) permitted, lies at the heart of the first industrial revolution" (Deane, 1965, 139; Brown, 1991, 102; Mann, 1993, 95). Then so too, it will be argued, does military expenditure.

As the Social Change School and neo-institutionalist causal arguments relating to the British Industrial Revolution have been reviewed, a few points have come to the fore. First, the neo-institutionalist causal story, ending with the Glorious Revolution, is important and cannot be ignored. Nevertheless, it is incomplete without the addition of military expenditures over the interval 1689-1784. In the years after the Glorious Revolution heightened conflict with France propelled the financial institutions governing British military expenditure to evolve. Via military spending a number of important credit instruments were created, a wider sharing of risk was promoted, a national stock market arose and expanded, the allocation of credit and capital was improved, interest rates were driven down,

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[32] "The growing supply of ever cheaper metal did facilitate enormously the mechanization of other industries (especially cotton textiles), the shift from water to steam power, and, eventually, the means of transportation. In the process the units of metallurgy grew until they overshadowed in their vastness and Vulcanian energy the largest cotton mills in the kingdom" (Landes, 1969, 89).

and a central bank came to preside over the money supply. Sound public deficit finance also enabled military expenditure to be an effective force of demand in key developing economic sectors, most importantly iron. Concurrently, the competitive market-based contracting methods and intermittent nature of British military procurement led to wide ranging changes in the infrastructural bases of British capitalistic production. In this way, decades of massive military expenditure interacted with Britain's unique institutional environment to help foment the industrial mode of development shift, as will be shown.

THE TECHNOLOGICAL SCHOOL – SUPPLY-SIDE CAUSALITY:

Let's now move on to the causal arguments that have been crafted by authors in the 'Technological School.' Many of these discussions revolve around polemics hailing the importance of the supply-side in determining the potential for, and rates of, economic growth (Mokyr, 1993, 56). For supply-side oriented theorists technology is the crux to economic growth: 'Up to three-quarters of Britain's increase in wealth between 1760 and 1860 resulted from better techniques and equipment' (Crouzet, 2001, 105). Of course then, authors in the Technological School tend to focus upon the independent role of the entrepreneurial inventor, making the case that unexpected radical inventions follow a purely technical logic rather than one driven by demand type necessities (Glete, 1993, 17; Mokyr, 1993, 26). T.S. Ashton (1968b: 62) sums up the supply-side view in his characteristically straight shooting manner: "Invention was the mother of necessity, not the other way

around." In concrete terms then this view asserts that technological innovation in the 18th century enabled goods and services to be produced cheaper, better, and faster, thus expanding demand and allowing Britain to attain modern rates of economic growth. "A prior shift of the industry demand curve is not an essential part of the story" (Mokyr, 1993, 62; Mokyr, 1977).

For the supply-side theorist there are two main ways to measure economic change at the macro-level: 1) count patents, 2) measure total factor productivity (Mokyr, 1993, 23). Of course the problem with counting patents is that such a straightforward aggregate provides little information regarding the usefulness of any particular invention. Additionally, many important inventions simply do not get patented (Mokyr, 1993, 23). Nonetheless, in the data section of the British Case there will be some discussion of patent growth and the ways in which this growth intersects with war; e.g. patent growth seems to spike post pronounced periods of hostility thus lending support to the notion that military contractors seek market outlets for their improved production techniques during peace. However, owing to the unspecific nature of 18th century patent aggregates, the bulk of the data backing the dissertation's theories relating directly to technological change and its timing will be founded upon historical narratives which contextualize the crucial inventions and the processes of innovation and diffusion which surrounded them, rather than straightforward patent counts.

Estimates of total factor productivity (TFP), on the other hand, are exceedingly complicated – inputs in an industry are weighted and then subtracted

from growth rates; the residuals measure the rate of productivity growth owed to technical change. Unfortunately, due to the poor statistical precision of 18th century data, TFP estimates for 18th century Britain are not particularly reliable, although there has been some interesting work done on the subject of total factor productivity during the British Industrial Revolution (Mokyr, 1993, 24). For example, between 1760 and 1800 Crafts and Harley (1992) estimate that total factor productivity explained about 10% of total output growth in Britain; between 1800 and 1831 they estimate the figure at 18%. Mokyr (1993: 24-25) marshals data to argue that between 1760 and 1800 "practically the entire growth of per capita income is explained by technological change. Economic growth was slow... but what little there was is explained by the residual." While I certainly admire the work that has been done on total factor productivity during the British Industrial Revolution, estimates are entirely dependent on how the inputs are calculated and weighted, and therefore considerably vary. Hence causal arguments relating to total factor productivity during the British Industrial Revolution are more exercises in economic conjecture than they are descriptions of real world materiality. Luckily, I have not found it necessary to rely on these somewhat unreliable estimated aggregates to provide compelling data supporting the theses presented in chapter one as applied to the British case; as will be demonstrated, less conjectural quantitative data and qualitative narrative do suffice.

Typically, causal arguments from supply-side scholars interested in the British Industrial Revolution also make use of narrative to some extent. Perhaps

the most compelling causal narratives that have been provided by theorists in the Technological School are those regarding the role of accessible coal deposits in Britain. These narratives relate to a seemingly less heralded but still important aspect of the transition away from the agrarian mode of development, that is, the substitution of mineral fuel for vegetable or animal substances. Nowhere was this substitution undertaken earlier or with more vigor than in England (Landes, 1969, 40; Church, 1994; Crouzet, 2001, 101). The wide use of coal in England was primarily a consequence of mid-17th century pressures on forests caused by rising population and increased agricultural enclosure. This drove England to focus "inventive and innovative effort and skills towards a clear target of converting all heat-using industry to mineral fuel" (Harris, 1988; Church, 1994). Greatly aiding Britain in this effort was the fact that England is built on an underground mountain of coal well served by waterways (Crouzet, 1990, 98; Mokyr, 1993). The attempt to master coal technology in Britain reaches back to the early 17th century, and over the course of the 17th century the use of coal in production spread in select industries (brewing, soap making, the smelting of non-ferrous metals), so that by the early 18th century England was preeminent in mineral fuel technology (Crouzet, 2001, 113).

Undoubtedly, coal merits some kind of seat at the British Industrial Revolution causal table; the existence of accessible coal fields did indeed give

Britain a natural stimulus to innovation.[33] Still, until the middle of the 18th century, the use of coal was confined to small sectors of production having little effect upon aggregate growth rates (Mathias, 1979, 17). The fact is that coal's precise causal role in the Industrial Revolution can really only be understood in relation to the iron industry. When supply-side technologists discuss coal as a causal factor of the British Industrial Revolution, they do not do so in terms of brewing, or soap making, or home heating, they do so in terms of iron; rapidly expanding demand for coal for use in manufacturing obtained in large measure only after the coal and iron sector began to fuse (Brown, 1991, 101; Crouzet, 1990, 97; Church, 1994). Prior to this fusion, which primarily occurred between the 1750s and the 1790s, coal was in oversupply, mining techniques were not improving, and collieries were exceedingly small (Ashton and Sykes, 1964, 11-12).

The narrative chapters of the British Case will make the case that military expenditure propelled the critical fusion of the British coal and iron sectors. Military spending provided a main, if not the main, initial source of demand for heavy coke smelted cast iron. Indeed, it will be shown that the technology for smelting cast iron with coal existed as early as 1709, and was developed at the ironworks of a major cast iron ordnance military contractor, Abraham Darby.

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[33] It should be noted however that many international regions had accessible coal resources in the 18th century (listed by their current national names): Belgium, Germany, Sweden, Spain, Russia, the Ukraine, Poland, Slovakia, Canada, Turkey, even France, and the list goes on; however only Britain pioneered the Industrial Revolution (Church, 1994; Cameron, 1994, 11; 19; Mathias, 1979, 16; Parker, 1979, 132). Furthermore, the precise outcome of resource endowments should be considered theoretically ambiguous, at best (Mokyr, 1993, 31; Gunder-Frank, 1998; Gerschenkron, 1962). At the very least then, the presence of accessible coal deposits in Britain must be taken together with other structural and institutional elements if one is to weave convincing causal arguments incorporating coal endowments.

However, there is a strange fifty year interval between this innovation and its widespread diffusion and utilization throughout the British iron industry (Ashton, 1968; Hyde, 1973; Harris, 1988). Historical data will be marshaled below in an argument averring that the pattern of military expenditures over this period accounts for both the innovation itself and the timing of its diffusion. A similar argument will be leveled for the invention and diffusion of methods utilizing coal in wrought iron production (i.e. puddling and rolling). Even the development of the steam engine, which in its earliest incarnation was utilized as a means of pumping water from coal pits, can be linked at least as well to military expenditure as it can to expanding demand for coal, as will be shown.

Related to the coal based supply-side causal arguments of the Technological School are those that highlight the 18th century transportation revolution in Britain. The British revolution in transport is conventionally dated from the 1750s when canal building first began to spread throughout the British countryside. Clearly, this particular spurt in canal growth was driven by increasing demand for coal utilized in manufacturing enterprise (i.e. iron): "Between 1750 and 1801 Parliament sanctioned 165 canal schemes of which 90 were primarily intended for the movement of coal" (Brown, 1991, 101; Rule, 1992, 231).

Supply-side theorists in the Technological School of course consider the mid-late 18th century British transport revolution to be a phenomenon of the supply-side (Mokyr, 1993, 63). The idea is that canals were an invention of sorts, and that this innovation improved transport, led to regional specialization,

accelerated rates of technological progress, decreased prices, and thereby engendered increased demand (Szostack, 1991). This seems to me a classic example of molding history in order to fit one's polemic rather than allowing historical fact to inform theory. Undoubtedly, the price of coal and iron tumbled dramatically with the building of the canals; however, the price of these two important industrial raw materials was falling prior to the outbuilding of the canal infrastructure (Brown, 1991, 156). The fact is that Britain's transport system slowly improved over the course of the entire 18th century. This was primarily an effect of growing regional specialization, which certainly picked up speed with the genesis of canal transport, but pre-dates it by some 100 years and can thus not correctly be considered an effect of transport developments on the supply-side.[34] A more historically accurate interpretation is that regional specialization (manufacturing and mining in the northwest, agriculture in the south, etc.) preceded and contributed to the rise of developed turnpikes and canals, and in a positive economic feedback loop, improved transport increased regional specialization. Indeed, far-reaching improvements to British transport were initially propelled by non-industrial type economic growth (putting-out). It can be assumed then that continued non-industrial economic growth would have also led to improved transport, although perhaps not at the same rate as achieved in the latter 18th century with the rise of industrial style development. Hence, it is likely that the canal boom, which reached its heights during the 1790s, was an effect rather than a

[34] Turnpike and waterway improvements clearly followed from increased interregional economic activity beginning as early as the 17th century (Rule, 1992, 245; Pressnell, 1960, 1).

cause of emerging industrial production.[35] What is certain is that better transport was a crucial enabling factor during the British industrial mode of development shift (Rule, 1992; Brown, 1991). In the final analysis, what we are concerned with here is not which came first, industrial growth (the chicken), or transport growth (the egg), but the role that military expenditure played in motivating capital expenditures on transport which in turn supported British processes of industrialization.

The causal role of military expenditures during the British canal boom is somewhat apparent; if military expenditure drove the 18th century coal-iron fusion, then it can also be said to have motivated many of the canals that rose to service this fusion. From 1758 to 1803 over 25% of the canals built in England were mainly taken up with iron ore transport, while another 55% provided emerging industrial enterprise with coal (Rule, 1992, 138). Indeed, of 52 acts for inland waterway improvement passed by 1774, 33 were in the Midlands and north and a further five in the Scottish lowlands, which were the budding industrial epicenters of iron production, and, not surprisingly, home to the major iron military contractors. These canals linked the vertically integrating iron firms back to their sources of supply and forward to their outlets; and as will be discussed more below, naval iron contractors vertically integrated first and furthest (Rule, 1992, 231-232; Brown, 1991, 99; 136). Additionally, the narrative chapters of the British Case will point to the fairly numerous times during the 18th century when increased military

[35] Note that excellent internal transport did little to help the Dutch industrialize (Mokyr, 1993, 31-32).

contracting and naval shipbuilding can be directly linked to improvements in regional transport infrastructure. Most importantly, it will be shown how developments in cast iron production, which were largely driven by heightened military expenditure, led directly to innovations in transport technologies, such as the use of cast iron rails and flanges and the advent of iron bridges. These crucial infrastructural innovations tended to appear and diffuse during peaceful intervals following intense conflict as ironmasters sought new uses for their capital intensive wares (John, 1955; Ashton, 1968; Deane, 1965). Moreover, it will be argued that the timing of the initial thrust of the canal boom can be explained by the 1750s decline in the rate of interest brought about by conversion operations on the national debt, which obtained as a consequence of heightened military expenditures during the War of the Austrian Succession (1739-1748).

But now the discussion has strayed from the strictly supply-side economics of the Technological School, for surely increasing economic demand driven by advancing regional specialization (amongst other factors) deserves primacy in the 'improving transport feedback loop' that accompanied the birth of the industrial mode of development (Deane, 1965; Rule, 1992; Brown, 1991). Let's move on then to the demand-side oriented causal arguments of the Macroeconomic School.

THE MACROECONOMIC SCHOOL – DEMAND SIDE CAUSALITY:

Most economic historians interested in the British Industrial Revolution accept the importance of supply-side technical innovation, but feel the causality

picture is left incomplete without the addition of factors relating to demand. "Demand pull explanations are based on the argument that users or potential users of new technology guide the innovators through an articulated demand for certain innovations" (Glete, 1993, 17). For example, Crafts (1981) argues that industrial inventions had a stochastic element to the timing of their emergence, but it is economic demand factors that led to their dispersal throughout the economy. Only when the environment caused a pressing need, only when the market was sufficiently large enough, and only when demand was adequately elastic to justify increases in output, did innovations diffuse. Scholars in the Macroeconomic School typically seek to analyze such demand-side factors through the use of aggregated macroeconomic statistics (Brown, 1991, 82; Rule, 1992, 252; Landes, 1969, 77).

Before a discussion of the key theories that have generated from demand-centered 18th century British statistical analyses is commenced, it may be useful to reiterate a key demand-side causal argument that girds the dissertation's data analysis concerning the 18th century iron sector vis-à-vis the opposing supply-side argument. The supply-siders of the Technological School argue that "an increase in aggregate demand will only have an effect on the supply-side if large underutilized resources can be brought into production. Evidence for these large underutilized resources is missing when aggregate demand began to grow in the second half of the 18th century" (Mokyr, 1993, 60). Subsequent chapters of the British Case will demonstrate that during the middle years of the 18th century there

is unambiguous evidence of resource underutilization in the burgeoning British iron sector, and that the increases in aggregate demand engendered by military expenditures did in fact cause a technical supply-side response. This response, entailing the use of mineral fuel, improved technique, heightened fixed capital investment, vertical integration, and geographical expansion, was crucial to the genesis of the industrial mode of development.[36] To be sure then, capital intensive military demand plays an important theoretical role in the causal mechanisms of the dissertation's theory as applied to the British Case, but what of other demand-side assertions; what role, if any, do they play in this work's causal story?

In the mid 20th century many economic historians attempted to link the British Industrial Revolution to the growth in consumption that occurred in Britain during the late 17th and early 18th centuries (Nef, 1950; Ashton, 1959; John, 1967; Landes, 1969; Thompson, 1973, 66; Mokyr, 1993, 59). Before the end of the 17th century it can be statistically demonstrated that 'consumer goods were absorbing an increasing share of the nation's economic resources' (Rule, 1992, 253). Through an assertion that this expansion of demand was generated by declining agricultural prices, some economic historians came to view the Industrial Revolution as a natural outcome of the earlier revolution in horticultural practices (Deane and Cole, 1962; John, 1967; Rule, 1992, 54). Other economic historians sought to declare

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[36] Anderson (1972: 15) argues: "Clearly, the impact of war on demand for the (iron) industry... (called) into use new resources... causing supply curves to shift bodily and irreversibly to the right, achieving economies of scale and growth and the incorporation of new technology."

population growth as a causal factor in the Industrial Revolution by way of the early 18th century growth in consumption (Fisher, 1992; Crouzet, 1990).

In later research economic historians noted a number of problems with these demand-side arguments. To begin with, there were changing tastes and growth in consumption aggregates throughout Europe at this time, especially in France and the Netherlands, yet only Britain generated an Industrial Revolution (Rule, 1992, 254). The same can be said of population growth rates, which were exceedingly similar across Europe until well after the onset of industrial growth in Britain (Fisher, 1992, 7; Crouzet, 1990, 32). Also, levels of disposable income per capita at the end of the 17th century in Holland and France do not differ widely from those which obtained in Britain prior to the Industrial Revolution (Mathias, 1979, 16). Moreover, reanalysis of 18th century statistical aggregates showed if there was a consumer revolution at all in Britain it definitely peaked before 1720; thus the long lag between the event and the onset of industrial growth makes any causal connection between the two rather tenuous (Mokyr, 1993, 60-61). Furthermore, if low grain prices drove the Industrial Revolution, how can it be that grain prices were higher in the three decades directly preceding industrial growth than they were in the five decades prior to that (Mokyr, 1977; Rule, 1992, 254)?[37] To these important points I would like to add the notion that the articles consumed at heightened levels in the late 17th and early 18th centuries were hardly the heavy

[37] Crouzet (1990: 90) has found through varied methods of analysis "that the causal relationship in England between the Agricultural Revolution and the Industrial Revolution was a weak one;" the main impetus to industrial change could not have come from the agricultural sector.

infrastructural fixed capital producer goods that came to compose the foundations of the industrial mode of development. We are talking about soap, tea, tobacco, snuff, sugar, glassware, china, wine, utensils, clocks, linens, muslins, hats, ribbons, etc (Rule, 1992, 256; Mathias, 1979, 162). Consumption and output of such goods could easily have continued to grow within a pre-industrial productive system, as it did throughout Europe at this time. The same cannot be said of Britain's unique form of capital intensive military procurement; certainly by the War of American Independence (1775-1784) such a system required an evolving industrial infrastructure of some sort.

Another macroeconomic demand-sided causal thesis that receives short shrift in this project relates to labor supply and wages in 18th century Britain. The thesis avers that expanding demand caused various labor shortages which led to relatively high wages in key manufacturing sectors in Britain. This in turn drove the English to develop labor saving machinery (Brown, 1991, 82). The problem here is that wages in new industrial sectors were actually higher than those in the old traditional sectors. If machinery was expressly intended to save on labor costs or to rationalize its use, one would expect wages to be lower in industrial enterprise, not higher. Furthermore, the evidence suggests that the regions that industrialized in Britain initially had lower wages, not higher, as compared with regions that failed to industrialize; "Textile innovations emerged in low wage areas" (Crouzet, 2001, 115; Hunt, 1986). It also has been shown that only 3.7% of patentees in 18th century Britain declared labor saving as a rationale for their

invention. Better, faster, more, these were the watchwords of industrial entrepreneurs. Additionally, there is no evidence of labor scarcity in 18th century Britain, especially in the towns that eventually became the industrial districts (Mokyr, 1993, 87-88; Brown, 1991, 317).

Entirely more persuasive are demand-side arguments that revolve around the growth in commercial trade Britain experienced in the decades before and during the Industrial Revolution. Such arguments generally assert that trade was a major contributor to economic growth and likely set the stage for industrial growth. From 1700 to 1775 imports rose steadily to a total increase of 172% over the period, while total exports (including re-exports) increased 156% over the same period. Trade grew faster than both population and national income in Britain. The increase was in excess of 2% per year and although this growth rate is not much greater than that which obtained from 1650-1700, it is clear that mercantile trade in the 17th and 18th centuries created more demand for English manufactured products and also contributed to circulating credit (Fisher, 1992; 13-14; Landes, 1969, 52; Deane, 1965; Deane and Cole, 1962).

Bearing these facts in mind, a number of crucial caveats warrant mention. First, rapid growth in commercial trade was a European wide phenomenon in the 17th and 18th centuries. Trade aggregates in Britain accelerate uniquely only in the 1780s, concurrent with the onset of industrial growth (Kindlerberger, 1975, 632; Crouzet, 1990, 17; Thompson, 1973, 93; Mathias, 1979, 15). McCloskey (1981) commenting on the work of Deane and Cole (1962), which asserted that the rise in

exports was of central importance to the sustained expansion of the British economy, concludes that "the strongest effect between commerce abroad and industrialization at home was industry to commerce, not the reverse. Trade was the child of industry." For supply-siders, foreign demand for manufactures was simply too small a proportion of the overall British market for trade to be considered a serious cause of industrial technical change (Kindleberger, 1964, 264-266; Davis, 1979, 62-63; Mokyr, 1993, 60-63).

But don't throw the baby out with the bath water yet, for causal arguments incorporating trade demand are much more persuasive for cotton textiles than they are for the British economy more generally. The cotton industry received its raw materials from abroad, and growth rates were largely dependent on the expansion of foreign markets. For cotton, the aggregate trade statistics seem to favor a demand-side causal explanation of growth; by 1815 Britain was exporting over half of its cotton textile production (Rule, 1992, 273; Deane, 1965). This of course counters the supply-side notion that foreign demand was too insignificant to drive technical innovation by focusing on the cotton textile sector alone rather than broadly looking at the market for British manufactures as a whole (Brown, 1991; Thompson, 1973; Deane and Cole, 1962).

International iron exports, on the other hand, were far less significant, and picked up only around 1788. Even then, merely a third of increased iron sales between 1788 and 1806 were realized in foreign markets (77% of the growth in iron consumption can be attributed to increased domestic use); and iron and steel

goods were only 5-7% of total exports between 1750 and 1800 (Brown, 1991, 173; Thompson, 1973, 93). It was the domestic market then that gobbled up iron in escalating quantities during the latter half of the 18th century. As will be evidenced, military demand accounted for a fair proportion of the mid 18th century British domestic market for iron – approximately 20% generally, and approaching 60% in the heavy cast iron sector.[38] On a related note, evidence will be provided in subsequent chapters showing that as a percentage of national income, military expenditures outpaced the total value of exports for much of the 18th century (O'Brien, 1991). This lends credence to the idea that military expenditures, made an effective force of demand by market-based contracting and sound public deficit finance, reached importantly large levels in relation to overall demand in the iron sector to have significantly affected technological trajectories. In other words, the role that foreign demand played in the development of the cotton sector can be viewed as paralleling the role that military demand played in the development of the all-important cast iron sector; foreign markets purchased nearly half of British cotton textile output in the late 18th century (Rule, 1992, 273), and the British military purchased approximately half of domestic cast iron output in the mid-late 18th century.

A more obvious and indubitable contribution foreign trade made to the genesis of the industrial mode of development devolves from the multiple decades

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[38] These estimates are again calculated using price, output, and naval demand figures found in Hyde, 1973; Harris, 1988; Pritchard, 1987; and Glete, 1993 as will be detailed further in the narrative chapters.

of mounting trading profits that accumulated in Britain, and elsewhere, over the course of the 17th and 18th centuries. These profits enlarged the base of savings that British public deficit finance tapped during 18th century wars. Interestingly, by the War of the Austrian Succession, foreign merchants held over a quarter of British debt securities, so it was not only British commercial profits, but commercial profits more generally that contributed to the expansion of public deficit finance in Britain. This is not to suggest that a commercial revolution was sufficient to bring about industrialization (the Dutch led the world in merchant trade and yet failed to lead the world to industrialism), but I am partial to the notion that a profitable commercial revolution was a necessary precondition to British industrialization (Deane, 1965; Landes, 1969, 55). Without mercantile profit, sound public deficit finance in England would have been impossible (Dickson, 1967; Deane, 1965), and as argued above, sound public deficit finance is taken here to be an overwhelmingly important factor propelling both military expenditure and the concomitant industrial mode of development shift.

The final Macroeconomic School topic I would like to address before moving on to the Industrial Organization School is taxation during the British Industrial Revolution. Macroeconomic historians study taxation during the shift to industrial production because, 1) the British state kept relatively complete, consistent, and clear aggregate statistics on taxation and the products which it taxed, and 2) the structure of taxation in 18th century Britain was clearly supportive of burgeoning industrial growth. In the 'military expenditure impetus to mode of

development shifts theory' presented in chapter one, efficient taxation composes one of the six independent variables involved in the 'multiple conjunctional causation' model. There is good reason for this: well over half of British military expenditure during the 18th century derived from taxation, and the rest was mortgaged upon future tax revenue: "The British government borrowed sufficiently and cheaply enough because its reputation for efficient tax gathering allowed anticipated revenues to provide the security for its present borrowings" (Rule, 1992, 277). Had British taxation been any less efficient or revenue any less certain the dissertation's proposed causal theory would not have been operative. Although few theorists have directly cited British taxation as a cause of the Industrial Revolution, many have been astounded not only by the high levels of taxation borne by the British just prior to and during the Industrial Revolution, but also by the fact that industrial entrepreneurs, along with investors in public deficit finance, largely escaped taxation altogether. The way that Britain achieved this interesting constellation was by efficiently taxing consumables over land, and the poor above the capitalist; 18th century Britain in effect had no capital gains taxes although its citizens carried the highest tax burden in Europe (Dickson, 1967; Mathias and O'Brien, 1976; Mathias, 1979; Brewer, 1988; Mokyr, 1993, 45; Crouzet, 2001). Complete data will be provided in subsequent chapters, but allow me to make something clear here; because of its critical role in military expenditure I am claiming that the configuration of British taxation was a causal factor in the British industrial mode of development shift. If the entire taxation story was one of

low tax rates for industrial entrepreneurs, then taxation would best be considered a permissive rather than a causal factor. But because the state effectively taxed the masses and directed those revenues towards untaxed military contractors who in turn used the funds to alter the infrastructural nature of production, taxation can be deemed causal.

The ironic juxtaposition of this modern day 'supply-side' tax argument appearing in the final section relating to macroeconomic demand-side causality is not lost on this author. The juxtaposition remains in order to make a point: In the real world, polemical debates between those supporting supply-side causality and those supporting demand-side causality are rather futile; I do not mean to reify them. What matters in the material world is fact, data, logic, trajectory, and in this case, the interaction between supply and demand. "Any attempt to demonstrate the primacy of one side or the other is likely to obscure the truth: that in the long-run the two way relationship was paramount" (Thompson, 1973, 144). During the formative years of the industrial mode of development gains from institutions, specialization, market extension, trade, finance, military expenditure, improvements in transport, technological progress, expansion of the iron sector, vertical integration, economies of scale, what have you, interacted and led to sustained industrial growth. Monocausal, linear, or polemical models simply cannot account for the historical reality. "Only models making use of multiple variables, positive feedback, and interactive path dependence will work" (Mokyr, 1993, 26-27). In establishing and supporting the dissertation's causal theory

relating to 'the military expenditure impetus to mode of development shifts' all three of these sociological tools are being employed. And what emerges is not explicitly a supply-side model, nor a demand-side model, nor a model describing the entire range of causal processes involved in the British Industrial Revolution. What I hope emerges for the reader is a model that illuminates the important, but necessarily partial, causality that derived from long-term large-scale military expenditure, and the variables that made it operative, during the transition to industrial production in Britain.

THE INDUSTRIAL ORGANIZATION SCHOOL:

That being said, let's move on to the final school of causal thought pertaining to the British Industrial Revolution; that of The Industrial Organization School. In studying the rise of the factory in Britain (the main focus of authors in this school), some Industrial Organization scholars have proposed the proto-industrialization thesis, which seeks to answer the question; why did merchants opt to gather workers under a single roof in the final quarter of the 18th century? The proto-industrialization answer focuses on the growth of 'put-out' commodity production in the century prior to the onset of industrial growth in Britain. Putting-out simply involves an organizing merchant who hires home workers to manufacture light consumables in their dwelling. The merchant provides the raw materials, receives back the finished product from the domestic worker, and then trades it on the open market (Alder, 1997, 127).

The proto-industrialization thesis states that rising demand for consumables caused mid-18th century merchants to desire a mechanism capable of augmenting the productivity of outworkers without raising wages; it was believed that 18th century outworkers did not respond to higher wages in an economically 'rational' fashion owing to a 'leisure preference.' Supporters of the proto-industrialization thesis also argue that geographic dispersion of the putting out industry had expanded to levels where further expansion was unprofitable given the poor state of transport in rural England. On top of these constraints, embezzlement in put-out manufacture may have become an increasingly serious problem in the mid-18th century. Since merchants had no means by which to monitor and / or force outworkers to increase their productivity to meet rising demand, they began organizing outworkers into supervised workshops. The rise of these workshops in turn spurred industrialization (Landes, 1969; Crouzet, 2001).

There are a number of glaring problems with the proto-industrialization thesis. First, as previously stated, growth in demand for light consumables reached its peak around 1720, at least sixty years before the rise of (somewhat) prevalent factory organization. Next, no hard evidence exists proving an 18th century 'leisure preference'; the theory arose because merchants sought to justify the low wages they paid to domestic outworkers. In fact, the evidence suggests that wages were actually higher in factories, and workers did respond rationally, for this is what induced men, women, and children to give up their domestic life (Mokyr, 1993, 91). Additionally, transportation improved throughout Britain in lockstep with

increased putting-out. There is no evidence that merchants found the distances involved in putting-out more onerous in the second half of the 18th century than they did in the first (Little, 1976; Rule, 1992). What's more, putting-out seems to be the natural method of petty commodity production in the pre-industrial world, for it occurred not only throughout Europe, but throughout the civilized world. Putting-out therefore seems neither a cause nor an important pre-condition to British industrialization, it was simply the normal manufacturing method for light consumables during the 17th and 18th centuries (Crouzet, 2001, 62; Gunder-Frank, 1998; Price, 1975).

Besides, industrial factory production involves significantly more than simply gathering workers under a roof. Early merchant organized workshops, such as those producing silk, china, or other light consumables, cannot rightly be considered incubators of vertically integrated engine and machine run factory production in Britain. In fact, early 18th century consumables workshops should not even be considered models for the initial rise of supervisory management. The workshops of the pre-industrial age depended largely on "a feckless, wandering reserve of migrants with a high rate of turnover and little sense of discipline" (Deane, 1965, 155). Workers were not held to tight quotas for workweek length, workday length, or output. Workers were paid by the piece and employers evidently didn't mind if workers came in late, took off Mondays, or drank while they worked. The intensification of control thesis as a prime cause of the rise of factory production in Britain has therefore been entirely overstated (especially in

neo-marxist literature) (Mokyr, 1993, 111-112).

So what did drive the rise of factory production in late 18th century Britain? Quite simply, it was evolving technology; although not circa mid-century developments in light textile machinery, such as the spinning jenny, as is commonly supposed. The first textile related technical devices that came about (early puncher, cutting, spinning, and stamping machines) reinforced the position of the home worker; they were 'eminently suitable' to the cottage or cellar. "It is only when a higher stage of machine construction is reached, with the building of large, power-driven devices that factory manufacture wins out" (Landes, 1969, 118). The factory rose because increasingly large metal machinery run by centralized power sources, such as cast iron waterwheels or steam engines, could not fit in a cellar (Mokyr, 1993, 111). In other words, economies of scale at the plant level became rational only with the introduction of centralized power supplies. Factory organization in textiles was exceedingly rare until the inventions of the power mule and the steam engine combined to foster engine based textile production. Prior to this convergence, towns were little more than commercial trading centers; they only became industrial with the onset of the use of steam power (Deane, 1965, 156; Brown, 1991, 409; Rule, 1992, 97). 'What made the factory successful in Britain was not the wish but the muscle': the machines and the engines that drove them (Landes, 1986, 606).

In fact, many Industrial Organization scholars aver, for good reason, that the iron sector alone was the true incubator of vertically organized, large-scale,

machine based, and managerially supervised factory production in 18th century Britain (Ashton, 1968; Deane, 1965; Harris, 1988; Brown, 1991; Rule, 1992). The centralized power source for textile production, Watt's steam engine, was clearly an outcome of decades-long technical progress in the iron industry; specifically, developments involving casting and boring technologies. And the iron industry was the initial sector to make wide use of this and other centralized power sources (i.e. huge cast iron waterwheels), along with a whole host of other innovative fixed-capital machines (Ashton, 1968; Landes, 1969, 105).

As will be detailed in the narrative chapters of the British Case, the development and use of steam engines, boring machines, and other heavy fixed capital machinery in the 18th century British iron sector, was directly stimulated by large-scale military expenditures. Additionally, the timing of the application of steam power to textile production can be partially explained by the post American War iron sector downturn, which drove ironmasters to find new uses for their enlarged and improved cast iron production facilities. Moreover, the occurrence of foreman supervised production under one roof as a dominant tendency of industry undoubtedly appears in the iron sector before any other; some three decades before the steam / textile fusion. Indeed, by the mid 1760s, large factories had become the prevailing trend in the coke powered casting sector. There, a growing range of heavy complex iron products, many commissioned by the Navy and used in capital intensive warfare, were manufactured (Rule, 1992, 150-153; Ashton, 1968; Deane, 1965; Hyde, 1973; Harris, 1988; Landes, 1969, 90; Mokyr, 1993, 111). Not

surprisingly then, the major cast iron military contractors were some of the first and largest enterprises exhibiting foreman supervised factory production (the foreman was necessary to integrate the increasingly numerous and complex fabrication chains involved in manufacturing an effective cast iron ware). As will be shown, rivalry for the awarding of outsized naval contracts provided a strong impetus driving not only fixed plant investment but also the rise of managerial supervision, cohesive production chains, and the concomitant transition to economies of scale in the 18th century British iron sector (Ashton, 1959; Deane, 1965; Hobsbawm, 1968; Rule, 1992).

The competition for naval contracts also propelled vertical integration in the iron industry, the first sector to exhibit this definitional industrial organizational model. Vertical integration entailed tremendously large fixed capital investment for the time (Rule, 1992, 117; Brown, 1991, 120; Harris, 1988, 68). As long as large long-standing naval contracts could be secured, such massive investment would assuredly prove worthwhile. Much of the timing of vertical integration in the iron industry can therefore be connected to vicissitudes in military spending. This is especially so from 1756 to 1763 and again from 1775 to 1784, when the Seven Years War and the War of American Independence respectively drove iron prices to rise; yet ironmasters' material costs were held down "because they

integrated backwards and efficiently into coal and iron mining" (Harris, 1988, 56; Hyde, 1973; Rule, 1992; Ashton, 1968).[39]

To conclude this section then, both the dissertation's theory and the empirical data that will be marshaled in support of it have basis in the work of the Industrial Organization School. Although the proto-industrialization thesis is summarily rejected (this is not uncommon in the current literature), the idea that factory organization developed and dispersed primarily as a consequence of the application of centralized power sources to manufacturing is accepted; as are narratives which conclude that vertically integrated, engine-based, foreman supervised factories reaping gains from economies of scale found their initial genesis in the 18th century British iron sector. Of course, the role that military expenditure played in propelling, furthering, and generalizing these particular outcomes, along with all of the other institutional, structural, and technical advents expounded above, will be highlighted in the narrative chapters of the British case, to which we now turn.

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[39] The final push to entire vertical integration in the iron industry obtained with the invention of Cort's puddling and rolling process (1783), which brought wrought iron into the coal powered production chain (Rule, 1992, 117; Brown, 1991, 120; Deane, 1965, 112-113). As will be shown, this invention too was strongly rooted in the capital flow of military expenditures (Ashton, 1959; Brown, 1991, 120).

CHAPTER 3: NARRATIVE OVERVIEW and THE NINE YEARS WAR

Before the British Case narrative commences, allow me to provide a road map outlining the path forward. In reviewing the four causal schools of thought pertaining to the British Industrial Revolution, we have touched upon each of the variables that will guide the historical narrative and empirical analysis. These variables of course devolve from the generalized and abstracted 'military expenditure impetus to mode of development shifts theory' as explicated in chapter one. Recall that the causal model presented in chapter one involved 'multiple conjunctional causation.' Therefore, in order to preserve the important contextual consistency of the historical narrative along with the causal interconnection of each variable, the following chapters will analyze the full set of connected independent variables in the temporal context of each major war England fought during the interval 1689-1784. These wars were: The Nine Years War (1689-1697), The War of the Spanish Succession (1702-1713); The War of the Austrian Succession (1739-1748); The Seven Years War (1756-1763); and The War of American Independence (1775-1784). The in tact historical narrative of each war will be guided by an examination of the following conjunctional causal variables: Military expenditure (its aggregate total in relation to the British economy, previous wars, and overall state spending); Taxation (its organization, incidence, and effect); Public Deficit Finance (its evolution and ultimate size); and Military Contracting

(its form and progress).[40] The analysis of each war will then conclude with a discussion of the dependent variable, the British industrial mode of development shift, and how it was effected and affected by the causal variables included in the model during the particular war at hand.

A synopsis now follows: During the Nine Years War (1689-1697) military spending caused state expenditure to triple, a large deficit emerged, England began to increasingly rely on excise taxation to meet the extraordinary expenses of warfare, debt came to oblige the entire nation as embodied by Parliament rather than just the King, interest payments on new loans became 'funded' out of parliamentary backed 'earmarks', 'irredeemable' annuities were eschewed for 'redeemable' public debt instruments, the state began utilizing the East India Company (whose shares were actively traded on the London stock exchange) as an intermediary floater of long-term public debt thus making public debt instruments widely assignable, and the Bank of England was incorporated in 1694, immediately becoming a major issuer, discounter, and 'ingrafter' of accumulated short-term public debt instruments. Taken together these changes to public expenditure and credit amounted to a financial metamorphosis which allowed England to emerge victorious from the Nine Years War; in later years these changes, born of war, would enable military expenditure to become an effective force of demand in the

[40] Two sets of independent variables included in chapter one's 'multiple conjunctional model' are omitted from the data analysis: 1) The institutional preconditions to economic development (parliamentary governance, secure property rights, and low transaction costs), and 2) Insulation from attack. This is because Britain's institutions governing economic exchange were not fundamentally altered after 1688 (North and Thomas, 1973); and because insulation from attack in Britain over the period 1689-1784 is simply an historical fact.

English economy. Also, during the Nine Years War, England came to rely on a market-based competitive bid contracting system to supply its increasingly capital intensive war efforts. The Naval and Ordnance Offices oversaw and guided procurement in this system but allowed firms in the capitalistic contracting marketplace to develop and innovate upon product and manufacturing processes. In the economy, we see military expenditure begin to combine with the contracting market to cause improvements to merchant shipbuilding, road construction, and cast iron production.

The War of the Spanish Succession (1702-1713) cost some 90% more than the Nine Years War, causing English public debt aggregates to swell approximately 150%. In response, the state continued to expand the bureaucratic administration of excises, increasingly relied on excises to fund extraordinary expenses, instituted a more regressive tax structure, and allowed investors in public debt and manufacturers in war related industries to effectively escape taxation. In public deficit finance a modern looking yield curve for public debt materialized during the War of the Spanish Succession and yields throughout the economy began to move in sympathy with rates on long-term government debt, establishing a sustained descending trend. Additionally, the Bank of England shored up its importance by managing numerous short-term 'exchequer bill' issues; the Bank became an institutionalized aspect of the Parliament centered English system of checks and balances (this time in regards to currency issue); the issue of irredeemable public debt instruments was entirely discontinued; and the state completed its first major

debt buyback program converting the charge on servicing the national debt to lower rates. Each of these developments improved public deficit finance in England, making it more secure, and thus endowing military expenditure with ever more transformative force. Such transformative force appears most clearly in the iron sector, especially the cast iron sector, where military expenditure drove some improvements to plant and process. Most notably, mineral fuel was first used to successfully smelt pig iron at the site of a major military contractor during the War of the Spanish Succession. Also, naval building at capitalistic merchant shipbuilders caused merchant ship and warship design to converge and improve during the war, thus enhancing England's ability to exploit the numerous trade gains attained as a result of England's successful military effort.

During the War of the Austrian Succession (1739-1748) taxation became even more regressive thus imposing a lighter burden on contractors and the wealthy classes financing public debt investments. Also, the cumulative size of the national debt increased some 62%. Importantly the Bank of England emerged in this war as the 'discounter of last resort' – London financial houses shied away from discounting government and commercial paper at the height of the war; the Bank stepped in and made sure the wheels of commerce and the economy continued to turn by becoming the primary discounter for all sorts of paper. This conferred heightened security and certainty to credit payments emanating from British defense departments. In fact Ordnance Office credit instruments for the first time passed as if they were cash during this war (i.e. no discount and no attached

interest). As a consequence, the enlarged procurement packages radiating from the British defense departments (ordnance expenditures were 75% per annum higher in this war than during the previous war) had significant and lasting transformative effects upon the British iron and shipbuilding industries along with Britain's transportation infrastructure. Most importantly, major military iron contractors applied steam power to immense cast iron waterwheels thus freeing the iron industry from the bounds placed on it by the need for power from natural river flows. The heavy fixed capital expenditures required to install such mechanical centralized power systems ignited a positive economic feedback loop in the cast iron industry that led to sustained growth in the postwar period. After 1750, cast iron increasingly became a producers good utilized in various manufacturing sectors throughout the British economy, particularly in regards to centralized hydraulic power systems. In short, military expenditures during the War of the Austrian Succession unmistakably helped to shift effective aggregate demand in the British economy towards products that required heavy capital goods, fixed capital investment, and enhanced infrastructure for their manufacture. Additionally, in the postwar period the First Lord Treasurer, Henry Pelham, was able to finagle interest charges on the national debt (which had gotten out of hand during hostilities) to well below the natural market rate of interest thus helping to spur a massive mid-century capital goods boom which directly contributed to the nascent British industrial mode of development shift.

The Seven Years War (1756-1763) is considered by many to be the first

truly global war; heavy combat occurred in four disparate world theatres. During the Seven Years War annual expenditure was 80% higher than it had been during the War of the Austrian Succession which took place merely a decade prior. This caused public debt and debt charges in Britain to swell by over 70%. When controlling for inflation and length of war, the Seven Years War emerges as the most costly conflict of the 18th century. To meet the costs and fund the heavy loans of the Seven Years War, the state rapidly amplified the tax burden in Britain, but again relied on increased excises for the extraordinary costs of war, while still avoiding whole areas of manufacturing relevant to the war effort and industrialization more generally. Importantly, the Seven Years War marks the first conflict that occurred after the 'English Financial Revolution' was entirely complete (Dickson, 1967). And as the 'military expenditure impetus to mode of development shifts theory' would predict, it is during this war that military spending most plainly impinges upon British economic development in a positive manner. Contributing to this positive effect was continued and wider use of market-based military contracting and an increased reliance on 'standing contracts.' During the Seven Years War the British economy was firing on all cylinders. The war had no negative impacts on any macroeconomic statistical aggregates; in fact the war stimulated pervasive growth in several British economic sectors. The capital goods boom initiated by Pelham's conversion became a veritable explosion when combined with the extreme military expenditures injected into the economy via the market-based contracting system as Britain conducted its capital intensive

methods of warfare. By this time the size and arming of British merchant ships made them immune to hostile action, and according to Kennedy (1976: 105) British shipping volumes rose an unbelievable 1462% during the war. The iron sector was enormously stoked by heightened military expenditures: the war established a steep trend of expanding domestic iron production that lasted well into the 19th century, fixed capital expenditures were greatly augmented in the iron industry generally, the war caused coke smelting of pig iron to widely disperse throughout the British iron industry (starting with the major military contractors), intense competition for standing military contracts drove iron contractors to vertically integrate (marking the first time that firms utilized this definitional industrial organizational structure), and the heavy sunk fixed capital expenditures that obtained as a consequence of wartime military expenditures caused ironmasters to invent many capital goods products suitable to peaceful market production in the post-war period (such as cast iron rails and flanges, the cylinder boring machine, and the cast iron separate condensing chamber steam engine). Indeed, patent issues tripled a year after the close of hostilities as enhanced fixed and human capital were released back into the commercial economy. The rapid development of the British iron industry during and after the war was also accompanied by explosive growth in transport infrastructure investment. There were notable improvements to waterways, turnpikes, and highways, especially in and around military contractors. In fact, Pelham's conversion along with military procurement during the Seven Years War encouraged the first canal construction boom in Britain. As cast iron goods were

extended and applied to widening manufacturing and infrastructural sectors, the British economy unequivocally began to transition to an industrial mode of development. In short, the 'military expenditure impetus to mode of development shifts theory' and all of its associated corollaries are palpable during and after the Seven Years War.

The total cost of the War of the American Independence (1775-1784) was, in nominal terms, some 60% above the costs of the shorter Seven Years War, propelling the national debt to nearly double in size. As a consequence the burden of taxation borne by the English public sharply rose during the American War, and for the first time in the 18th century, the rate of growth in tax revenues outpaced the rate of growth in expenditure. Over the course of the war, however, the British state began to move away from the regressive taxation structure that had previously funded war efforts, and after the war a rudimentary income tax was established. Nevertheless, investment in debt, stock, and fixed capital remained untaxed during the war, and the state still avoided taxing manufacturing sectors directly relevant to war efforts. The American War was also the first 18th century war that unambiguously exhibited the corrosive economic effects of crowding out; inflation rapidly trended upwards and interest rates reached as high as 7%, which was two and a half times the rate that obtained in the 1750s. Clearly the economic slack that had enabled extreme military expenditure and large-scale public deficit finance without the concomitant effects of crowding out was driven from the British economy in the years prior to the American War. This ultimately was a

consequence of the twenty year capital goods and privately financed public works boom initiated by Pelham's conversion and strengthened by the Seven Years War. Indeed, with government debt yielding returns well above the average rate of return on long-term capital goods and infrastructural investments the boom was extinguished in soon to be defeated Britain. Nevertheless, this dissertation maintains that crowding out is not necessarily bad for economic development in the long-run if public expenditure finds its way into the hands of private contractors in dynamic leading sectors of the economy who use public funds to augment fixed capital infrastructure and improve manufacturing processes. This assuredly occurred during the War of American Independence. Naval contracting during the war caused the epicenter of British shipbuilding to move from the Thames to the northeast, which had redounding effects upon British transport infrastructure. In the iron sector war caused there to be increased output, increased fixed capital expenditure, and more vertical integration. Major military iron contractors applied the separate condensing chamber steam engine to all aspects of the iron production chain during the war. And importantly, a naval purchasing agent, Henry Cort, invented 'puddling and rolling' during the war at Cyfarthfa, one of the largest naval iron contracting firms of the time. Puddling and rolling allowed for the use of coked coal in the final production of wrought iron. This invention, which was expressly intended to enable the British Navy to acquire increasingly dear wrought iron at a fair price and good quality, led the domestic British iron industry to explosive growth in the postwar period. Steam and complex iron machinery were

applied to ever widening manufacturing sectors throughout Britain, especially cotton textiles. Patent issue rates increased by over 60% immediately following the war. And in the 1780s industrial growth finally incontrovertibly appears in macroeconomic statistical aggregates. Britain had entered the Industrial Age. After the 1780s industrialism plainly had a life and pace of its own quite separate from military expenditure. In fact, owing to crowding out, military expenditure began to negatively impinge upon the potential developmental trajectory of the newly formed British industrial mode of development; which required low inflation, low interest rates, and peaceful trading lanes to reach its inherent growth potential. Thus the British case analysis, which spotlights the role that military expenditure played in causing the British industrial mode of development to come into being, comes to a close with the end of the War of American Independence.

THE NINE YEARS WAR – 1689-1697:

In the late 17th century, war had been getting more frequent and expensive within the European interstate system for quite some time (Tilly, 1990). England, overshadowed by the mercantile Dutch and the imperial French, had not yet reached great power status (Kennedy, 1987). At the outbreak of the Nine Years War the Dutch sovereign was paying 4% on his national debt, while the English sovereign was paying 12%. Many British taxes had failed to produce enough revenue to repay the loans charged against them. Investors did not trust the English state. In fact, in 1672, a relatively small war against the Dutch had forced the

English state to stop payments on its loans (Carruthers, 1996, 60). Far more capital flowed through Amsterdam's financial system, and the economy of France was much larger. These balances first began to shift in England's favor during the 'War of the Grand Alliance' (1689-1697), also known as the 'Nine Years War' and / or the 'War of the League of Augsburg.'

The Nine Years War was by all historical accounts, a messy and complicated affair. Louis XIV's expansionist plans were successfully thwarted by an alliance of the United Provinces of the Netherlands, England, and the Austrian Habsburgs. The war was primarily between the French and the Dutch. Nevertheless, the War of the Grand Alliance became the first major European wide conflict in which England played a significant role (Kennedy, 1987). An economic structure that approximated incipient industrialization was not present in England or elsewhere during the Nine Years War. Here then, our main focus will be the institutional and financial innovations spurred by the conflict; innovations that would soon set in motion a series of positive economic feedback loops fomenting Britain's 18th century mode of development shift.

NINE YEARS WAR EXPENDITURE OVERVIEW:

"The immediate result of England's entry into the war with France in 1689 was to make public expenditure increase between two and three times", from under £2 million per annum prior to the war to between £3 million and £6 million per

annum during the war (Dickson, 1967, 46).[41] Such expenditure was quite large in terms of the overall English economy. For example, in the year 1690 military expenditures totaled £3.3 million, while total private investment expenditures aggregated to approximately £2.04 million; i.e. military expenditures exceeded total private investment expenditures by over 60% during the Nine Years War. Interestingly, in the preceding year of peace, private investment expenditure in England was approximately £2.00 million; lower than the war years. This suggests there was very little, if any, crowding out going on in England at the time of the Nine Years War (O'Brien, 1991, 34-5).[42] However, heightened military expenditures did cause the English national debt to mushroom from £3.3 million in 1692 to just shy of £17 million in 1697. This was an astonishing aggregate for the time, especially given that English state revenue lagged this total by a wide margin; average annual tax revenue during the Nine Years War was £3.64 million, giving rise to a deficit worth some 50% of total revenue over the course of the war (average per annum public expenditure during the Nine Years War was £5.46

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[41] **GENERAL NOTE**: Total public expenditure figures here and throughout the British case include Army, Navy, and Ordnance expenditure, along with borrowing costs occasioned by military expenditure, and costs of civil government. The costs of English civil government during this war and all subsequent 18th century wars totaled less than 10% of state expenditure with the bulk of this going to pay the enlarged base of tax administrators required to collect the enhanced revenue necessary to prosecuting wars. All state expenditure, defense expenditure, debt aggregates, and revenue statistics throughout the British case are as reported in Mitchell and Deane, 1962 and Brewer, 1988 unless otherwise noted.

[42] It is evident that there was little if any crowding out during the Nine Years War, not only because private investment expenditure was lower before the war than during the war, but also because inflation remained quiescent during the conflict while interest rates generally declined (Dickson, 1967).

million). A closer look at the means and methods the English state utilized to derive tax revenue during the war now follows.

THE STRUCTURE OF TAXATION DURING THE NINE YEARS WAR:

As the structure of taxation is reviewed during the Nine Years War, and subsequent British case wars, our analytical focus will fall upon three main aspects of taxation: aggregate revenue, organizational efficiency in collection, and overall incidence. The amount of revenue is critical in so far as larger aggregates allow for augmented spending and debt earmarking thus increasing the potential for heightened defense expenditure. Organizational efficiency in collection allows for swelling revenue without imposing undue burden on economic development and / or social compacts (Brewer, 1988). Overall incidence is important for two associated reasons: 1) The ideal taxation constellation for the proper functioning of the 'military expenditure impetus to mode of development shifts theory' is one where the state funnels revenue to defense contractors working in dynamic capital intensive economic sectors while allowing said contractors to escape taxation altogether, as discussed in chapter one. 2) As distasteful as it may be, a progressive tax incidence would clearly limit the investment potential of the classes primarily involved in defense-inspired infrastructural economic transformation; not only manufacturers and contractors themselves, but also investors in public debt who tend to be landed and / or wealthy (Mathias and O'Brien, 1976). Therefore, in terms of the operation of the 'military expenditure impetus to mode of development

shifts theory', a regressive tax structure is preferable. Any taxation system that relies on direct taxes (land and income taxes) above indirect taxes (excise and customs taxes) is bound to be progressive for direct taxes target established wealth while indirect taxes fall upon consumables (Riley, 1986, 47; Mathias and O'Brien, 1976). Since the English state became more reliant on indirect taxes as the state was progressively stressed by warfare over the interval 1689-1784, the composition of taxation became ever more supportive of the transformative mechanisms underpinning the 'military expenditure impetus to mode of development shifts theory' as explicated in chapters one and two. Keep these points in mind as we now review the structure of English taxation during the Nine Years War, and subsequent wars.

Although English tax revenue was insufficient to cover the heady costs of the Nine Years War, English tax collection at this time was relatively efficient as compared with other European states. Because public expenditure increased so suddenly with the outbreak of hostilities, the Treasury began precisely recording income and expenditure, "England being the first European power to take this elementary step" (Dickson, 1967, 46). The records show that in 1689 there were three main categories of taxes in England – the excise (taxes on consumables), the customs (taxes on imports and exports), and direct taxes on land and property (Kiser and Kane, 2001).

The excise tax began as a tax on alcohol and soon expanded to include many other goods, such as soap and salt. By 1689, bureaucratic state

administration of excises was in place; excise collectors were chosen by exam, and there was good monitoring, fixed salaries, and career ladders (Brewer, 1988, 69; O'Brien and Hunt, 1999, 74; Kiser and Kane, 2001; Binney, 1958). Beginning with the Nine Years War, augmentation of efficiently imposed and bureaucratically collected excises became commonplace in England to meet the spiraling costs of warfare; heavily regressive duties were imposed on salt in 1694 and then increased again significantly in 1698 as a result of financial predicaments. Such impositions were extended into 1720 in order to meet the heavy debt burden fostered by the Nine Years War. Between 1688 and 1697 excise revenue totaled £7.04 million, or 21.4% of total revenue (Dickson, 1967, 352-357; Brewer, 1988, 193; Mitchell and Deane, 1962, 386).

Collection of customs taxes was less bureaucratic than the excise. Although the customs had been taken out of tax farming in 1671 and partially centralized in 1686, customs collection was mired by corruption, poor monitoring, and de facto venality. In the 1690s customs taxes produced less revenue than direct taxes (although slightly more than excises), and owing to the strength of the merchant class in Britain, customs rates did not rise during the Nine Years War. Between 1688 and 1697 customs revenues totaled £7.05 million, or 21.5% of total revenue (Brewer, 1988; Carruthers, 1996; Mitchell and Deane, 1962, 386; Kiser and Kane, 2001).

The main direct tax in England during the Nine Years War was known as the land tax. The land tax was collected annually and collection methods remained

largely the same throughout most of the 18th century; the land tax was based on fixed quotas from counties and collection was entirely in local hands. As a result, the land tax never adequately tapped subjects' wealth (Beckett, 1985, 296; Kiser and Kane, 2001). Nonetheless, during the Nine Years War, the inefficiently collected land tax produced the most revenue; 42% of total, £13.8 million aggregate (Mitchell and Deane, 1962, 386; Brewer, 1988, 95-96).[43] Thus during the Nine Years War English tax incidence was progressive, however, a trend towards a more regressive structure was being established as efficiency in excise collection spurred the state to increasingly rely on excises to meet the extraordinary costs of warfare.

PUBLIC DEFICIT FINANCE DURING THE NINE YEARS WAR:

By 1689, the British state had warred enough for Parliament to understand that modern battle required a functioning borrowing and payment system (Carruthers, 1996). As a result of the slow, cumbersome, and sometimes uncertain pace of tax collection, short-term loans were necessary to the smooth functioning of government during hostilities. This would be true whether Britain's tax receipts fully covered the extraordinary expenses of war or not, but as we have seen, they did not. For the first three years of the Nine Years War, Parliament sought to finance yawing deficits with high interest short-term loans, which were loosely

[43] Approximately 15% of tax revenue came from miscellaneous imposts such as 'stamps' and 'post office'; the percentage of revenue provided by such taxes would decline in later wars (Mitchell and Deane, 1962).

secured on new excise levies. The ultimate return of these levies was exceedingly uncertain, as was which loan each new tax was supposedly securing. Unsurprisingly, lenders demanded early repayment and required the King to pay compound interest (Dickson, 1967, 40; 50). Nevertheless, in this new environment of costlier war, issue of short-dated paper beyond the capacity to redeem it regularly was an unavoidable fiscal temptation; rising from negligible amounts, total short-term loans recorded by the Exchequer between 1689 and 1697 cumulated to over £32 million, approximately nine times annual revenue (Dickson, 1967, 341-343). Most of this short-term paper took the form of 'tallies' – transferable interest bearing promissory notes with a high fixed payout and variable price meant to be redeemed as soon as the Exchequer could afford to pay (i.e. indeterminable maturity with an implied date of any day now). As a result of discounting, tallies were subject to wild devaluations during the slightest fiscal crisis – as payment was pushed into the future or became less likely, their value rapidly sunk, thus reducing the credit flowing to the state to a trickle as no new creditors wanted to hold increasingly worthless tallies (Dickson, 1967).

By early 1693 the English state was facing a major default; financial markets had became hopelessly clogged with heavily discounted tallies. Short-term debts had risen to £6 million, nearly twice England's yearly tax receipts. The state was having trouble issuing more credit at reasonable rates. Britain was rapidly approaching bankruptcy (Dickson, 1967). In that same year, England took its first

tentative steps towards a modernized system of long-term debt.[44] In order to substitute long-term borrowing for short, the English government needed to convince domestic monied interests that long-term loans were in fact more secure than short-term loans. The Treasury Department made an initial foray by creating a permanent fund to service long-term debt. The money for the fund came out of the portion of the excise that could be anticipated with some certainty. Precisely funding interest payments on specifically designated loans by linking them to the revenue of settled tax funds became known as earmarking; loans with earmarked payments were termed 'funded.' For the first time, starting in 1693, earmarks were guaranteed by Parliament. Parliament assured the public that the fund would be in place for 99 years, hence securing full and timely payment on the 'funded' annuities protected by the earmarks (Dickson, 1967; Brewer, 1988; Carruthers, 1996).

With the fund institutionalized and backed by Parliament, England attempted to float its first substantial long-term debt venture. Creditors were to pay up front, and in turn would receive earmarked interest payments for 99 years at a rate of 8%, significantly lower than the rates then being imposed on short-term loans. The creditor was never to get back the principal, just interest, but these interest payments ran for a century and for the first time were guaranteed by the British nation (rather than the sovereign). The original float of the proposed long-term loan had the English government hoping for a subscription of £1 million.

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[44] Generally, long-term borrowing is more attractive to governments than short-term borrowing because it greatly increases the government's flexibility to repay.

Disappointingly, only £108,100 was supplied; the loan had failed. The cynical public was not interested in a funded long-term loan with relatively low interest rates that never paid back the principal. Eventually, Parliament did manage to raise 90% of the expected total loan subscription, but not before interest charges had risen to 14%, approximately 2% above the going rate for short-term loans prior to the outbreak of hostilities. Nevertheless, default had been averted for the time being (Dickson, 1967, 54).

As the monied public warmed to the idea of guaranteed earmarks and long-term debt, Britain was able to raise another £1 million long-term loan in 1694. Experimentation also continued; at this time holders of unfunded lifelong annuities were given the option, for a fee, to convert their lifelong annuities to a funded 96 year terminable annuity which would pay back the principal (life annuities never paid the principal).[45] £700,000 poured in from annuity holders. Thus began official 'redeemability', another key aspect of England's emerging system for long term debt. Redeemability meant that Parliament had the option to pay off the principal at anytime and thus stop further servicing. The fact that so many life annuity holders were willing to convert their holdings to funded terminable annuities clearly indicated to Parliament that the public was increasingly confident in parliamentary earmarking, along with Parliament's deft management of the war more generally. Most importantly, "with redeemable annuities, the government could take advantage of a drop in market interest rates by paying off annuities

[45] Lifelong annuities paid a fixed rate over the course of an individual's (or assignee's) life.

issued at the older higher rate and issuing new ones at the lower prevailing rate, in effect, refinancing the debt." And with confidence in Parliament growing, interest rates were likely to drop in the near future (Carruthers, 1996, 76).

Still, the overwhelming majority of new and outstanding loans remained short-term; the monied citizenry, for the most part, were opting not to tie up their savings for several decades. Of course, a liquid market for transferable long-term bonds, which would enable holders of government securities to raise capital on the open market whenever they so chose, presented a means around this conundrum. But with assignable short-term government tallies facing steep discounts, the late 17th century English public understandably approached the notion of transferable long-term government debt with great trepidation. Interestingly, just as the English public was eschewing assignable government debt, they were increasingly embracing tradable shares of joint stock companies. Prior to 1689 there had been only fourteen publicly traded companies in England; by 1700 there were over 100. Peter Carruthers has suggested "The most important proximate cause of the surge in market activity in the early 1690s was probably the outbreak of the Nine Years War with France" (Carruthers, 1996, 166). The Nine Years War increased the risks involved in expanding mercantile investment and the English stock market filled the gap:

> "Overseas traders who were not bankrupted by wartime problems had idle capital on their hands, and to put their cash balances to profitable use many invested in the stock market. The flow of money out of trade into stocks was noticeable at the time... In 1688 there was no organized stock market in England, but by the late 1690s there was... by historical standards the

> appearance of this market was almost an instantaneous event" (Carruthers, 1996, 166; 170).

Naturally, the 17th century investor preferred company securities to a government promise; companies created value and their stocks paid regular dividends. Moreover, company stocks and bonds were easily transferable to any English citizen in a standardized and commonplace practice (unlike the cumbersome process of tallie exchange developed by the Exchequer). Plus, stocks of large merchant companies tended to rise in price. Investing in large companies was therefore considered less risky in the 1690s than investing in government debt (Brewer, 1988; Carruthers, 1996).

The question for English political leaders of the day remained; how could the English state create a liquid market for transferable long-term government bonds? In the early 1690s, the East India Company, with both a political and economic interest in the war, emerged as the perfect intermediary between the public's appetite for transferable company stocks, and the English state's desire for long-term low interest rate credit (Dickson, 1967). The East India Company had been the largest trading company and financial conglomerate in England since its chartering in 1600. At the outset of the Nine Years War it was already readily apparent that the fate of the East India Company and the English state were inextricably linked; the state depended on regular payments from the Company, these payments had become quid pro quo for naval protection of Company trading lanes. This symbiotic relationship between Company profit and English Blue

Water military policy[46] was further formalized during the Nine Years War through the evolving organizational configuration of long-term public deficit finance in this way: Rather than issue long-term bonds to the public directly, Parliament opted to authorize The East India Company to issue new stock, which the public quickly devoured. The Company then lent the capital raised from this new issuance of stock to the government for long-terms at low rates. In return, Parliament guaranteed the Company interest payments on the long-term loans via funded earmarks. After taking a fee for the administration of the loan, the Company sent Parliament's interest payments to its shareholders by issuing dividends. As long as the government paid the interest on the loan, the Company could write dividends to its shareholders. Because Company shares were easily transferable, the state had, in effect, developed a liquid assignable market for long-term government securities. Moreover, Parliament was able to stipulate to the Company that the long-term loans it floated were entirely redeemable; interest payments could be halted if the government paid back the principal, and if interest rates fell, the government would have the option of refinancing the loans at a lower rate (Dickson, 1967; Brewer, 1988; Carruthers, 1996; O'Brien, 1991).

This new system of long-term public deficit finance quickly became a success.

Parliament managed their funded earmarks increasingly well as war expenditures

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[46] Blue Water Policy: the retention of taxable trading profits via the establishment of naval supremacy; also the use of continental allies to divert the French from attempting to establish naval supremacy (Brewer, 1988, 175).

continued on to successively greater heights during the latter half of the Nine Years War. The total number of individual creditors investing in the symbiotic joint stock / public deficit finance system also rose enormously, thus driving down rates of interest on public debt just as this debt was expanding. Indeed, by the close of the War of the Grand Alliance, the East India Company was making a majority of its profit raising large sums of money from the English public and loaning it to the English state at a fair market interest rate (Carruthers, 1996; Brewer, 1988).

Once a successful system for long-term debt had been established, Parliament quickly looked to repair its broken short-term credit system using the same joint-stock company intermediary model. Thus the idea for an entirely new joint stock company, whose sole purpose would be to aid the government in the flotation of short and long-term loans, began to be bandied about Parliament. So it was in 1694 that the Bank of England was established. In return for its charter to issue stock to the public, the Bank guaranteed that it would assist Parliament in the management and funding of short and long-term debt (Carruthers, 1996, 76-77). Its initial float was for £1.2 million. The public subscribed to the loan (bought bank stock with a guaranteed dividend paid out of funded government interest payments), and the Bank then loaned the full £1.2 million to the government at 8% interest, which marked a 33% drop in charges attached to state loans since the inception of the war. The Bank's corporate charter also allowed it to issue paper money, take deposits, and discount bills of exchange for immediate payment, thus enabling the Bank to be an effective financial hub for the complex web of emerging

institutions involved in the English war effort; deposits were received from tax collectors, stock jobbers, financiers, insurers, merchant contractors, supplies contractors, and defense contractors, with a majority of the bills of exchange that made military finance and procurement possible now being discounted at the Bank (Jones, 1988, 12; Dickson, 1967; Ehrman, 1953, 540-543).

The Bank solidified its institutional position as the crux to defense finance late in the war. In 1697 the pace of combat increased and outstanding short-term tallies piled up. Discount rates were rising and the public again feared a stop of payments. The Bank of England sprung into action. Those holding short-term tallies were allowed to exchange them for Bank stock; over £1 million worth of short-term tallies were exchanged in a process termed 'ingraftment.' By assuming the short-term debt, the Bank had, in effect, immediately converted £1 million worth of heavily discounted and highly risky short-term tallies into long-term debt, thus giving the state considerable wiggle room in paying off the once short-term bills. The credit crunch of 1697 immediately eased; discounts on tallies fell from 40% or so down to 15%. "The Bank's ingraftment of tallies saved the country from economic and political ruin" (Dickson, 1967, 15; 352-357).

In addition to ingraftment, another vital component of the evolving English system of public deficit finance emerged from the 1697 credit crunch – the wide diffusion of Bank backed 'exchequer bills.' To further ease the crunch, the Bank of England issued, for the first time, short-term exchequer bills. These undated bills carried a daily interest rate cumulating to between 4% and 7% annually. The Bank

would cash them on sight; so theoretically, they were as good as coin. To endorse their role as money, Parliament allowed taxes to be paid in exchequer bills, starting in 1697. Parliament astutely foresaw the potential for debasement of these instruments if the Bank was allowed to print them at will, so, also in 1697, Parliament passed an act limiting the amount of outstanding exchequer bills to £2 million; "By dint of yearly cancellations this limit was observed." All exchequer bills issued by the Bank were funded by parliamentary earmarks. As a result these short-term credit instruments did indeed change hands as freely as money. The Bank backed exchequer bill quickly became the preferred short-term credit instrument not only for the government, but also for the plethora of merchants, contractors, financiers, insurers, and jobbers in the English economy. The era of heavily discounted tallies had come to a close; the age of sound state-backed paper money was dawning (Dickson, 1967, 370-372).

As a result of its financial evolution, England fared well in The War of the Grand Alliance. England was able to fund and deploy unprecedented military forces which helped check the much larger nation of France. Nonetheless, the interest rate on public debt in England over this period averaged a high 8.3%; some 2.3% higher than the state's legal maximum for private interest rates and 4-4.5% higher than yields on Dutch public debt. Furthermore, in 1700 merely 33% of the total outstanding national debt was long-term and funded, the rest was still short-term, mostly unfunded. The English Financial Revolution had only just begun, as

had England's growing rivalry with France (Carruthers, 1996, 80; Brewer, 1988; Dickson, 1967).

DEFENSE CONTRACTING DURING THE NINE YEARS WAR:

During the Nine Years War, the English Navy was the largest employer of men and the greatest consumer of material in the country. It was a substantial importer of raw material, the biggest shipbuilder both by its own right and by contract, one of two biggest purchasers of agricultural produce and clothing (the army being the other), a large medical institution, and with 15,000 men on its payrolls in 1688, the biggest employer of labor. Perhaps the most striking aspect of the Navy, however, was its reliance on the English market for the production of the overwhelming majority of its many goods and services (Ehrman, 1953, 158; 174).

Throughout the Nine Years War, and subsequent wars, naval contracting generally worked as follows: the bureaucratically organized (i.e. salaries, promotion by merit, hierarchical monitoring) Naval Office, headed by the Admiralty, would place announcements in The London Gazette advertising the Navy's current needs. Responding contractors were then called into the Naval Office, at which time bids were made. The Admiralty would then dismiss the contractors and discuss the bids. On a different day, the various contractors with the best bids were called in again, and negotiations would commence with the Naval Office making counteroffers and the contractors making counter-bids.

Finally a provider and a price were agreed upon (Ehrman, 1953, 63; Pool, 1966, 47-48).

Prior to the Nine Years War, most naval warships had been constructed in state owned and operated dockyards, for the size and complexity of naval warships dwarfed the ships produced in the merchant yards. The massive necessity for new warships stimulated by the Nine Years War altered this. In 1677, 7 of 30 warships had been built by contract, but in 1690 18 of 30 were built by contract, and in December of 1690 the Admiralty contracted with commercial shipyards to build a full array of 30 warships. In order to accomplish this novel feat, merchant contractors had to extend their fixed capital investments. They increased the physical size of their existing yards and docks while adding new ones, and their businesses began to deal in fiscal amounts previously unseen (Pool, 1966, 47-49).

After the successful completion of the contracts let in December of 1690, the Admiralty's circle of shipbuilding contractors was widely extended. As a result, the construction costs for warships dropped, even as orders progressively mounted. The positive effects garnered from widening the circle of warship contractors during the Nine Years War is hard to overstate; England's general ability to efficiently and inexpensively produce immense merchant trading ships was greatly expanded just prior to a sustained upturn in English commercial trade (Pool, 1966, 57-60; John, 1955).

During the war the 'the idea of building several warships to the same design became feasible.' Hence merchant contractors were expected to construct warships

in line with the Navy's evolving requirements for rated battleships (Glete, 1993). To insure this, the Naval Office appointed an overseer to monitor the construction of each contracted ship. The overseer would actually take up residence at the yards where the ship was being built. Interestingly, the overseers would many times work with the private merchant shipbuilding companies to implement innovative ship designs; designs that had been developed by the engineers and shipwrights working for the bureaucratic Naval Office. While design emanated from the Naval Office, the construction processes that brought the designs to fruition were largely determined by the merchant contractors (Ehrman, 1954; Pool, 1966; Glete, 1993). This organizational structure – naval officers guiding outcomes at privately owned and managed facilities – approximates Peter Evans (1995) conception of embedded autonomous state bureaus acting as technological handmaiden to market producers. So here, for the first time, we see embedded autonomous state / market interaction during wartime yielding technological progress.

A developing embedded autonomous organizational structure also appeared in the emerging division of labor between the state run naval shipyards and private shipbuilding contractors during the Nine Years War. As the shipbuilding contractors became more adept at constructing warships, the Admiralty came to realize that contracting out warship construction was actually more efficient than building ships at the state run yards. This owed to the large chain of bureaucratized command present in the Navy; such a long chain of command unnecessarily slowed

construction. Moreover, farming construction out to the private marketplace freed the state run yards to concentrate on repair and upkeep. Thus, during the Nine Years War there began a division of labor where private contractors built the ships and the state run naval yards repaired them as needed (Ehrman, 1953, 79). Interestingly though, there was overlap at the top of this emerging division of labor: head merchant builders would be called in to counsel on repairs, some of the biggest and best naval warships were still built in the Naval Yards with top shipbuilding contractors now playing the counseling role, and master shipwrights would work for the Navy one year and for a merchant builder the next (Pool, 1969, 50). This porous organizational configuration then too approximates Peter Evans' (1995) conception of negotiated embedded autonomous technological steering.

As a result of this integrating defense department / defense contractor synergy, the English Navy was able to grow by leaps and bounds. In 1688 the Navy totaled 173 ships at 101,892 tons and gun-power of 6930 pieces. By 1697 the Navy boasted 323 ships at 160,000 tons and gun-power of 9912 cannon (Ehrman, 1953, xx). This large 43% increase in the number of cannon, however, was not attributable to the Naval Office and its associated contractors, but to the English Ordnance Office and its associated contractors.[47] The Ordnance Office was responsible for providing ordnance, cannon, and guns to both the Army and Navy, and had been a separate state defense department since the 1580s (Tomlinson,

[47] Much of this increase was also attributable to the practice of stealing cannon from captured warships in this era. Later, captured cannon would pale in comparison to British cannon, and the practice ceased.

1979). Like the Navy Board, the Ordnance Board was bureaucratic (with salaries, promotion based on merit, hierarchical monitoring, etc.), and run by accountants, administrators, and technicians. In regards to naval gunnery, the Admiralty specified the amounts of guns and ordnance required, and the Ordnance Office filled the Admiralty's needs, with responsibility for delivery and installation devolving to the Ordnance Office (Ehrman, 1953, 175; Lavery, 1987, 80; Tomlinson, 1979, 32).

Like in the case of shipbuilding, the Ordnance Office increasingly contracted with private entrepreneurs to manufacture the large variety of military guns and cannon used during the Nine Years War as the war progressed, so that by the end of the war the Ordnance Office was largely composed of 'middlemen' (Tomlinson, 1979, 107). In fact, the late 17th / 18th century English Ordnance Office can also be said to approximate Evans' (1995) conception of an embedded autonomous developmental state bureau. Ordnance engineers many times drafted designs for guns and stores, and overseers were often appointed to guide and negotiate cannon casting processes at contracting firms. Also, expert casters regularly moved to and fro between iron contracting establishments and the engineering arm of the Ordnance Office (Tomlinson, 1979, 50-54).

The contracting procedures for the Ordnance Office were exactly the same as those for the Naval Office. Once Parliament authorized funding through the Treasury, ordnance needs were posted in The Gazette. The Ordnance Board would then haggle with the various contractors who showed up at the Ordnance Office on

the specified day, and contracts would be let to the most reliable artificers who met the Board's desired price. Contracts included details regarding quantity, quality, timing, and potential penalties. Goods that were delivered by the contractors underwent a rigorous proofing upon receipt. This proofing was undertaken by in house ordnance specialists, and if the goods were not up to the standards specified in the contract, the goods were rejected and heavy penalties were assessed (Tomlinson, 1979, 52-57).[48]

Now that the contracting procedures of the Naval Office and the Ordnance Office during the Nine Years War have been reviewed, let's briefly explore the methods of payment that passed between these state defense departments and privately owned market-based contractors during the war. Of course, like in all aspects of English military expenditure, credit instruments were paramount. Payments emanating from the Naval Office will be taken up first. Naval contractors were typically paid in short-term credit instruments known as naval bills. These bills carried a daily interest rate and were easily assignable to a third party. Since naval expenditure was quite large, naval bills exchanged hands widely throughout England during the Nine Years War and after; these bills in fact became a normal means of exchange. London banks were usually willing to discount naval bills for a holder who needed to realize cash; while the Bank of England was always willing to discount naval bills on sight. Like tallies, the discount rate on

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[48] Interestingly, whereas the Admiralty adjudicated discrepancies between the Naval Office and its contractors, the Treasury arbitrated discrepancies between the Ordnance Office and its contractors. Thus the English Treasury monitored ordnance contracting to some extent (Tomlinson, 1979, 35; 39).

naval bills was based upon the length of time expected before the Naval Office redeemed them with cash. Discount therefore varied with the number of bills in circulation at any one time along with the date of their issue; during credit crunches the discount on naval bills could reach as high as 50% (Dickson, 1967).

Over the first three years of the Nine Years War, the market became increasingly clogged with naval bills. From 1689 to 1690 naval debt rose by 50%, reaching £867,203 (Ehrman, 1953, 329). Starting in 1690, naval contractors began increasing prices being charged to the Navy, as the naval bills they were being paid with were receiving steep discounts in the marketplace. By 1692, there was financial chaos at the Naval Office, and contractors began to refuse to release their finished products, as they were receiving worthless paper in return. At the same time the English state was facing default (1693) naval production was coming to a standstill. By 1694, however, the state had successfully floated a number of long-term loans (as described above), and used a portion of the proceeds to pay off a good deal of naval bills. This decreased the discount rate on outstanding naval bills to a level that contractors were comfortable with. The government's largest contractors, however, were now shrewd enough to only accept payment in bills that had been earmarked on a settled tax fund. Thus, in the same way that government default was avoided in the 1693-1694 period, so too was a collapse of the naval contracting system (Ehrman, 1953, 328-337; Pool, 1966, 46; 66). The Naval Office seems to have managed the flow of naval bills relatively well for the rest of the war; discount rates did not again approach 1693 levels, and only experienced a

slight uptick during the 1697 credit crunch. Between 1691 and 1697 the Naval Office issued an astonishing (for the time) £15,577,444 worth of naval bills (Dickson, 1967, 404).

Payments issued from the Ordnance Office were similar in form to naval bills and took a similar course over the Nine Years War. The Ordnance Department typically paid its contractors in 'ordnance bills', but also made wide use of tallies during the Nine Years War. Ordnance bills were similar to naval bills in every respect, except, owing to the smaller total of ordnance expenditure, ordnance bills did not circulate as widely as naval bills. Nonetheless they were easily assignable and carried a daily interest rate. Although ordnance bills were of less significance to the overall economy, they were crucial to the iron sector, for during the Nine Years War, ordnance expenditure per annum was some 350 times greater than the total capital of the largest ironworks; it was also approximately four times the value of the total yearly domestic output of pig iron in late 17th century England (Harris, 1988; Hyde, 1973; Ashton, 1968).[49]

Like naval bills, ordnance bills were receiving heavy discounts in the marketplace early in the war, and contractors were balking at supplying new munitions. Between 1693 and 1694 "the Ordnance only maintained its credit with the major contractors by having their debts counted as Exchequer loans, which

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[49] For these figures Ordnance Department expenditure is approximated at £350,000 per annum (Tomlinson, 1979, 169; Mitchell and Deane, 1962); The capital of Crowley Ironworks is estimated at £1000 (Ashton, 1968); the output of pig iron in the 1690s is estimated at 20,000 tons (Ashton, 1968); and the cost of pig iron is estimated at £4 per ton (Hyde, 1973). Of course it should be noted that a hefty portion of Ordnance Department expenditure went to transport and installation in addition to cannon construction.

were settled on a specific fund with a 6% interest rate" (Tomlinson, 1979, 192). In 1694, £85,000 worth of Bank of England subscriptions were allocated to the Ordnance Department, thus further easing the squeeze in ordnance bills and tallies. 1697 however saw an acute credit crunch return to the Ordnance Office; the discount on ordnance bills and tallies ran to 35% in that year. The weaker artificers were being bankrupted by such heavy discounts. Fortuitously, the Bank of England's 1697 ingraftment of £1 million worth of short-term debt included a significant portion of tallies issued by the Ordnance Office, thus allowing the Office and its contractors to weather the storm, by 1702 ordnance bills were exchanging at par (Dickson, 1967, 345-347; Tomlinson, 1979, 179, 197-207).

So in both the case of the Ordnance and Naval Office we see improving public deficit finance during the Nine Years War enabling procurement at a pace and intensity previously unsustainable in England. Although the credit crunches of 1693 and 1697 did bankrupt the weaker contractors, optimistic entrepreneurs consistently rose up from the competitive marketplace to fill the gap. Additionally, the strongest contractors, typically owed the largest debt, continued to freely contract with the Admiralty and Ordnance Department in the hopes of garnering payment preference down the line: "The contractors... refused to deliver their goods; but they did so because they hoped thereby to get a better security for repayment, not because they believed payment was impossible" (Ehrman, 1953, 482). As Bernard Pool (1966: 66) has pointed out, "In the long run a contractor could not afford to make a complete break in commercial relations with their

largest permanent customer." Besides, English military contractors all had significant business interests in the commercial marketplace. Their increasingly profitable commercial ventures were supported by the large flow of credit emanating from the state defense departments, even if this credit was exchanging at heavy discounts for a time. Thus over the course of the war, the larger contractors came to rely on the liquidity provided via military contracting as much as the military needed contracted procurement. Hence during difficult moments, standards of credit were relaxed, and defense departments were given wiggle room (Ehrman, 1953; Pool, 1966; Dickson, 1967; Tomlinson, 1979). A symbiotic synergy between commercial contractors and bureaucratically organized state defense departments had emerged in England over the course of the Nine Years War. Over the century to come this synergy would help propel the English economy to unimaginable developmental heights.

THE NINE YEARS WAR STIMULUS TO METALS AND SHIPBUILDING:

Now that we have reviewed the evolution of taxation, public deficit finance, and defense contracting in England during the Nine Years War, the effects of the increased effective demand generated by said evolution will be analyzed. Here we will zero in on the two market sectors most stimulated by procurement during the Nine Years War – the metal and shipbuilding industries, beginning with iron. The mid 17th century British iron industry was average at best; the Swedes, Dutch, and Spanish all had superior output in terms of quantity and quality (Jones, 1988, 45;

Ashton, 1968, 209). Furthermore, the iron price in England was highly inelastic – a small increase in supply produced more than a proportional fall in price; not exactly an auspicious environment for growth (Ashton, 1968, 104-105, 109n; Ehrman, 1953, 65).

Swimming against this middling tide was Englishman Sir Ambrose Crowley. Crowley established a sprawling campus like ironworks at Sunderland in 1682. Crowley's company was not a 'putting out' endeavor as was typical in England at this time; there was integration between the forgers, smithies, and finers all in one locale. Most importantly, the naval contracts Crowley secured from 1693 onwards led to a marked expansion of his business and the subsequent diffusion of his business model. For the most part however, Crowley was a forger (forgers produce wrought iron goods at the forge), not a founder (founders produce cast iron goods by pouring molten ore into molds); his naval contracts therefore entailed providing the chains, clasps, and hooks used in the rigging of warships, rather than cannon (Jones, 1988, 309; Flinn, 1958, 151).

Throughout the 17th century, cannon and ordnance had been the principal products of English cast iron 'foundries.' Although casting at this time was also utilized for pots and utensils, the quality of the product was poor, thus wrought iron was preferred (Ashton, 1968, 27). Casting however was more effective for large cannons and ordnance, where precision and quality took a back seat to price and pace of output. During the war production techniques for cast iron cannon remained rather primitive. If a contractor could produce one iron cannon per week,

the contractor was considered competent. Nevertheless, technique did advance over the course of the war as evidenced by improving standardization of naval cannon in terms of quality and caliber (Glete, 1993, 24-29; Lavery, 1987). Additionally, the value of total cast iron output in 1690 was probably less than £10,000, while the Ordnance Office spent £350,000 per annum between 1692 and 1697, some significant proportion of which entered the cast market (Harris, 1988, 19; Ashton, 1968; Hyde, 1973). Thus it seems eminently reasonable to infer that the Nine Years War provided a great stimulus to the small English cast iron sector.[50]

Perhaps the largest stimulus the Nine Years War provided to the English metals industry actually came outside of the iron sector, as aptly expressed by A.H. John (1955: 330), "The existence of war, by increasing the demand for metals, by making their import more difficult, and by raising the price of wood as a the result of greater shipbuilding, set in motion cost and profit changes which quickened the search for methods of using coal for smelting purposes." The first step in this revolution was the use of the reverberatory furnace, which between 1688 and 1698 was applied to the production of non-ferrous metals in England, such as brass and copper (John, 1955). It is likely then that the Army's reliance on brass cannon during the Nine Years War, which were lighter, albeit more expensive, than cast

[50] Iron output and use data are particularly poor for the period under consideration here (Deane, 1975, 98). The value of cast iron output is calculated by taking 5% of a total pig iron output of 20,000 tons. Pig iron was priced at a rate of £4 per ton at this time; value added for casting is estimated at between £2 and £2.5 per ton (Harris, 1988, 19; Ashton, 1968; Hyde, 1973).

iron naval cannon, quickened the introduction of the reverberatory furnace in England (John, 1955; Ashton, 1968, 9).

As previously alluded to, the animating effect of Nine Years War military expenditures is much more certain in the case of the English shipbuilding industry. Although ship construction at this time was not an industrial endeavor per say, it was the sole capitalistic enterprise requiring massive fixed capital investment and complex integrated chains of production (Glete, 1993). Fixed capital investment therefore expanded significantly in various English shipbuilding regions during the Nine Years War. Postwar, coastal merchant yards were primed to efficiently and inexpensively build the large ships necessary to exploit the vast trade gains England achieved as a result of hostilities (Ehrman, 1953, 576). Additionally, Parliament passed a number of river improvement acts in and around merchant contractors working for the Navy towards the end of the Nine Years War. Hence it seems likely that defense contracting and the declining interest rates fostered by English financial innovations supported transport improvements in the important coastal areas of England during and after the Nine Years War (Jones, 1988, 101; John, 1955).

In conclusion, England's per capita expense greatly exceeded that of any other nation during the Nine Years War and in myriad ways it paid off (Jones, 1988, 28). The Glorious Revolution of 1688 was upheld, Ireland was made secure, Louis XIV's continental desires were checked, the English Navy attained strategic command of the seas, a domestic trend towards a growing reliance on capital

intensive naval warfare was established, merchant shipbuilding was now on a higher plane, coastal transport had been enhanced, and the British metals industry was stimulated (Kennedy, 1976; 80; Jones, 1988, 15). In the aftermath of the war it was apparent that England's Blue Water military policy had been effective. Indeed, colonial re-exports jumped from a pre-war negligible level to one-third of total exports by 1700, while commercial trade (and resultant revenue) took a rapid and sustained postwar turn upwards (Kindleberger, 1975, 624). But the next war was already looming. In 1701 Louis XIV's provocations and attacks on English trade convinced Parliament that hostilities were again imminent; Parliament was correct (Brewer, 1988, 141).

CHAPTER 4: THE WAR OF THE SPANISH SUCCESSION – 1702-1713

During the five years of peace in between the Nine Years War and the War of the Spanish Succession, English merchants enjoyed the augmented profits devolving from England's successful Nine Years War naval efforts, while France recovered. When the childless King of Spain died in 1701, Louis XIV saw an opportunity increase his power in Europe through the unification of catholic France and Spain. Nothing could have been better calculated to reunite the Grand Alliance in a war against France. The War of the Spanish Succession was in all the important respects quite similar to the Nine Years War, except in the end France was thoroughly weakened, thus giving England two decades to enjoy the fruits of their victorious 25 year struggle against Louis XIV (Kennedy, 1976).

The War of the Spanish Succession entailed unprecedented levels of expenditure. England maintained a double forward commitment: armies in both Flanders and Spain, and a navy at sea. War driven expenses again forced the rapid development of England's systems of public finance. Nonetheless,

> "the naval administration of Queen Anne found itself able to rely to a considerable extent upon the strength and the experience which had been provided for it, in the numbers and the composition of the fleet, in the equipment and the disposition of its bases, and in the relations established with the merchant and financial interests of the country, by its sorely tried predecessors during the first and more hazardous of the two great wars with France" (Ehrman, 1953, 622).

Thus during the War of the Spanish Succession we see the trends first established during the Nine Years War in regards to taxation, public deficit finance, military contracting, and economic development strengthen as the institutional /

organizational structure that would soon transform the British economy gelled into an enduring political economic system. Subsequently, two decades worth of economic fuel in the form of increased mercantile profit was fed into that system, so that by the time of the War of the Austrian Succession (1739-1748), the British economy was primed for defense expenditure inspired transformation. But before that tale is told, let's survey the progress that occurred in the dissertation's four main dynamic causal variables of interest (military expenditure, taxation, public deficit finance, and defense contracting), concluding with a synopsis of the economic changes stimulated by heightened defense expenditure, during the War of the Spanish Succession.

WAR OF THE SPANISH SUCCESSION EXPENDITURE OVERVIEW:

Total government expenditure during the war accumulated to £93.2 million, averaging £7.77 million per annum. This aggregate total is 90% higher than total expenditure during the Nine Years War, while average per annum expenditure was 42% higher in this war as compared with the last. Total tax revenue during the war was approximately £64.2 million or £5.35 million per annum (Brewer, 1988; Mann, 1986, 485; Rule, 1992, 79; Dickson, 1967, 79-81). This compares favorably to the £3.64 million per annum collected during the Nine Years War, marking a 32% increase in per annum revenue. However, Patrick O' Brien (1991) has estimated that only 26% of the extraordinary costs of the War of the Spanish Succession came from increased tax revenues, the rest came from the progressively advanced

financial machinery of England. Public loans were again necessary to cover the annual £2.42 million deficit fostered by heightened military expenditures, pushing England's national debt from £14.1 million at the start of the war to £36.2 million at the close; a gain of 157% (Carruthers, 1996, 70; Brewer, 1988, 96; Rule, 1992; 278-279).

In terms of the overall English economy, military expenditure during the war was again quite substantial. For example, in the year 1710, exports and re-exports totaled £6.3 million, some £2.4 million less than military expenditure,[51] while military spending as a percentage of total national income was approximately 9% (Ashton, 1959, 184; Brewer, 1988, 41). Also, in 1710[52] total private investment expenditures in the English Economy tallied to somewhere around £2.54 million while military expenditure reached £8.7 million. Interestingly, in 1700, a year of peace preceding the war, private investment expenditures were roughly £2.24 million (O'Brien, 1991, 34-5); hence, with private investment expenditures higher during the war than previously, it seems reasonable to infer that there was little crowding out occurring during the War of the Spanish Succession. Declining rates of inflation and interest between 1702 and 1710 lend support to this notion, although increasing inflation after 1710 indicates decreasing economic slack and mounting crowding out late in the war; the stable to deflationary trend in both prices and rates was reestablished immediately in the

[51] The export index makes for a good comparison with aggregate military spending because the data are consistent for every year after 1700 (Schumpeter, 1938).
[52] Five year average centered on 1710.

peacetime interval. The organizational changes to taxation and public deficit finance that enabled enlarged defense spending during the War of the Spanish Succession will now be reviewed.

THE STRUCTURE OF TAXATION DURING THE WAR OF THE SPANISH SUCCESSION:

The trends towards a larger and increasingly efficient excise administration strengthened during the War of the Spanish Succession with per annum excise revenue rising from £1.4 million in 1702 to £2.1 million in 1713. Over the course of the war excise accounted for 32% of total revenue, up strongly from 22% during the Nine Years War (Brewer, 1988, 99-100; Dickson, 1967, 74-75). Customs administration, on the other hand, remained rife with corruption and sinecurists. Nevertheless, customs revenue composed 25% of total revenue during the War of the Spanish Succession, up from 21% during the Nine Years War; a result of improving imports rather than augmented imposts or better administration, no doubt (Brewer, 1988, 100-1; Kiser and Kane, 2001; Mitchell and Deane, 1962, 386). Assessment and collection of the land tax remained entirely non-bureaucratic and rather inefficient. Although rates were increased somewhat the land tax as a percentage of total revenue declined from 42% during the Nine Years War to 37% during the War of the Spanish Succession (Brewer, 1988, 100).

As previously discussed, the declining significance of the land tax was an important buttress to the materialization of a taxation system that endowed military expenditure with transformative strength. The inefficiently assessed and collected

land tax could not have possibly provided a secure revenue base for defense expenditure inspired economic transformation. The only competent taxation strategy to secure large military expenditures in the 18th century – a time wherein a developed infrastructure for direct tax assessment and collection was everywhere lacking – was to effectively tap growing consumerism by efficiently assessing and collecting excise taxes (Mathias and O'Brien, 1976). Moreover, in England excises were levied at the site of production, and then passed onto the consumer, where in a sense they became invisible. This allowed England to rapidly increase per capita tax burdens without provoking economy destabilizing civil unrest (Mathias and O'Brien, 1976): "The percentage of national income appropriated as taxes rose from approximately 3.5% in the 1670s to over 9% by the end of the War of the Spanish Succession" (Brewer, 1988, 91). Thus during the War of the Spanish Succession a move towards a more regressive tax structure is clearly visible even as the aggregate tax burden was rapidly rising. In terms of the operative mechanisms of the 'military expenditure impetus to mode of development shifts theory' there really could be no better constellation in regards to taxation. For increased revenue enlarges the base upon which public deficit finance can be mortgaged thus enabling elevated military expenditure, while a more regressive tax structure allows individuals with a higher propensity to invest in government bonds, entrepreneurial endeavors, and / or fixed capital, to do so (Mathias and O'Brien, 1976; Mathias, 1979, 129; O'Brien, 1991, 26). Moreover, Parliament decreased taxation on contractors producing for the war effort, and eliminated taxation on income derived

from investment in national debt securities altogether during the War of the Spanish Succession, thus further supporting both investment in public deficit finance and the entrepreneurial efforts of contractors competing for public deficit funds (Dickson, 1967; Ashton, 1968; Mathias and O'Brien, 1976). Importantly, these trends only gathered strength in succeeding 18th century wars (Mathias and O'Brien, 1976; O'Brien, 1991); thus generating a high powered dynamism contributing to defense expenditure inspired economic transformation.

PUBLIC DEFICIT FINANCE DURING THE WAR OF THE SPANISH SUCCESSION:

Key elements of successful long-term borrowing, including earmarking revenues, the rise of a central bank, and the creation of a liquid market for transferable government debt, had been forged during the Nine Years War (Carruthers, 1996, 80). By the onset of the War of the Spanish Succession a contemporary yield curve for public debt begins to be perceptible in England, with yields on Bank of England stock, East India stock, and government debt securities, representing the long end; and rates on exchequer bills, naval bills, ordnance bills, and prices on East India bonds indicating the short end (Ashton, 1959, 112). English capital markets were becoming rather sophisticated, and rates on funds, mortgages, equities, bonds and bills accurately reflected liquidity and risk. Most importantly, yields throughout the economy began moving in sympathy with the yield on the long-term government stock (Little, 1976, 92-93; Brewer, 1988; Dickson, 1967).

In general, debt financing during the War of the Spanish Succession proceeded well. Annual debt charges as a percentage of total debt went from 8.8% in 1700, to 6.8% in 1712, and down to 5.1% by 1720 (Carruthers, 1996, 80; Dickson, 1967). At the short end, the Bank of England's management of exchequer bill issues significantly improved. This war required much larger amounts of exchequer bills than the last war. Periodically during the war Parliament was forced to raise the ceiling on the amount of exchequer bills that could be outstanding at any one time, but continued to cap it at reasonable levels. In 1709, with fighting escalating, outstanding exchequer bills breached the existing cap by a good margin. The Bank, in association with the Treasury, adeptly ingrafted a significant portion of the outstanding exchequer bills, converting them into funded long term debt paying 6% secured on new tax duties. With these notes cleared, the Bank issued a fresh circulation of £2.5 million exchequer bills to meet ongoing short-term needs. These bills carried a 3% annual rate and could be redeemed at any time. "The advantages of this new system of exchequer bill finance... are fairly obvious: the ready availability of large sums at 3% in anticipation of government revenue, and the limitation of negotiations about this to a restricted circle" (Dickson, 1967, 387). England, by using exchequer bills and ingraftments, had solved the long-standing conundrum regarding unpredictable short-term credit exigencies during wartime in an ingenious way, thus endowing military expenditure with increasing stability and transformative force.

Parliament of course provided the main check on this system of credit

creation by securing all debts, short and long, with taxes, and by continually monitoring the level of outstanding bills. Interestingly, the privately managed Bank provided a secondary check. The for profit Bank of England would never accede to a note issue if it was not capable of discounting a sensible fraction of the new notes for cash; the way it assured its ability to do so was by issuing stock to the public on the exchange before undertaking any new exchequer bill issues. For example, prior to the 1709 exchequer bill issue Parliament signed off on the Bank's plan to double its capitalization through an offering of stock. Had the offering not been successful, which would have indicated either declining public confidence in the debt system or dwindling surplus capital available for further deficit spending, the Bank likely would have balked at the augmented note issue. Ultimately, neither the Bank nor Parliament could afford to allow confidence in public credit to be eroded; otherwise the entire edifice of Whig power and profit derived from English politics and finance would assuredly topple (Carruthers, 1996). Owing to this evolving system of financial checks and balances, exchequer bills were confidently exchanged and widely diffused throughout the English economy during the war, finishing at par (Dickson, 1967, 371-375). All in all, over the course of the War of the Spanish Succession, the exchequer bill system came to resemble 'a well managed modern bank-note issue' (Dickson, 1967, 84-87; 379).[53]

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[53] "Bank of England notes were issued in large denominations, under conditions of convertibility into gold on demand, and issued only in response to 'genuine' needs by a cautious institution reflecting the conservative, established interests in the City. The Bank accommodated the Government as its most important customer, but only within its usual strict rules" (Mathias, 1979, 288).

Perhaps the most famed change to English public deficit finance during the War of the Spanish Succession came in 1711 as conflict intensity reached its apogee. Discounts along the entire curve were increasingly heavy, and over £9 million worth of short-term bills (mostly naval and ordnance) were outstanding (whereas per annum tax revenue was well south of £6 million at this time). In response, Parliament opted to charter a new joint stock company, this time on the East India model. The South Seas Company, chartered in 1711, was to engage in South American colonial trade and act as a public deficit finance intermediary.[54] Upon its incorporation the South Seas Company ingrafted a large portion of the floating short-term debt, converting it to long-term funded debt by exchanging its stock for short-term paper through the English stock exchange. Parliament secured a payment rate of 6% on the newly issued South Seas stock by levying new excise taxes on wine, vinegar, and tobacco. The fact that the interest rate Parliament paid on South Seas stock was 25% lower than the rate paid to the Bank for its ingraftment in 1697 (8%) corresponds to the falling trend in long-term rates occurring concurrently with increased military expenditure as an effect of England's financial evolution. By 1712 separate ingraftments administered by the Bank and the South Seas Company had cleared the market of £10.9 million worth

[54] Interestingly little trade ever occurred, and what did was not profitable, eventually causing a massive collapse in the value of South Seas Stock. The collapse, which occurred during the peaceful 1720s, had little to no consequence in regards to our narrative here. For a wonderful description of the mechanisms and machinations that resulted in the 'South Seas Bubble' see Dickson, 1967.

of short-term floating debt (Dickson, 1967, 79-81; Carruthers, 1996, 24, 78, 152-154).

In 1713 the East India Company, the Bank of England, and the South Seas Company stood as the government's first line of defense against spiraling debt. By the close of the war, these three companies had in effect loaned the government £16,754,167, which was approximately 62% of the outstanding funded debt, and 35% of aggregate outstanding debt (Carruthers, 1996, 73; 155). Still, in late 1714, non-redeemable debt instruments (such as lifetime annuities) amounted to at least 31% of outstanding debt.[55] As interest rates continued their decline after 1714 the inflexibility of irredeemable annuities presented a real encumbrance; their use was entirely discontinued after the close of the War of the Spanish Succession (Brewer, 1988, 122; Carruthers, 1996, 73).

In the postwar period Parliament set out to reduce the annual charge on the national debt by redeeming and refinancing the redeemable debt, thus marking the first major governmental debt 'buyback' in order to convert payments to lower rates in history. In 1715 a significant proportion of the redeemable national debt carried interest rates at or above 6%. The managers of the monied companies, which held a good deal of this debt, were sought out in a bid to convert the rates on this outstanding redeemable debt down to 5%. Parliament told the managers that either they accepted the conversion, or Parliament would raise capital on the private market at 5% to redeem the principal, thus stopping future interest payments. The

[55] Early in the war, the state had issued this type of debt for much of the public was still fearful of the new methods of finance (Carruthers, 1996, 18).

Whig controlled Bank was on board from the start, which tied the hands of the East India and South Seas Companies, for the Bank could likely raise enough capital from the public at 5% by itself to buy out the other companies' holdings of public debt. This debt however provided a secure stream of revenue and profits to the companies thus supporting their stock prices. Plus, in the increasingly competitive world of English finance, the companies could not afford to potentially lose their rights to float and administer English public loans vis-à-vis their rival, the Bank. Given that interest rates were already trending below 5%, thus making it unlikely that the companies could find secure future investments yielding over this rate, the companies readily acquiesced, as did the overwhelming majority of their stockholders. So without so much as raising a hair of extra capital, Parliament was able, in 1715, to convert £9,534,358 worth of debt carrying a 6% charge or over, to 5%, lowering the annual charge on the national debt by 13% (Dickson, 1967, 80-90; Brewer, 1988, 123-124; Carruthers, 1996, 18).

Later that year, the remaining outstanding short-term debt floated during the war, totaling £946,929, was funded in 4% stock managed by the Bank – in other words, the going rate on English public debt had been cut in half over the course of the War of the Spanish Succession. At the same time, Parliament established a new and more secure sinking fund, capitalized out of a few settled taxes with known revenue expectations, in order to pay interest on the newly minted 4 and 5%s, with an eye towards eventually discharging their entire principal. Thus by 1717, short-term debts from the War of the Spanish Succession had been largely cleared, the

interest on all redeemable long-term debts had been reduced to 5% or lower, and an uncomplicated sinking fund had been established to eventually liquidate the entire national debt. England's financial system had weathered the 15 year storm stirred up by War of the Spanish Succession swimmingly (Dickson, 1967, 84-92; Brewer, 1988). The stage was now set for military expenditure to become an effective agent of economic transformation in subsequent wars.

DEFENSE CONTRACTING DURING THE WAR OF THE SPANISH SUCCESSION:

During the war there were no notable procedural changes to defense contracting. The market-based contracting system that had proven effective during the Nine Years War did so again, albeit on a larger scale (Merriman, 1961, 143; Pool, 1966, 63). The Navy entered the war in good condition, and "merchant builders were able to fully cope with any requirements that could not be met by the royal yards" (Pool, 1966, 60). Extensive shipbuilding did take place, with the large majority of it being contracted out to the established merchant shipbuilders (Merriman, 1961, 62). By the end of the war the English fleet was equal in size to the combined strength of France, the Netherlands, and Spain (Glete, 1993, 227).

The Ordnance Office also fared fairly well during the war. The main difficulty the Ordnance Board encountered was the still problematic technological state of the English casting sector. Traditional iron casting techniques were clearly being strained by the evolving capital intensive methods of English sea-borne warfare. For example, it often took multiple months for an ironmaster to fill a

cannon contract calling for only 25 to 50 cannon at this time. Nevertheless, over the course of the war, many of the poorer varieties of cannon disappeared from the market, and the proportion of cannon rejected by the proofers at the Ordnance Office declined. Evidently, cannon contractors were attempting to rationalize and improve their casting techniques in order to secure more orders and higher profits; and as will be detailed below, some did so successfully (Tomlinson, 1979, 103; 160).

In general, payment of contractors went smoother during the War of the Spanish Succession than it had during the Nine Years War. Most notably, naval bills printed after 1700 included the tax fund from which the bill was to be paid (Dickson, 1967, 400). Nonetheless, there were rocky moments. Between 1702 and 1710, £17,323,160 in naval bills were circulated, and the Naval Board managed to overspend this figure by another £2.5 million (Dickson, 1967, 404). Discounts on naval bills ran to 12% in 1708, 20% in 1709, and 30% in 1710. Contractors began to chatter with the Admiralty about withholding their wares (Dickson, 1967, 363). For the Ordnance Office as well expenditure and debt mounted from the onset of war into 1710 (Tomlinson, 1979, 199). Between 1702 and 1713 the Ordnance Office circulated approximately £2,666,178 in bills (Tomlinson, 1979, 179). By 1705 surging ordnance bill discounts threatened to shut down the production of ordnance. "We are likely to be in a little time... without stores money and credit" complained the Ordnance Board (Tomlinson, 1979, 140). In December 1706 the Office was unable to meet the naval demand for the supply of mortar and shells as

contractors were increasingly refusing ordnance bills. Bank ingraftments forestalled a stop, although ordnance credit continued to gradually worsen into 1711 (Tomlinson, 1979, 140; Dickson, 1967, 363). Such issues were paramount in Parliament's decision to green light the South Seas Company. A total of £9,177,967 in the form of navy bills, ordnance bills, and other debts resulting from the war were exchanged for South Sea stock in 1711.[56] Ordnance and naval bills immediately increased in value by approximately 20% (Carruthers, 1996, 152-4). Payment of contractors was unproblematic for the rest of the war (Dickson, 1967, 404).

THE WAR OF THE SPANISH SUCCESSION STIMULUS TO IRON AND SHIPBUILDING:

Now that we have reviewed the evolution of taxation, public deficit finance, and defense contracting in England during the War of the Spanish Succession, the consequences of the increased effective demand generated by said evolution will be analyzed. Here once more we will zero in on the two market sectors most stimulated by procurement during the War of the Spanish Succession – the metals and shipbuilding industries, beginning with iron. Undoubtedly, the small but growing English iron industry was stimulated by Ordnance Office expenditures

[56] Interestingly, by exchanging their short-term debts for long-term funded stock many contractors became major long-term creditors of the state. In succeeding wars this only became more the case; why not support the state with funds that eventually found their way back into contracting business coffers, securing interest all the while? This too then became a method of redistribution of public capital towards contractors – the state serviced the national debt with tax money accumulated from the masses while contractors profited directly from those service payments (Dickson, 1967, 117; Mathias and O'Brien, 1976).

during the War of the Spanish Succession, especially in the diminutive casting sector: "In the early 18th century… wartime demand for cannon and shot increased the demand for casting" (Harris, 1988, 48). Ordnance Office expenditure was approximately £214,000 per annum during the war years (Mitchell and Deane, 1962, 389), while the value of cast iron output in 1705 can be roughly estimated at £17,000.[57] Thus if around 8% of Ordnance Office expenditure was directed at the domestic cast market, it would account for the industry's entire output; certainly then at least half of the demand for cast iron product during the war can be assumed to have come from the Ordnance Office.[58] Not to mention that some small percentage of naval expenditures, which totaled nearly £28.6 million over the course of the war (Mitchell and Deane, 1962), found its way into the domestic iron industry; the value of British pig iron output from 1702 to 1713 can be crudely estimated at £1.3 million.[59] Additionally, the war reduced iron imports from Sweden thus boosting British domestic iron bar production. Signs of stimulus abound; for example, between 1701 and 1709 there were notable river and road improvements in the major iron producing districts (Hobsbawm, 1968, 24; Harris, 1988, 27; Hyde, 1973; Ashton, 1968).

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[57] Overall pig iron production placed at 24,000 tons (Harris, 1988, 48; Ashton, 1968, 234; Hyde, 1973, 408). Cast iron accounted for approximately 10% of the market (Harris, 1988, 48). Price per ton for pig iron was approximately £4.5 in 1710. Value added for casting naval quality product was probably around half the price of raw pig iron at this time (Hyde, 1973).

[58] Iron industry and detailed contracting data is again scant and approximate for these years; also, the Ordnance Office spent excessively on transport and installation (Deane, 1975; Hyde, 1973; Harris, 1988).

[59] £108,000 total value per annum calculated using prices from Hyde, 1973; and pig iron output estimates from Harris, 1988 and Ashton, 1968.

Nonetheless, the English iron industry remained very scattered in nature during the War of the Spanish Succession. Mills were not near forges and forges were not near furnaces. Ownership was typically separate as well. As long as wood remained the main fuel, works stayed dispersed (Ashton, 1968, 22-23; 163). During the war, an amazing breakthrough occurred that would eventually release the entire cast iron industry from the binds that wood fuel imposed upon it. At his Coalbrookdale ironworks, naval contractor Abraham Darby, in 1709, smelted iron ore with coked coal producing 'coke-smelted' pig iron at a commercially acceptable quality, for the first time. Although the resulting iron was too brittle for use at the forge, it worked perfectly well at the foundry. Now the cost curves for foundry produced cast iron could potentially fall dramatically vis-à-vis forged wrought iron, which still required expensive wood fuel at every stage of production (Ashton, 1968; Hyde, 1973; Harris, 1988).[60]

Throughout the War of the Spanish Succession, Darby's Coalbrookdale firm was the main provider of cast mortars to the Ordnance Office, thus it is quite likely that heavy Ordnance orders between 1702 and 1709 did much to motivate and capitalize Darby's complex and costly coke-smelting experiments (Ashton, 1968, 41). Interestingly however, Darby's new process did not diffuse widely until the mid-18th century; not until the 1760s did coke smelted pig iron become a

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[60] Wrought iron goods were made through a three-step process at this time. First iron ore was smelted into pig. Then pig iron was worked into bar iron at forges. Then bar iron was wrought into finished goods at forges. All three steps required wood fuel at this point. Darby's discovery, on the other hand, allowed iron ore to be coke-smelted into pig iron of a quality suitable for direct use at foundries (Hyde, 1973).

dominant trend of industry. This has presented historians with an interesting conundrum (Ashton, 1968; Hyde, 1973; Harris, 1988). In the chapter on the Seven Years War below, data will be marshaled to make the case that any solution to this puzzle is necessarily incomplete without an analysis including the pattern of military expenditures over the years 1710 to 1763. For now, it is interesting to note that by 1715 Darby's coke smelted cast pots were renowned throughout England, thus indicating that Darby was able to adeptly adapt his new process to peacetime production in the postwar period (Ashton, 1968, 41).

Meanwhile, at the end of the War of the Spanish Succession, those industries which directly served the Navy were still the most expansive; shipbuilding, carriage, dockyard contracting, timber, and victualling (Kennedy, 1976 72). These sectors were now well prepared for the type of economic dynamic that would obtain in the coming decades. The signing of the Treaty of Utrecht gave England substantial new land claims in North America, Gibraltar, and Minorca. England also gained the terribly profitable and simply terrible Asiento trade in slaves to Spanish America. Most importantly, French dominance of Western European trade was thwarted (Kennedy, 1976, 86-7). By the end of the war England was its own entrepot (Wilson, 1965). Its shipping and geographical range of trade had greatly widened. It was no longer focused on the Dutch market. As a result of successful military and maritime enterprise Britain's colonies became the most dynamic trading areas in America (Glete, 1993, 207). And improved shipbuilding owing to naval contracting at the merchant yards helped England to

exploit its new gains. English mercantile ships were changing in response to the proliferation of gunned battleships; they were becoming larger, more streamlined, faster, and now many times carried cannon. Although warships were built in the private yards in a more expensive fashion than trading ships in order to provide suitable platforms for numerous cannon, much similarity in building process evolved between large merchant ship and large warship construction over the course of the War of the Spanish Succession. Large merchantmen now had several decks like cannoned warships, the interior of the hulls now corresponded, warships like mercantile ships were built with large areas for storage, the need for all weather military ships enabled the development of year round mercantile traders, and both warships and cargo carriers now had immense openings in their decks for the transfer of heavy loads between decks and ships. Over the interval 1689-1713, large merchant ships, like battleships, had become an increasingly expensive and complex investment; and it is the combination of the two that made either investment profitable (Glete, 1993, 51-53).

Despite the fact that France had four times the population, England won the War of the Spanish Succession and the longer 25 year struggle against Louis XIV. Total British naval dominance was also established in this period; Great Britain was now undoubtedly a great power. Through two long wars, Britain was able to fund and deploy unprecedented military forces, and on a per capita basis its efforts far surpassed those of any other major combatant (Carruthers, 1996, 54; Brewer, 1988, 172; Jones, 1988, 311). By 1720 the British economy had settled into a kind

of peaceful economic growth; one marked by smoothly rising trends in all aspects of mercantile trade. For the next decade-and-a-half there emerged a political tranquility during which British mercantilists amassed profits and savings; profits and savings that would later in the century become fuel fed into the mechanisms of the 'military expenditure impetus to mode of development shifts theory' with explosive effect.

CHAPTER 5: THE WAR OF THE AUSTRIAN SUCCESSION – 1739-1748

The relatively peaceful years of 1720 to 1735 witnessed a leveling off in the rate of expansion of the English economy (Thompson, 1973, 37). Little (1976: 64) has asserted that there was in fact outright stagnation in regards to British economic development during this interval: "Methods of production were more or less the same after 1725 as they were before, to the extent that accumulation took place it usually consisted of duplicating – sometimes with slight modifications – existing types of equipment." The synchronization of peace and static economic development in the years following 1720, contrasts notably with the synchronization of war and broad economic development that had obtained between 1690 and 1715 (Little, 1976; Dickson, 1967), thus suggesting that military expenditure was the primary agent of transmogrification in the English economy around the turn of the 18th century. Tellingly, sustained economic transformation in the British economy materialized once again during the war torn 1740s.

British military involvement actually began to pick up during the latter half of the 1730's. The belligerence of these years was the product of a fear that other colonial powers, particularly the French, were squeezing the English out of key trading markets (Brewer, 1988, 173). The new imperial struggle with France commenced indirectly in 1739 with a declaration of war between Britain and Spain. The Spaniards had claimed the right to search British ships in the Caribbean, while Britain had denied the right. Captain Jenkins' ear was a casualty of the

disagreement, compelling Parliament to initiate the 'War of Jenkins Ear.' This war morphed with a series of conflicts that had broken out in Europe between France and Austria over the succession of Charles VI who had died leaving the Austrian succession undecided. War between Britain and France was formally declared in 1744 with Britain supporting Austria against France and Spain in what had by then become known as the War of the Austrian Succession (Barnett, 1970).

WAR OF THE AUSTRIAN SUCCESSION EXPENDITURE OVERVIEW:

State expenditure during the War of the Austrian Succession was £8,787,900 per annum; £87.9 million aggregate. This is slightly less than the aggregate £93.2 million for the longer War of the Spanish Succession, albeit per annum, the cost of the War of the Austrian Succession was 14% higher. Annual tax revenue during the war was £6,422,800 per annum; per annum revenue was thus 20% higher during this war as compared with the last. Nonetheless, public deficit finance was again indispensable to meet the £2.37 million per annum deficit that surfaced during the war, which equated to 36% of total tax revenue. To wit, the national debt stood at £46.9 million at the outbreak of war in 1739 and rose to £76.1 million by the end, an increase of 62% (Brewer, 1988, 30, 114-116; Mann, 1986, 485; Mitchell and Deane, 1962).

Military spending was again quite substantial as compared with Britain's underlying economy. In the year 1740 military expenditure was 10% of national income and this percentage rose throughout each year of the war. In the year 1745

military expenditure reached £6.43 million, while exports,[61] which had steadily increased throughout the peaceable years 1715-1739, totaled only £5.7 million (Mann, 1986, 485; Ashton, 1959). Meanwhile total per annum private investment expenditures in the British economy were approximately £4.3 million in 1745, some 33% below military expenditure. Moreover, in 1735, a year of peace, private investment expenditures had totaled around £3.10 million. Thus with private investment expenditure aggregates rising during the war, it seems unlikely that there was much crowding out going on in Britain at the time of the War of the Austrian Succession (O'Brien, 1991, 34-35); although, similar to the War of the Spanish Succession, interest rates did rise in the final year or two of conflict, thus indicating that crowding out may have obtained had the war continued. Interest rates resumed their downward trend immediately following the close of hostilities (O'Brien, 1991, 34-5; Brewer, 1988, 41; Mitchell and Deane, 1962).

THE STRUCTURE OF TAXATION DURING THE WAR OF THE AUSTRIAN SUCCESSION:

The trends in taxation established during the War of the Spanish Succession were sustained into the peacetime interval, so that on the eve of the War of the Austrian Succession nearly half of the national revenue was raised through excises (Little, 1976, 58). During the conflict, Parliament consistently increased excise duties on the home market while deftly avoided raising taxes on goods necessary to prosecuting the war. Excise yields returned £2.98 million per annum during the

[61] Excluding re-exports.

war, thus accounting for 46.4% of total revenue, up again strongly from 32% during the last war. The yield of the land tax, on the other hand, decreased between the two wars, as the assessment rate was cut from four shillings to one. Land tax revenue averaged approximately £1.8 million per annum over this war, whereas it averaged approximately £2 million in the last war, a decline of 10%. The land tax now accounted for only 28% of total revenue, down from 37% during the last war. Customs revenue also declined during the war, as trade took a slight hit, but still averaged approximately £1.3 million per annum, or 20% of total revenue (Mitchell and Deane, 1962, 386-387).

These figures yet again display Britain's increasing reliance on excises and a regressive tax structure to fund the extraordinary expenses of hostilities. To boot, manufacturers involved in the war effort largely escaped taxation; this was especially so of producers not heavily reliant on overseas trade, such as iron contractors. Since iron goods carried no excises and military contractors largely depended upon the domestic market for their raw materials, iron contractors were virtually untaxed during this and succeeding 18th century wars; thus fostering a pitch perfect environment for transformation in the British iron sector, which was increasingly the crux of Britain's capital intensive war machine (Ashton, 1968; Mathias and O'Brien, 1976; Glete, 1993).

PUBLIC DEFICIT FINANCE DURING THE WAR OF THE AUSTRIAN SUCCESSION:

As we have seen, public deficit finance in England took enormous strides between 1689 and 1713, and the system continued to be streamlined in the aftermath of the War of the Spanish Succession. By the time of the War of the Austrian Succession, public deficit finance procedures had become highly routinized. Buying, selling, and trading of government stock was quite straightforward. Purchasers simply had to attend the offices of the Bank of England, the East India Company, or the South Seas Company on the appropriate day. Most were known to be jobbers, and their presence together with brokers clearly indicates the development of a speculative stock market. The development of this market, as we have seen, was largely driven by war (along with the post-1688 changes to institutions) (Rule, 1992, 283; Dickson, 1967, 511; North, 1990).

The ability of the government to redeem the principal on loans at anytime had become fully institutionalized by the time of the War of the Austrian Succession, and the government had done so often enough that it no longer needed to set a maturity date on bonds: "If an efficient market in securities had not developed in London, where lenders could sell their claim to annual interest in return for a capital sum, the state would hardly have been able to float long-term loans without promising to repay them" (Dickson, 1967, 245). The trend towards a totally funded national debt also continued through the War of the Austrian Succession. During the Nine Years War over 70% of debt had been unfunded; by 1712, funded debt had exceeded unfunded debt, and in no major war after 1714 did

unfunded debt exceed 20% of the total. The highest floating unfunded debt proportion reached during the War of the Austrian Succession was 14%, a result of stop gap emergency spending after France entered the war in 1744 (Brewer, 1988, 119).

The beginning years of the war saw no real crisis or change in public deficit finance. Until 1744 new loans were relatively small and long rates remained at par around 4% (Dickson, 1967, 216-7). When France officially declared war on Britain the debt situation changed. Long rates sank below par (100) to 92 as the scale of long-term borrowing sharply increased. In late 1745, the Bank was caught with low bullion reserves during a French inspired Jacobite uprising. This forced the Bank to limit its discounts to only paper coming due within a month, causing a run. During December, the Bank was forced to further shorten its discount window to 15 days, and raised the charge on foreign bills to 5%, the legal private maximum. In January of 1746 however, the Bank successfully raised capital on the exchange, and with a key victory against French forces in February, the crisis passed; the Bank quickly resumed its normal discount operations, discounting any and all legal paper offered to it. In fact, due to this alarming episode, the Bank increasingly became the primary discounter for all types of commercial and public credit instruments during the second half of the war, as private financial houses shied away from discount operations. Indeed, by the close of the War of the Austrian Succession the Bank's role as official 'discounter of last resort' was fully institutionalized. The importance of this role, born out of war, for the maintenance

of financial stability during any sort of subsequent mid to late 18th or 19th century economic or industrial crisis is difficult to overestimate (Pressnell, 1960, 160-163; Deane, 1965; Dickson, 1967).[62]

In 1746 the aggregate size of the national debt and the continuing need for new loans began breaching sound economic limits. A cash loan on the Land Tax at 4% had been only partially subscribed as was a new float of short-term exchequer bills. By the middle of 1746 the price of government paper had sunk to 74 (100 par). In early 1747 the Bank of England again came to the rescue, pushing through with a funding of £986,000 worth of exchequer bills at 4% and lending the government another £1 million on the security of the land and malt taxes, even though the capital backing these floats had not yet been fully subscribed. Which begged the question; how many more times could the Bank fund government military endeavors in this way without threatening its ability to discount, or ultimately crashing the price of its outstanding shares? "By the end of 1747, Henry Pelham, who was First Lord of the Treasury from 1743, was seriously questioning... whether England could fight for another year" (Dickson, 1967, 216-228).

In 1748 the war news was unfavorable, and in January and February credit became increasingly tight. By April prices on long-term government paper were

[62] The Bank's 18th century role as discounter of last resort parallels the Federal Reserve's role as lender of last resort today. In moments of crisis the Federal Reserve, backed with capital of all sorts, willingly lends at rock-bottom rates to economically important companies facing a momentary credit squeeze, thus keeping the wheels of the economy turning. In moments of 18th century financial crisis, the Bank of England would step in, backed by capital of all sorts, and willingly discount any type of commercial or public paper at reasonable rates. This kept the wheels of the 18th century economy turning during times of crisis (Martin and Epstein, 2003; Dickson, 1967)

down to 77, some 23% below par, temporarily conferring an effective long rate between 26% and 28%. Luckily, and not unconnectedly, peace preliminaries were signed in October of 1748 and prices swiftly recovered; the previously languishing 1746-1747 loan subscriptions were sold out by November. The Treasury and the Bank had managed to navigate the extensive costs of the War of the Austrian Succession successfully. The French part of the war had added over £28 million to the national debt. This was about a third of the total war cost. At the end of the conflict, the national debt stood above £70 million, and its annual charge had risen from £1,736,000 in 1739 to £2,632,000 by 1748; a gain of over 50% (Dickson, 1967, 223-228).

It should be mentioned that foreign creditors, for the first time, played a crucial role in enabling expanded British national debt aggregates during the War of the Austrian Succession (especially in the latter half). Foreign holders were thought to hold a quarter of British debt in the 1740s and contributed at least £5 million to loans during this war. Furthermore, one-third of South Sea Company stock was now in foreign hands and foreigners had provided over 10% of the subscriptions to the largest loan of the war years. Indeed, after the Bank enlarged its capital to navigate the late war credit crunches, foreigners came to hold over 33% of Bank stock (Dickson, 1967, 305; 320; 322; 335).

This trend toward increased foreign holding of British debt, which really gathered momentum during this and the next war, was important to the nascent industrial mode of development shift for a couple of reasons. First, it decreased

interest on government debt to lower rates than would have been realized otherwise, thus decreasing the costs of military expenditure and freeing domestic capital for investment elsewhere; although foreigners did not directly invest in the private market for British capital, the decline in long-term rates was likely communicated to the entire British capital market, as public and private rates moved in sympathy with the yield on long-term government stock by this time (more on this in a moment) (Pressnell, 1960, 179, 190; Dickson, 1967; Ashton, 1959; North and Weingast, 1989, 825). Additionally, in a real sense, some significant proportion of this foreign capital made its way, through the state via the competitive contracting marketplace, into the hands of military contractors, while at the same time keeping down the charges on their circulating credit (Deane, 1965, 185). As will be discussed in some detail below, military contractors during the War of the Austrian Succession and the Seven Years War clearly utilized these increased capital flows carrying lower charges to augment their fixed capital expenditures.

Also supporting the decline in rates charged for circulating credit in the British economy during the 1750s was Henry Pelham's aforementioned postwar heroic effort to reduce the annual charge on the aggregate national debt. Recall that after the War of the Spanish Succession most of the debt outstanding carried a charge of 6%, and this was largely reduced to 5% in line with economy-wide falling interest rates. Also recall that this conversion met with little resistance. After the War of the Austrian Succession most of the national debt carried a charge

of 4%. Treasurer Pelham now sought to reduce it to 3% in order to limit annual servicing payments. This time, government creditors fiercely resisted the conversion (Dickson, 1967).

How come? Well, in this case Pelham was attempting to reduce the charge on the national debt to a level well below natural market rates. European interest rates had generally bottomed out between 3.5% and 4% just prior to the mid-18th century; they then began trending upward in the second half of the century. There is very little evidence of private rates, such as those on first-class mortgages, trending below 4%; indeed rates such as these tended to lie between 4% and 5% during the middle 18th century, and for the most part stayed closer to 5% (Williamson, 1984, 694; Mathias, 1979, 101; Pressnell, 1960, 189). This was also true in Amsterdam.[63] Not surprisingly then, the Dutch as well were quite reticent to accept a conversion from 4% to 3% on British long-term debt (Dickson, 1967, 31).[64]

Nonetheless, the early years of the war had emboldened Pelham; while expenditure was low and the pace of combat slow, the government had been able to float a couple of small loans carrying a charge of 3%. As the war progressed and

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[63] In the 1740s public Dutch rates bottomed out around 3.5% but began rising from there. Private market Dutch rates were less different than British rates than is often supposed. Rates were much different in the early part of the century but differences had largely been closed by 1750 (Dickson, 1967, 322).

[64] In fact, the first proposal to reduce the charge on the national debt to 3% came in 1737, a couple of years before the outbreak of widespread combat. Given that rates throughout the economy were significantly higher than 3%, this proposal was met with extreme indignation from every corner. Indeed, the proposal caused there to be a short sharp run on the Bank of England, "every face appeared confounded by the proposed reduction of interest." The architect of the bill, one Lord Barnard, was even burned in effigy (Pressnell, 1960, 204). The bill quickly met with a resounding defeat (Dickson, 1967, 210-214).

expenditure mounted, however, the government was forced to pay 4%; an overwhelming proportion of the War of the Austrian Succession debt was issued at 4%. Indeed, in 1750 only 13% of the debt of over £70m was funded with 3% stock (Dickson, 1967, 231). And in the final year of the war 3%s were 23% below par, while ingraftments to the Companies were carrying a rate of 4%. Clearly the entire international capital market was more comfortable with a 4% rather than a 3% charge on British debt (Pressnell, 1960, 204; Dickson, 1967, 230).

How then did Pelham manage to convert the charge on the vast majority of outstanding British long-term national debt instruments to rates well below 4% starting in 1750? Through the use of good old fashion and partially clandestine political maneuver of course. Initially, Pelham's 3% proposal was scoffed at. Even the Bank would not acquiesce, fearing such blatant disregard for its shareholders would surely tank its rapidly increasing market capitalization. Pelham astutely switched his proposal to a reduction of 3.5% for seven years followed by a final reduction down to 3% in 1757, along with a guarantee of no further reductions in the future. The Bank continued to balk. Without the Bank on board, it was clear that Pelham could never raise the necessary capital to pay off the tremendous amount of dissenters who would ask that their principal be repaid immediately. With rates generally around 4%, Pelham's Treasury would independently have to raise approximately £60 million at a charge of 3.5% to cover the dissentient redemptions; simply impossible. Someway, somehow, Pelham needed to get the Bank of England behind the proposal (Dickson, 1967, 232-245).

Here is where the First Lord Treasurer turned crafty. Pelham had long been a close confidante of the largest shareholder of the Bank of England, one Samson Gideon. For all of 1749, Gideon had steered clear of the issue, not wanting to alienate his fellow shareholders; they were well aware of his close ties to the First Lord Treasurer. In January of 1750 Gideon and Pelham met in the Treasurer's office several times. What precisely transpired between the two is simply unknowable. However, in February of 1750 Gideon suddenly came out swinging for team Pelham. After a series of Bank of England shareholder meetings, during which Gideon must have utilized all of the tried and true methods that largest single shareholders have employed to get their way before or since, the Bank of England Corporate Board narrowly voted to support Pelham's conversion; the Bank would assist the Treasury in raising the necessary capital at 3.5% to pay off any potential dissenters. In the words of PGM Dickson (1967: 237), "It would be nice to know what arts Gideon used to turn the lion of January into the lamb of February." With the Bank now on board, Pelham used the carrot and the stick method to strong arm the East India Company into acquiescence. The stick: Pelham informed the Company that not only would the Bank buy the Companies' large amount of 4%s (totaling around £4.2 million), which given the competitive and profitable nature of public deficit finance at the time, amounted to a hostile takeover, but the Company would also be out of favor in the future in regards to both new issues of debt and the renewal of its corporate charter. And the carrot: if the Company would support the conversion, Parliament would pass a bill allowing the Company to increase its

capital by £4.2 million. The Company acceded. With the East India Company now on board, Pelham looked to convince the even more intransigent South Seas Company. The South Seas board of directors flat out rejected the conversion to 3.5% regardless of the consequences, as their balance sheet could not withstand it. However, if Parliament were to allow the South Seas Company to issue £2.1 million in stock now, and more in the following years, by 1757 the Company would be in a position to allow a reduction of its 4%s all the way down to 3%. In the meantime, no redemptions or buy outs of South Seas held government debt would be allowed to take place. Pelham, acting as go between, got Parliament to accept this proposal (Dickson, 1967, 236-240). With all three monied companies now backing the conversion, the larger public was sure to follow, and for the most part they did: By May of 1750 £50.8 million of a possible £57.7 million of 4% stock had been subscribed to the conversion. Effectively 88% of 4%s had been reduced to 3.5% immediately, and then to 3% in seven years, reducing the annual charge on the national debt by 12% in 1750 and 25% in 1757. With the Bank's assistance, the government was able to fully repay the dissentients' principals – approximately 12% of the holders of 4%s had dissented (a not so insignificant proportion). After the successful conversion, Pelham oversaw a consolidation of all government stock from the entire century into one easily managed account with interest regularly being paid from a settled 'sinking fund'; the consolidated 3%s, better known as the famous British 'consols', had come into being. The market, though, is a fickle sort of a beast, and one resistant to political manipulation at that.

Indeed, the market price of consols reached their zenith in 1752, only to decline for the rest of the 18th century (Dickson, 1967, 232-245; Crouzet, 1972, 32).

As should now be clear, Pelham managed through shrewd political maneuvering to force a reduction of rates on British long-term debt significantly below what the market would naturally swallow. This hopefully has provided the reader with an interesting anecdote, but why should the story matter? At the risk of getting ahead of the narrative, it seems prudent to answer this question now, while the story of Pelham's conversion is still fresh in the mind. The episode is vital because this reduction in interest rates on the national debt is an essential ingredient linking the English Financial Revolution to the British Industrial Revolution. The emergence of 3% consols marks the end of the English Financial Revolution; by 1757 the financial structure that came to gird industrial accumulation was for all intensive purposes complete (Dickson, 1967). And in the 1750s there suddenly emerges a boom in capital goods investments of all sorts, including turnpikes, canals, and most importantly, cast iron factories; i.e. the industrial mode of development shift seemingly ignites during and immediately after Pelham's successful conversion. Below it will be shown that military expenditure combined with Pelham's conversion to cause intensive transmogrification in British productive infrastructure after 1755. But that tale belongs to the Seven Years War (1756-1763). For now, the task remains to theoretically connect Pelham's conversion, born of heightened military expenditure and its concomitant charges

during the War of the Austrian Succession, to the initiation of the 1750s capital goods explosion in the private sector of the British economy.

As aforementioned in chapter two, linking Pelham's conversion to the onset of industrial infrastructural development is a somewhat controversial proposition. The middle century capital goods explosion was a private sector affair, and it is debatable whether a reduction of rates on long-term government debt would have been communicated to the private sector effectively during the mid 18th century (see note 65 below for more on this debate) (Crouzet, 1972, 53; Mathias, 1979). Nonetheless, there is ample theoretical and historical justification for asserting Pelham's conversion of public rates to below natural market rates as a prime cause of the 1750s capital goods explosion. The theory goes as follows: As the yield on long-term government debt decreased below the natural market rate, investment capital seeking long-term higher yields was squeezed out of the capital market for government paper and into private capital markets. Increased monetary flows into private capital markets lowered rates of interest there, thus reducing charges on circulating capital, therefore supporting increased long-term investment in productive capital goods and infrastructure where profit yields now suddenly exceeded both public and private rates of interest. For example, the average investment in a 1750s turnpike or a 1760s canal yielded over 4%. Additionally, if money needed to be raised in order to directly finance capital investment, it could be raised at lower rates in the easy money market fostered by the low yield on government debt. By these mechanisms, it seems likely that sliding rates on

government paper resultant from Pelham's conversion caused heightened capital goods expenditures throughout the British economy (Pressnell, 1960, 184; Dickson, 1967; Thompson, 1973, 118; Landes, 1969, 64; Rule, 1992).[65]

This process, the theory continues, was crucial not only to improved transport infrastructure after 1750, but also to heightened fixed capital expenditure in manufacturing during the middle 18th century. As discussed in chapter two, British mid-century manufacturers inserted themselves into the matrix of credit fomented by British military expenditures. There they accumulated circulating capital which allowed them to use personal capital and profits to augment and improve their fixed capital (Mokyr, 1993, 100; Rule, 1992, 164; Crouzet, 1990, 163; Brown, 1991, 197; Dickson, 1967). "The importance of circulating capital to

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[65] The most damaging argument that can be leveled against this theory is the idea that there simply were no mechanisms linking public pools of investment capital to private pools of investment capital in the middle 18th century; thus, lower rates on long-term government debt would not cause increased investment in the private sector (Dickson, 1967; Rule, 1992; Mokyr, 1993). Such an argument would be persuasive for the early 18th century only; it becomes ever less persuasive as the century progresses, for the huge national debt, and the myriad of credit instruments which supported it, forged extensive links between provincial and city capital markets, and public and private capital markets, in Britain throughout the first half of the 18th century (Mathias, 1979, 92-93; Dickson, 1967, 453; Pressnell, 1960; Thompson, 1973; Mokyr, 1993). Qualitative data supports the assertion that changes in public rates were being communicated throughout increasingly integrated public and private British credit markets prior to Pelham's 1750-1757 conversion (North and Weingast, 1989, 825; Pressnell, 1960, 201; Ashton, 1959, 87-88). In the 1740s private London Banks kept a large proportion of their capital in government paper as security in case of sudden demand for note conversion, for it was clear that they could quickly and securely get government paper discounted at the BOE (the discounter of last resort) in order to switch into any particular asset at anytime (Pressnell, 1960, 158). Because government paper, long or short, was an alternative capital option to commercial loans for private financial houses, and because the Bank could be relied on to discount government paper for cash at anytime (meaning that a commercial bank could quickly convert a public security into a private security), the effect of lower rates on government paper was communicated to the private market (Pressnell, 1960, 175-176). Moreover, in the 1740s long rates on government debt became the benchmark by which private investors measured 'fair' commercial rates. Also, by the late 1740s, mortgagees had the habit of threatening to redeem their mortgage if the rate did not follow public market rates downward; on the other side mortgagors would threaten to recall their loans if charges did not follow public rates upwards (Pressnell, 1960, 187; Ashton, 1959, 87-88). Clearly, the links between British public and private capital markets had been forged in war prior to Pelham's 1750 conversion (Pressnell, 1960, 179; Ashton, 1959).

the industrialist meant that fluctuating interest rates would have rippled across the world of industry and trade" (Pressnell, 1960, 195; Crouzet, 1972). This effect was extra profound in industries making wide use of government paper, such as the iron industry – where contractors directly received government paper in the form of exchequer, ordnance, and naval bills, and where fixed capital costs were quite high thus driving ironmasters to increasingly rely on credit for their heavy circulating needs. There can be little doubt that cast iron contractors benefited from Pelham's conversion, thereby facilitating an industry wide transformation; a transformation that explosively gathered pace during the Seven Years War (1756-1763) (note that this war began a year before the end of Pelham's conversion procedures). As will be evidenced below, the subsequent rapid development of a cast iron industrial infrastructure in Britain was clearly rooted in these defense expenditure related mechanisms. Hence it is eminently reasonable to consider Pelham's 'unnatural' mid-century conversion, born out of fiscal necessities stemming from heightened military expenditure during the War of the Austrian Succession, as a prime cause of the 1750s and 1760s British capital goods expenditure boom; a boom which most certainly paved the way for the emergence of the industrial mode of development (Ashton, 1959; 1968b; Pressnell, 1960; Dickson, 1967). In the now all but forgotten words of A.H. John (1955):

> "The importance of the lowering of the rate of interest in the half-century before the Industrial Revolution has never been properly stressed by historians. If we seek – it would be wrong to do so – for a single reason why the pace of economic development quickened about the middle of the 18th century, it is to this we must look. The deep mines, solidly built

> factories, well constructed canals, and substantial houses of the Industrial Revolution were the products of relatively cheap capital" (quoted in Ashton, 1968b, 9).

Of course, before a full review of the 1750s-1760s capital goods explosion, and the way this explosion interacted with military expenditures during the Seven Years War, can be undertaken, the analysis of the War of the Austrian Succession must be concluded. The independent variable of military contracting during the War of the Austrian Succession will now be explored; to be followed by an examination of the wide transformative effects military expenditure conveyed to British industry prior to Pelham's conversion.

DEFENSE CONTRACTING DURING THE WAR OF THE AUSTRIAN SUCCESSION:

In its organizational form and procedure defense contracting remained largely unchanged from the arrangements that had proven so practical and powerful during the War of the Spanish Succession. The most important alterations to the military contracting system came from improvements to the security of naval and ordnance bills. These means of payment between the state and its contractors evolved into nearly risk-free credit instruments during the war. In regards to naval bills, they now carried a 5% rather than a 6% per annum yield. This decline reflects improved financing at the Naval Board. By regularly paying on naval bills, and when necessary clearing them from the market through ingraftments to the Bank of England, the Naval Office was able to limit market discounts of naval bills, thus allowing for a decline in their official interest rate. In fact, during this

war substantial accumulations of naval bills appear in the capital holdings of London private banks and financial houses, thus indicating that they were considered a secure form of payment suitable for distribution throughout the entire English trading / manufacturing edifice (Dickson, 1967, 400-406). Improvement to the security of ordnance bills was even more extreme during this war. By its close, ordnance bills carried no daily interest rate. In other words, the Ordnance Board paid off its bills to contractors so swiftly that ordnance bills rarely received discounts in the marketplace, thus they did not need to carry a formal interest rate in order to limit market discounts; ordnance bills had become as good as cash (Dickson, 1967, 398).

The importance of the rise of secure paper in the payment of naval and ordnance contractors in mid-18th century Britain is difficult to overstate. The Naval and Ordnance Boards were the organizational center of Britain's capital intensive war machine. Huge streams of capital passed through the Boards' hands to contractors. Indeed, over the course of the War of the Austrian Succession payments issued from the Boards increased significantly as compared with the War of the Spanish Succession; The Ordnance Office distributed approximately £3.74 million during this war; nearly 75% more per annum than it distributed during the War of the Spanish Succession. The Naval Office, on the other hand, spent approximately £24.9 million during this war, a more reasonable 5% per annum gain from the years of the War of the Spanish Succession (Mitchell and Deane, 1962, 390). The fact that the credit instruments used to make these huge capital transfers

to contractors were secure, and in the case of ordnance bills as good as cash, enabled military expenditure to be an effective force of demand, most notably, in the soon to be all important cast iron sector. For example, ship construction figures suggest that at the height of the War of the Austrian Succession the Ordnance Board was contracting out the construction of nearly 700 cannon per annum. This implies a vast improvement in domestic cast iron process and output from the last war when contractors were taking months to fill orders requesting as few as 25-50 cannon (Pool, 1966, 79-80; Brewer, 1988, 197; Tomlinson, 1979, 160; Glete, 1993). The unambiguous positive effects of massive and secure capital injections of military expenditure into the British cast iron industry during the War of the Austrian Succession will be evidenced in the following.

THE EMERGING BRITISH INDUSTRIAL MODE OF DEVELOPMENT SHIFT:

'There is general agreement that the War of the Austrian Succession stimulated iron production, evoking considerable increase in productive capacity and output' (Anderson, 1972, 13; Little, 1976, 71; Ashton, 1968). To begin with, in the 1730s over half of British iron consumption had been imported, and up to that point, increases in domestic consumption had been met with increased imports. The outbreak of hostilities blocked trade between Britain and its major iron suppliers, while directly stimulating domestic production, thus initiating for the first time a declining trend in the level of foreign iron imports into Britain. In fact, after the war, British exports of iron were 50% higher than they were at its

beginning (Ashton, 1968, 37-38; Harris, 1988, 58; 28).

Other metrics also indicate that domestic military expenditures over the course of the war propelled the British iron industry to sustained growth. At the end of the War of the Spanish Succession, total domestic pig iron output was somewhere between 20,000 and 25,000 tons. It remained in that range until the onset of war again some 25 years later. Towards the close of the War of the Austrian Succession domestic pig iron production easily approached 30,000 tons and continued upwards from there (Harris, 1988, 48-49; 79). Military expenditure clearly played a large role in this new expansion, for the cast iron sector (the sector at the crux of Britain's capital intensive fire-powering naval war machine) grew at a more rapid pace over the war years than the rest of the industry. Prior to the war the proportion of cast iron output in the British iron industry was certainly south of 10%; Hyde (1973) asserts that directly following the war cast product accounted for upwards of 20% of domestic production (Harris, 1988).

But precisely how large a stimulus was military expenditure providing to the British iron industry during the War of the Austrian Succession? Can quantitative figures regarding the percentage of domestic output purchased by the military in the middle decades of the 18th century be gleaned from historical data? The mid-century estimates for naval iron procurement recorded by Pritchard (1987) and Glete (1993) allow for the approximation of some percentages: During the middle 18th century the amount of iron the British Navy required for building, current operations, and upkeep can be conservatively estimated at 2800 tons per

annum (Pritchard, 1987, 143; Glete, 1993). The amount of cannon and ordnance purchased for the Navy in an average year between 1748 and 1763 has been estimated at 1300 tons (Pritchard, 1987, 143). Thus approximately 4100 tons of iron per annum was purchased through British naval spending in the middle 18th century. In 1750 domestic finished wrought and cast iron output was approximately 20,000 tons (Harris, 1988, 49).[66] Hence up to 21% of total British domestic iron output was being purchased in the form of finished goods by the Navy around the time of the War of the Austrian Succession (discounting Army purchases).[67] The proportion of output purchased by the Navy moves up significantly if one narrows focus to the cast iron sector alone: Again, 1300 tons per annum is a fair estimate of the amount of cast iron cannon and ordnance consumed by the British Navy during the middle 18th century (Pritchard, 1987, 143). Add to this a conservatively figured total of 1100 tons per annum the Navy needed for other cast iron ware,[68] and an estimate of 2400 tons per annum is arrived at for naval demand for cast iron (Pritchard, 1987; Glete, 1993; Lavery, 1987). The total output of finished cast iron product was at most 4000 tons per annum at this time (20% of 20,000) (Harris, 1988, 49). Thus the Navy was purchasing upwards of

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[66] This figure differs from raw pig iron output; it is typically lower by about a third (Harris, 1988).
[67] In 1793, when better records were kept, the government was buying 17-19% of a much enlarged and commercially successful domestic iron sector (Harris, 1988, 56), thus lending credence to this 21% calculation for the middle decades of the 18th century. On a separate note, Army purchases have been discounted throughout this discussion because Britain was not renowned for either the quality or quantity of their musket production (Hogg, 1963; Barnett, 1970).
[68] 40% of the 2800 tons required by the Navy for non-ordnance purposes; which is likely too low for over 40% of the Navy's non-ordnance iron needs were probably cast. Commonly used heavy cast iron products in the mid 18th century British Navy include ballast and anchors (Lavery, 1987; Glete, 1993).

60% of the small but growing cast iron market during the warring middle years of the 18th century; with most of this demand occurring fairly suddenly with the onset of war in 1739 after 25 years of relative peace (Pritchard, 1987, 143). These estimates suggest that military demand was large enough in relation to the overall domestic iron sector to be extremely stimulating during the middle years of the 18th century; which of course witnessed the two largest wars in British history up to that point – The War of the Austrian Succession (1739-1748), and The Seven Years War (1756-1763). Moreover, as aforementioned, the goods purchased by the military were necessarily held to exacting proofing standards as outlined in naval and ordnance contracts (Ashton, 1968; Pool, 1966). Certainly the need to pass rigorous inspection in order to receive payment and further contracts down the line drove mid-century ironmasters to rationalize process and augment fixed capital (Hobsbawm, 1968).

In fact, there is much qualitative evidence indicating rationalized processes and augmented fixed capital expenditures at iron contractors during the War of the Austrian Succession. Throughout the war, Abraham Darby II's Coalbrookdale, the site of the first coke powered cast iron operations, continually expanded plant, building huge new furnaces and linking them with wooden 'wagon ways' to the Severn River. Surely this was a partial (if not total) consequence of the massive orders for cast iron ordnance filled at Coalbrookdale during the war (Ashton, 1968, 43; Anderson, 1972). Additionally, in 1743 Darby II installed a Newcomen

'atmospheric' engine[69] at Coalbrookdale, but not one for draining water from mines as was typically the case. This Newcomen pumped back water to a reservoir after it passed over the huge cast iron waterwheels Darby used to energize blowing at his Coalbrookdale furnaces. For the first time this allowed for a continuous blast even in dry seasons. Not only was iron casting less dependent on flowing stream water as a result, but an important developmental feedback loop was being established: Improved casting led to better Newcomen engines and larger waterwheels, while better Newcomen engines and larger waterwheels increased productivity in iron manufacture; better productivity meant enlarged market share for cast iron producers, which in turn led to elevated demand for Newcomen engines and massive waterwheels, which required expanded and improved casting facilities, repeat. Key to the expansion and progression of this positive economic feedback loop was amplified elasticity in the demand curve for iron, which was unquestionably one consequence of heightened military procurement during the War of the Austrian Succession (Kanefsky and Robey, 1980, 182; Anderson, 1972; Little, 1976, 71).

Importantly, many new casters aping Coalbrookdale manufacturing processes initiated operations during the War of the Austrian Succession. Notably the Walkers opened shop in South Yorkshire. From the beginning, one of their

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[69] The Newcomen Engine, patented in 1708, was a half wooden half metal device that used changes in atmospheric pressure produced by steam to haul water from mine pits. This large importable inefficient contraption was a pre-cursor to Watt's steam engine (to be discussed later), but was itself incapable of powering production in any direct manner. It remained a contrivance for water displacement only.

primary products was naval cannon; their Masbrough ironworks would eventually grow to be one of the largest and most successful enterprises in all of Britain. John Wilkinson also began producing, researching, and developing during the war with the goal of constructing superior cannon and ordnance. Wilkinson would soon come to be one of the most celebrated and world-renowned figures of the Industrial Revolution. Additionally, Sussex and Weald ironmasters received bulk ordnance orders, giving them new incentive to activity (Ashton, 1968, 44-48; 131; Rule, 1992, 119). In all such contracting establishments it became the norm to have full process ironworks owned by one capitalist "in an integrated business on a scale which was probably unique at this period" (Ashton, 1968, 20-1). Like Darby II, the owners of these integrated works sought to be free of their dependence on rivers for power, for war was a year round event while stream currents were not. Thus, the feedback loop described above (increasingly large cast waterwheels being driven with water pumped by efficiently cast Newcomen engines generating increased market share amid heightened military demand) circulated widely during the second half of the War of the Austrian Succession; and its extension was facilitated further in the postwar years by the drop in interest rates sponsored by Pelham's conversion and its concomitant effects on capital expenditure and investment as described above (Pollard, 1994; Ashton, 1968, 41-2; Little, 1976, 84; John, 1955, 334).

After the War of the Spanish Succession growth and development in the domestic English iron industry had for all intensive purposes ceased. Not so after

the War of the Austrian Succession. It appears that the positive feedback loop established in the iron industry during the war, and the heavy fixed capital expenditures required in order to enact Newcomen powered cast waterwheel production, propelled ironmasters to innovation after 1748 as they searched for new outlets for their war born fixed capital; "The range of alternative uses to which the products of these war-expanded industries could be put, led to a continued development in the intervening years of peace" (John, 1955, 331; Ashton, 1968, 45). The cast iron sector went on to capture larger market share in the early 1750s, expanding into products such as cooking wares and utensils, along with building supplies and materials. For example, in the early 1750s the soon to be famous engineer John Smeaton pioneered the use of cast iron in the construction of roads and turnpikes (Brown, 1991, 97). Additionally, the use of cast iron waterwheels and windmills dispersed throughout numerous sectors of the British economy after 1750, greatly improving power generation in manufacturing activity of all sorts (Brown, 1991, 102). In short, there can be little doubt that the War of the Austrian Succession roused the British iron industry, kicking off a feedback loop that would soon propel iron to leading sector of the greatest technological revolution in known history up to that time.

As for the rest of the postwar economy, Britain had successfully defended and expanded its colonial trade, and its manufacturing sectors greatly benefited. "For some three decades after the War of the Spanish Succession British ships bound for Africa still carried mainly foreign goods; from shortly after the War of

the Austrian Succession they carried overwhelmingly British ones" (Hobsbawm, 1968, 30-2). In the post war boom, imports, exports, and re-exports soared to unprecedented heights (Ashton, 1959, 149-50). Public deficit finance expenditures continued into peacetime, thus underpinning boom-time conditions.[70] Moreover, interest rates were declining after the war (part and parcel of Pelham's conversion), thereby supporting the economy in general, and privately financed road construction in particular; in 1749 turnpike acts numbered 10 per year, while in the 1750s they came to average over 40 per year (Ashton, 1959, 96). It can be said then that victory in the War of the Austrian Succession, along with Pelham's mid-century conversion, created an environment of optimism from which there emerged entrepreneurs willing to commit a growing proportion of their money to fixed capital and infrastructure (Ashton, 1968b, 69). The war also expanded and strengthened Britain's colonial trading connections, thus giving Britain increased access to the raw materials and international markets that would in the future help to sustain the Industrial Revolution. However, at this time, the Industrial Revolution was still embryonic at best, while the mid-century battle against France was far from over. The peace of the early 1750s was tense and marred by frequent skirmishes in far off lands. Indeed, the vast scope of the rapidly approaching Seven Years War would easily dwarf in size and spending any previous hostilities; the era of global war was about to commence (Kennedy, 1976; Thompson, 1973, 38; Hobsbawm, 1968, 8).

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[70] From 1748-1750 public deficit finance expenditures were actually above wartime levels as the nation deactivated its defenses and paid off leftover floating short-term debt (Ashton, 1959, 67).

CHAPTER 6: THE SEVEN YEARS WAR – 1756-1763

The Seven Years War can be considered the first 'world war' for sustained and significant fighting took place upon three continents. There were actually four main theatres of war: In the West Indies the British / French rivalry resumed with questions over neutral islands and the cheaper production of sugar by the French. In India there had been ruthless competition for power and profits since 1748, with both nations' East India Companies repeatedly intervening in Indian affairs. The most important struggle was in North America, "where the westward drive of the British settlers into the Ohio region clashed with the French scheme to link their Canadian territories with the Mississippi." Europe was the fourth, and perhaps the least important theatre. There the Austria-Prussian rivalry had drawn in France, thus aiding Britain's colonial objectives (Kennedy, 1976, 99).

During the Seven Years War the extraordinary scale of operations together with their exceptional cost led the British nation 'to expand its political horizons and to raise its expectations of the spoils of victory' (Brewer, 1988, 175). When allowing for inflation, it becomes apparent that the per annum cost of the Seven Years War marks it as the most expensive conflict of the 18th century (Brewer, 1988, 255). In the middle of the conflict, Britain had a remarkable string of victories, many resulting from amphibious operations involving a coordinated navy and army. "The triumphs of the Seven Years War marked an apogee of patriotic bellicosity" in Britain. There were taverns and public hostelries named for heroes, laudatory songs, popular prints, and engravings. Generally, the British wanted

military glory without 'European militarism', and in a real sense, during the Seven Years War they got it (Brewer, 1988, 60).

SEVEN YEARS WAR EXPENDITURE OVERVIEW:

Average annual state expenditure during the Seven Years War reached £15.8 million; an astounding 80% gain from the average per annum expenditure that obtained during the War of the Austrian Succession. Total expenditure during the Seven Years War tallies to £126.3 million, 44% higher than the total reached during the previous war, and this in a considerably shorter period of time. Average per annum tax revenue for the British state during the Seven Years War was £8,641,125, an impressive 35% gain over the last war. This, however, still left a gaping £7.2 million average per annum deficit; a deficit nearly matching per annum tax revenue, and an unimaginably 204% higher than that which obtained in the prior war. Needless to say, public deficit finance was more than crucial to a successful British war effort during the Seven Years War. Approximately 46% of all expenditure was met through borrowing, the highest proportion of borrowed expenditure for any 18th century war; the figure actually approached 70% during the more intense war years. This caused the national debt to mushroom from a level of £74.6 million at the start of the war to £132.6 million by the end, a rise of 78%. The charge on the national debt also mushroomed from £2.76 million in 1756 to £4.67 million in 1763, a gain of 70%, raising the proportion of tax revenue

devoted to debt payments from 29% in 1756 to 46% in 1764 (Mitchell and Deane, 1962; Mann, 1986, 485; Brewer, 1988).

Unsurprisingly, military expenditure during the war was simply massive when compared with the underlying economy that sustained it. Military spending aggregated to an incredibly large 16% of total national income over the course of the war. In the year 1760 military expenditures reached £13.5 million, while the value of British exports[71] totaled some £2.5 million less. Meanwhile, total per annum private investment expenditures in the British economy, approximately $4.68 million in 1760, were a fraction of per annum military expenditure throughout the war (O'Brien, 1991, 34-35). Moreover private investment expenditures were lower before the war than in the midst of it or after, thus suggesting that little crowding out occurred during the Seven Years War; although inflation and interest rates did notably pick up in the final two years of the war, the historical record indicates that the British economy continued to fire on all cylinders (Brewer, 1988, 41; Fisher, 1992, 20; Ashton, 1959). The public deficit finance system that enabled long-term large-scale military expenditure in Britain had surely come into its prime. And, as will be shown, at the same time that the British state enacted entirely unprecedented military expenditure packages, over half of which were debt financed, the British infrastructural industrial mode of development shift rapidly gained traction and pace; one might even say, it took off.

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[71] Not including re-exports.

THE STRUCTURE OF TAXATION DURING THE SEVEN YEARS WAR:

The Seven Years War, 'fought on an unprecedented scale, at an unprecedented expense', produced the most rapid growth in tax administration since the Treaty of Utrecht (Brewer, 1988, 67). Tax revenues gradually rose to 1756, but experienced rapid amplification during and subsequent to the Seven Years War. The spine of tax revenue growth again came from excises. Excise revenue averaged £4.1 million per annum during the war, up from £2.98 million in the last war, now accounting for 47.5% of total revenue. Once again the state avoided imposing excises on goods necessary to sustaining the war effort (Mitchell and Deane, 1962; Mathias and O'Brien, 1976, 618).

Customs revenue also had a steep growth curve during this war, bringing in £1.97 million per annum, up from £1.3 million per annum during the last war, and now accounting for 22% of total revenue. Interestingly, customs revenue during the 18th century generally stayed stable or shrank in times of war as trade was disrupted; the Seven Years War was the first war in which British customs revenue appreciably rose, as trade did the same. With the rise in both customs and excise revenue, the percentage of revenue that came from indirect taxation reached nearly 70% during the Seven Years War. The land tax remained the primary direct tax, and although assessment rates were raised, aggregate returns reached only those levels last witnessed in the 1690s, increasing the proportion of revenue taken up by direct taxes from 21% to 26% during the war. Needless to say, the tax incidence in

Britain continued to be highly regressive (Mathias and O'Brien, 1976, 612-622; Brewer, 1988, 99; Mitchell and Deane, 1962).

Hence, by the Seven Years War we see a dynamic and changing economy ably shouldering the burden of increased commodities taxation, both by per capita and aggregate, during the most expensive conflict of the 18th century. Meanwhile, goods necessary to the war effort escaped taxation as did iron contracting firms. Also, all major forms of investment, such as that in plant, fixed capital, or government debt, remained untaxed during the Seven Years War, thus eliciting an ideal economic environment for defense inspired economic transformation (Schumpeter, 1938; Mathias and O'Brien, 1976; Brewer, 1988).

PUBLIC DEFICIT FINANCE DURING THE SEVEN YEARS WAR:

As a result of Pelham's mid-century conversion down to 3% on long dated public debt instruments, completed in 1757, Britain was able to initiate the Seven Years War in excellent financial shape (Brewer, 1988, 124). For the first four years of the war, the British financial system, birthed by and for war over the previous several decades, handled the rapid increase in debt, from under £75 million to over £100 million, quite well. The Bank and the Companies floated loans and issued stock at ever greater amounts, and the public eagerly supplied capital (Dickson, 1967, 505).

In 1761, however, the rosy picture for the British debt environment began to change. The pace of combat and expenditure amplified over the first half of the

year, and now Spain was threatening to join the fray. In the summer of 1761 3% consols fell from 86 to 66 (par 100), Bank stock fell from 114 to 95, East India Stock fell from 143-112, and 5% India bonds fell from a premium of £2 14s to a discount of 5s. Discounts steepened throughout 1762 (Brewer, 1988; Dickson, 1967, 216). The reality was that five years into the Seven Years War debt and debt charges were spiraling upwards. Victories were continuing, but at what eventual cost to the underlying British economy? Servicing the debt was becoming very costly. Payment of charges on the public debt had stood at £2.7 million a year before the war. By 1760 this figure had risen to £3.4 million per annum; an increase of over 25% within the space of just a few years (Mann, 1986, 485; Schumpeter, 1938, 28; Mitchell and Deane, 1962, 390).

Britain's political leaders began to fear that the charges and discounts on the national debt were too much for the nation to bear; the entire economy could buckle under the weight of such high interest rates, thus threatening future tax revenues. From there it was not hard to imagine ever increasing discounts and charges on the debt causing a vicious spiral eventually obliterating all future economic prospects in Britain. And this is how British political leaders now made militaristic strategic decisions. Expensive capital intensive warfare required strong economic growth, for it necessitated higher revenue, which relied on rising consumption and trade. Over the course of the warring 18th century, the question English leaders faced had morphed from, could victory be attained tomorrow? To, could economic growth supporting future war efforts be maintained if we attempted to achieve another

victory tomorrow? When Britain opted to sign the Treaty of Paris in 1763, which brought a close to hostilities, the answer to the first question was undoubtedly yes, further victory could be attained tomorrow. The answer to the second question, however, was entirely uncertain, as the nation had entered uncharted financial waters (Kennedy, 1976, 106; Dickson, 1967, 216).

The coming of peace sent all public debt instruments in Britain back towards par, signaling that the financial and economic system had successfully weathered the strain imposed by the enormous military costs of the Seven Years War. Crucial to the maintenance of the system were the increasing international capital flows that streamed into the British public deficit finance system before, during, and after the war (John, 1955, 342-343; Dickson, 1967, 323). Understandably, "The greatest eulogies to public credit came in the aftermath of the unprecedented expense and extraordinary victories of the Seven Years War. Public credit was now praised as a National Good... a masterpiece of human policy and a bulwark of the state" (Brewer, 1988, 210). After the Seven Years War, there were few detractors left; the national debt had been institutionalized as a perpetual public good in Britain (Dickson, 1967, 16).

DEFENSE CONTRACTING DURING THE SEVEN YEARS WAR:

The organizational changes that occurred in the British market-based military contracting system as a result of the heightened expenditure occasioned by the Seven Years War will now be examined. For the most part, contracting

procedures remained unchanged for the Ordnance and Naval Offices during this war; although there were some modifications on 'points of detail' (Pool, 1966, 104). Contracts now contained clauses prohibiting sub-contracting.[72] Schedules of penalties were also more clearly elucidated than previously, and the Navy now reserved the right to enter merchant yards and complete unfinished work if the merchant fell behind or neglected his responsibilities. More often, if a contractor fell behind or encountered difficulties, the Navy would allow different contractors to bid on contracts relating to completing the unfinished work; a plethora of bidders regularly emerged (Pool, 1966, 95).

Perhaps the most notable modification to military contracting during the Seven Years War was an increasing reliance on standing contracts. Standing contracts were for indefinite quantities of goods and sometimes for indefinite lengths. The contractor was expected to maintain a reasonable stock so that requirements could be met without delay. In an environment of unpredictable, immediate, and spiraling military expenses and needs, the use of standing contracts made sense. Realistically, the Naval and Ordnance Offices could not possibly punctually tender bids for all the vast and sudden military exigencies cultivated by intense global-wide capital intensive hostilities. Moreover, the larger and longer was any contract, the higher was its value and hence the more competitive was the

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[72] Over this war and the last, some contractors had begun sub-contracting government work to smaller contractors where naval surveyors and ordnance proofers were not present. This resulted in some shoddy work, for these contractors, which had not directly entered into the bidding competition, tended to be more interested in "quick returns than uniformly good work" (Pool, 1966, 95).

bidding, which ultimately led to cheaper goods for the Naval and Ordnance Offices (Pool, 1966).

Clearly the use of standing contracts very much favored large and already established contractors (there were many such firms in the competitive contracting marketplace by this time) (Pool, 1966, 102). This was especially so in the iron industry, where augmented fixed capital enabled not only the rapid filling of sudden military needs, but also created economies of scale allowing for extra-competitive bidding (Hobsbawm, 1968; Deane, 1965). And as will be evidenced below, competition for standing contracts drove a boom in capital expenditure, and established a trend towards vertical integration, in the iron sector during the Seven Years War.

It should also be noted that at the time of the Seven Years War the Naval and Ordnance Offices had clear records on bids, prices, contracts, and contractors dating back to the Nine Years War. The Boards would use these records to their advantage when haggling out standing contracts; at times requesting prices that had obtained 50 years prior. Interestingly, such information was public knowledge in Britain, so contractors would also consult these records as they determined their bids; pointing out to the Boards that much had changed in five decades. Such honest and public interactions between the state defense departments and their contractors, along with a clear and open records history, most certainly increased the efficiency of the market-based contracting system, enabling contractor profit and reasonable pricing at the same time (Pool, 1966, 102).

Interestingly though the Naval and Ordnance Offices tended to not closely monitor the vicissitudes of commercial market prices. Hence, if market prices for any particular contracted good fell, the standing contractor stood to receive a windfall. Rarely, however, did this windfall materialize. The competitive and open nature of the British contracting system ensured that the defense departments did not need to watch prices, for competitors would often take the initiative in quoting lower prices to the Boards. All standing contracts had clauses outlining procedures of notice for contract termination; the Navy and Ordnance Offices made frequent use of these clauses, and made sure that all the well known contractors generally knew the value of current contracts. When terminating contracts owing to an improved method or bid from an alternate contractor, the defense departments would open the bidding to the entire market rather than just the one competitor whose lower bid or improved method had caused the termination of the original contract. In this way the competitive marketplace itself became the stick assuring efficient pricing while also driving contractors to improve upon their production processes (Pool, 1966, 103-106).

As might be expected, the British market-based system of military contracting was once again astonishingly effective during the Seven Years War. Britain's Navy, and now amphibious Army, ruled the seas and seashores worldwide, unleashing a fury of capital intensive warfare whenever and wherever the nation chose. Even though per annum military expenditures nearly doubled between this war and the last, The Naval and Ordnance Offices encountered little

difficulty in regards to paying the contractors facilitating Britain's way of warfare. Ordnance bills carried no interest rate and received no discount throughout every year of the war; they remained as good as cash. The daily rate on naval bills was reduced from 5% per annum (the rate carried during the last war) down to 4% per annum. Discounts on naval bills were nil until the final years of the war, reaching a zenith at a relatively low rate of 10%. Through the use of ingraftments the market was regularly cleared of short-term military expenditure instruments, and all short-dated bills were at par a few months after the close of hostilities. Over the course of the war, the Ordnance Office spent £4.97 million, or 66% more per annum than during the last war which occurred less than a decade prior; again, as will be shown, the effect on the domestic iron industry was extreme. The Naval Office on the other hand spent £37.3 million total, an astounding 85% per annum gain from the War of the Austrian Succession (Mitchell and Deane, 1962; Pressnell, 1960, 167; Dickson, 1967, 397-398). Now let's review the ways in which Britain's costly, yet highly effective, methods of capital intensive warfare incontrovertibly helped to foster an infrastructural industrial mode of development shift during the Seven Years War.

THE INDUSTRIAL MODE OF DEVELOPMENT SHIFT DURING THE SEVEN YEARS WAR:

Astoundingly, the entire British macro-economy turned up in lockstep with mounting hostilities throughout the war. The simple reality is that every sector of the British economy flourished during the most costly conflict of the 18th century;

the Seven Years War had no negative impact on any of the statistical series reviewed in this study. Contrariwise, output and investment were vigorous (Ashton, 1959, 149-50). Unbelievably, shipping loads carried by Britain rose from 32,000 tons in 1756 to well over 500,000 tons by 1763, 'or about one-third of all of Europe', conveying an extraordinary 1462% gain in shipping volumes over the course of the Seven Years War. Kennedy (1976:105) asserts that this was due, in large measure, 'to the stimulus of war orders to industry', British protection of its merchant shipping, and the destruction of every other nations' shipping prospects. Well armed British merchant ships now dwarfed the vessels of all other nations, military or otherwise; in effect, British merchant ships, built in the same private shipyards via the same basic methods as British warships, had become immune to hostile enemy action (Kennedy, 1976, 105; Ashton, 1959, 60).

The stimulating effects of low interest rates, massive military expenditures, and rapid war production were abundantly apparent in the British iron sector during the Seven Years War. The war years mark an epochal transformative moment for the British iron industry; a moment that for all intensive purposes directly precipitated the British infrastructural industrial mode of development shift. To get some sense of the size of military expenditure in relation to the iron sector, the Ordnance Office spent £621,250 per annum during the Seven Years War, while the total worth of output of the entire British pig iron industry can be roughly estimated at £245,000 in 1763 (Hyde, 1973; Harris, 1988; Mitchell and Deane, 1962).[73] On

[73] 35,000 tons of pig iron valued at £7 per ton (Harris, 1988; Hyde 1973).

the outbreak of hostilities, the price of iron moved suddenly upward (Ashton, 1968, 121). With government procurement likely capturing over half of British cast iron output at this time, and perhaps between 20-25% of the overall domestic British iron industry,[74] iron output rose persistently as the war progressed, establishing a 6% or over per annum growth rate; a trend that would later extend well into the 19th century (Harris, 1988; Hyde, 1973; Brown, 1991, 96; Brewer, 1988; Mann, 1986; Flinn, 1958, 44; Brown, 1991, 96; Ashton, 1959, 71). Moreover, despite amplified domestic demand, iron exports moved upwards as well, from 7500 tons in 1754-5 to 8700 tons in 1762-3, an increase of 16% (John, 1955, 332).

As a consequence, numerous new ironworks initiated production during the Seven Years War, and large new furnaces were lit all over Great Britain (Ashton, 1968, 131-2). Rapid growth of the iron sector was most discernible in South Wales, where the industry moved from having trivial presence prior to the war, to becoming one of the major industrial epicenters for iron production (by 1800 South Wales would produce one third of all British pig iron) (Harris, 1988, 54; Brown, 1991, 95). Within these new regions and new iron companies there emerged a momentous transformation in process: The Seven Years War along with Pelham's interest rate conversion were crucial factors propelling the rise of coke smelting throughout the British pig iron industry at this time. Recall that Abraham Darby had first used coked coal to smelt pig iron in 1709, but the process did not widely

[74] See the War of the Austrian Succession section for a discussion of the data supporting these estimates.

catch on until the late 1750s. Well, a number of theories have been proffered to explain this gap; some are still useful, others have been entirely rejected. But none have explicitly incorporated military expenditures and / or the Seven Years War as integral factors explaining the timing of the diffusion. I seek to remedy this strange and surprising oversight.

The first renowned scholar to seriously tackle the question of the mysterious half-century diffusion gap was TS Ashton (1968). Ashton came up with a threefold explanation for the lack of diffusion of coke smelted pig iron production between 1709 and the 1750s: secrecy, the fortuitous purity of coal in Darby's vicinity, and the continued unsuitability of coke-smelted pig for forge work. In later years, the first two theories were rejected, while the third was amended. First, qualitative evidence has been uncovered showing that Darby freely discussed his coke-smelting techniques; he did not even attempt to patent the process. There is just no proof or warrant for the secrecy thesis. Second, many areas in Britain had low sulfur coal deposits similar in nature and accessibility to Darby's; in fact, these coal veins were widely exploited in the latter half of the 18th century (Hyde, 1973; Harris, 1988, 34).

In regards to Ashton's third theory, Hyde (1973) has shown that Darby improved upon his coke-smelting methods, so that by the middle of the 1720s Darby's coke-smelted pig iron was suitable for forge use, but at an additional 30% cost to the forger. Thus forgers continued to use charcoal smelted pig iron. Casters also continued to use charcoal smelted pig iron, primarily because the expense of

converting to coke-smelting outweighed the higher costs of wood fuel. However, in the decade surrounding 1750, and thereafter, the cost of producing charcoal pig iron took a sustained turn upwards while the costs of producing coke-smelted pig iron slowly declined, thus shifting the relative cost curves between coke and charcoal pig iron production, thereby initiating the dispersal of Darby's coke smelting techniques (Church, 1994; Harris, 1988).

Of course then, the question follows, what caused the production costs of charcoal smelted iron to rise? Well the natural answer to that question that theorists quickly settled on was that there must have been major timber shortages around 1750. Even as late as 1990, some researchers hearken to this notion; and some even claim that the increasing use of wood for warship construction caused charcoal to be scarce (Crouzet, 1990, 92; Ashton, 1968b; Hobsbawm, 1968). But this idea is clearly wrongheaded. As Michael Flinn pointed out in 1958, 18th century ironmasters used cordwood, not timber, for their charcoal. Coppices of cordwood were cultivated and planted specifically for the iron industry; cordwood did not compete with timber for use in construction and shipbuilding (Flinn, 1958, 151; Church, 1994; Harris, 1988, 34).

So what then caused the relative production cost curves of charcoal smelted pig iron and coke smelted pig iron to shift in the decade around 1750, a shift which increasingly favored coke as the century progressed? Researchers have settled on a two pronged answer: 1) Coal decreased in price; 2) Iron demand took a sustained turn upwards in the decade and a half or so surrounding 1750. Both of these

assertions are supported by the existing historical data, but the latter is much more so than the former. Coal prices did not rapidly decrease until *after* the iron industry had largely transitioned to coke smelting. In fact, between 1700 and 1770, coal prices exhibited a gently declining slope, for mining improvements were extremely gradual. The more widely cited factor explaining the timing of the diffusion is therefore increased demand; "It seems undeniable that some improvement in demand for iron in the 1750s resulted in a situation where charcoal ironmasters could only meet it with increased costs of production and price of iron" (Harris, 1988, 37). Rising charcoal iron production costs made the switch to coked pig iron production, where input costs were slowly declining, rational. As coke smelting dispersed, techniques improved, as did methods of mining and transporting coal, which in turn caused a sustained shift to coke pig iron production (Hyde, 1973; Harris, 1988; Church, 1994).

This tidy explanation leaves us with one glaring question: What caused demand for charcoal iron to rise in the decade and a half or so surrounding 1750? The answer scholars have contented themselves with up to now seems to me quite unsatisfactory; that the demand came "from an economy beginning to industrialize" (Hyde, 1974, 195; Harris, 1988, Church, 1994). First off, industrial growth doesn't show up in economic aggregates until the 1780s, and then it progresses at an awfully gradual pace (Crafts, 1987; Mokyr, 1993). Developments in iron, especially the switch from charcoal to coke in pig iron production, clearly pre-date industrial growth, and thus it makes more sense to view this momentous

transformation as a cause, not an effect, of industrial change. Researchers have provided no justification, qualitative, quantitative, or even definitional, for claiming that industrial development somehow preceded and therefore caused the mid-century switch from charcoal to coke in the British pig iron industry.

On the other hand, much data can be marshaled to argue that military expenditures both preceded and caused the switch from charcoal to coke in the British pig iron industry; and that the technical, cost, and organizational changes that this switch prompted in turn played a key role in driving subsequent British industrialization. The argument requires that we go back to the evolving iron industry of the War of the Austrian Succession (1739-1748), some thirty to forty years before the official onset of industrial growth. After three decades of little to no growth, demand for domestic iron turned up during the War of the Austrian Succession, moving output levels from around 20,000-25,000 tons to somewhere closer to 30,000 tons (Little, 1976; Harris, 1988, 48-49, 79; Hyde 1973). Hyde (1973: 405), the originator of the demand theory of changing cost curves between charcoal and coke smelted pig iron, asserts that the war torn 1740s were likely the period when relative costs first began to shift. Indeed in the late 1740s the high price of charcoal smelted pig iron caused Parliament to permit duty-free import from the American colonies (Flinn, 1958, 145). Also recall that during the War of the Austrian Succession large military contracts for iron goods drove heavy fixed capital expenditures in the cast iron sector, and that in the post-war period casters, who could not afford to let their new and expensive factories sit idle, successfully

applied their cast iron facilities to the products of peace, thus expanding output. Hence it seems likely that the War of the Austrian Succession initiated a change in the demand and cost curves of charcoal iron that was sustained during the interwar period (John, 1955, 331; Ashton, 1968, 45, 233-235; Brown, 1991; Hyde, 1973; Harris, 1988; Anderson, 1972)

Without even so much as mentioning the incredibly massive war that ignited in the mid 1750s, Hyde (1973: 408) points to that decade as a time when charcoal ironmasters attempted to increase output in response to suddenly increased demand thus further driving up the prices of their inputs. These price increases kicked off a search for productivity enhancing innovations, leading to the dispersal of coke methods of smelting pig iron. As aforementioned, the Ordnance and Naval Offices released a torrent of funds into the British iron sector starting in 1756, or even a bit before, as hostilities got underway. Not surprisingly, pig iron prices increased suddenly and sharply in the mid to late 1750s, even as output was expanding (Ashton, 1968, 121; Hyde, 1973; Harris, 1988). Surely then the demands of the Seven Years War were integral to rising production costs for charcoal smelted pig iron in the 1750s. This in fact is evidenced by the pattern of coke furnace construction. Between 1750 and 1755 only three new coke furnaces were installed (Hyde, 1973, 408; Kennedy, 1976; Pritchard, 1987); but from 1755 to 1765, the number increased to 14, a gain of 367% (Hyde, 1973, 408). This 367% rise in the number of coke furnaces installed was likely a direct consequence of defense procurement during the Seven Years War, for each of the new furnaces

was lit in the works of a major military ordnance contractor (Ashton, 1968; Harris, 1988, 34-37; Hyde, 1973). But before these contractors are reviewed, I'd like to make some other points that have also been left out of causal discussions relating to the momentous shift from charcoal to coke in pig iron production; these too involve military expenditure.

First, as alluded to above, ironmasters in the middle 18th century not only took into account the relative cost of producing coked pig iron as compared with charcoal pig iron, but they also had to calculate the capital expenses involved in making the transition. New coke powered furnaces were quite large and expensive, costing upwards of £1000 (Hyde, 1973, 415). In order to accumulate the necessary capital, ironmasters would have needed to enter into the matrix of circulating credit based on public deficit finance. There they could finance all of their everyday costs, even as those costs were increasing as an effect of expanding output, thus freeing their own accruing capital and profits for augmented fixed capital expenditure. As discussed previously, Pelham's reduction of interest on the national debt meant that circulating credit could be obtained more cheaply, hence liberating extra ironmaster resources for fixed capital investment. Thus it seems to be less coincidence, indeed more causal than coincidence, that Pelham's reduction temporally correlates with the transition from charcoal to coke pig iron production in Britain. Moreover, competitive bidding for large, long-term, and highly profitable standing military contracts provided, in the 1750s and 1760s, a clear profit incentive to increased capital expenditure which would allow for expanded

output at cheaper prices. One must further consider the fact that cast iron producers did not need to take into account the extra 30% or so costs of working coked pig iron into a form suitable for forge use; they only had to weigh the capital costs of converting to coked-pig vs. the cost of continued charcoal pig utilization.[75] Thus it is not surprising that the major casters, who were also the foremost military contractors, increasingly switched to coked-pig production and utilization as the Seven Years War progressed. Not only was demand soaring, but charcoal production costs were rising while circulating credit and coal costs were declining, thus combining to make the Seven Years War an ideal era for widespread conversion to coke-smelting amongst contractors (Brown, 1991, 95; Harris, 1988, 38; Hyde, 1973; Anderson, 1972; Ashton, 1968; Deane, 1965).

Now let's review the key ironmasters and iron firms that led the switch to coke powered pig iron production in the 1750s and 1760s; for they were all, as would be expected, primarily occupied with military contracting during these years. First there was Dowlais, started in 1759 by Willey and Company, with a capital of £4000. Dowlais was a major ordnance and naval contract caster from its inception. Dowlais, which after the War of American Independence (1776-1783) came to be valued at over £20,000, played a crucial role in British industrial development (Ashton, 1968, 132; Hyde, 1973, 415). Then of course there was John Wilkinson,

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[75] As noted in the War of the Spanish Succession chapter, which covered Darby's initial discovery, coked pig, for all intensive purposes, was directly usable for casting at foundries. As alluded to above, in order for coked pig to be usable at the forge, it required some extra effort, thus raising costs for forgers by 30% or so. It should further be noted that at this time wood fuel was still required for the final stage of forge wrought iron production (Hyde, 1973; Harris, 1988).

who after dabbling in research and development over the course of the War of the Austrian Succession, reconstituted his ironworks to utilize coke at the height of the Seven Years War. His New Bersham ironworks had a corporate charter proclaiming the 'casting of guns and cannon' as the company's chief purpose. From its first days the New Bersham Company was busy making coke-smelted grenades, shell, and cannon. There are existing records of immense cannon shipments from New Bersham to the Ordnance Board in the 1760s, and heavy amounts of cannon were sent from New Bersham to the East India Company, whose merchantmen often fought along side the Navy. In succeeding decades, New Bersham Company would go onto become one of the leading iron producers in the world. Indeed the British Industrial Revolution came to depend on innovations that would soon emanate from New Bersham (Ashton, 1968, 45-6). The already famous Coalbrookdale also rapidly expanded during the Seven Years War, adding a number of new and larger coke furnaces as a consequence of its enlarged contracting responsibilities. The same can be said of the Walker Brother's Masbrough Company, which remained a premier naval ordnance contractor during the Seven Years War (Ashton, 1968; Harris, 1988). Let's not forget John Roebuck's legendary Carron Company: "Carron Ironworks was portent of a new type of undertaking; and the lighting of its first (coke) furnace, on Boxing Day, 1760, may serve to mark, for those who like to be precise in such matters, the beginning of the Industrial Revolution" (Ashton, 1968b, 54). Carron's initial capital outlay for coke furnace construction was £12,000 (Hyde, 1973, 415). After

its establishment in 1760 Carron Company owed anywhere from half to two-thirds of its sales to government contracts for cannon and shot (Brown, 1991, 94; Lavery, 1987, 104). Carron quickly became the 'greatest arsenal in the country', perhaps the world (Ashton, 1968, 36-7).[76] The war also stimulated demand for Carron's iron ballast, which was universally used in the Navy, and also in many merchant ships (Ashton, 1968b; Ashton, 1968, 52, 132). Carron was thus a major market mover in the private sector as well. For example, in 1760 a cast iron blowing cylinder which allowed for superior coke-powered furnaces was innovated at Carron; this invention soon affected the cast iron market in all its aspects (Landes, 1969, 89). Finally there was Cyfarthfa, which was incorporated immediately after the war, but was capitalized by Anthony Bacon, a noted naval iron contractor during the Seven Years War. Cyfarthfa cast naval and other types of iron utilizing coked pig, and also produced wrought iron for the Navy. Cyfarthfa would in fact come to be one of the preeminent naval defense contracting companies during the War of the American Independence (1776-1783), and was also the site of a tremendously important 1780s innovation crucial to subsequent British industrialization (to be discussed later) (Hyde, 1973, 415). In summation, 27 new coke furnaces were lit between 1750 and 1771, and the overwhelming majority of these were grouped together at known military ordnance contractors

[76] Notably, Carron Company introduced the 'carronade' – a short, light, but extremely powerful cannon. By the end of the American War, Roebuck's carronades were famous throughout Europe, and carronade had become a synonym for cannon.

(Harris, 1988, 34-37).[77]

The Seven Years War, and the huge contracts it inspired, not only propelled the transition from charcoal to coke in the wildly expanding cast iron industry, but it also inaugurated an incredibly important organizational change to the nature of British production; the vertically integrated factory reaping benefits from economies of scale emerged in the iron defense contracting sector during the Seven Years War. As stated previously, the outsized producer that could reap benefits from economies of scale was favored in the competition for standing military contracts. Not surprisingly then, all of the coke powered ordnance contractors listed above built ironworks with tremendous size, capacity, and fixed capital. Each used Newcomens and mammoth cast iron waterwheels powering cast iron blowing cylinders connected to immense furnaces. These market-based military contractors cast parts for these heavy capital intensive goods along with, increasingly, other heavy wares for the private sector as well (Deane, 1965, 109; Pollard, 1994; Landes, 1969, 89-93).

Still, the private market alone could not at this time provide a continuous and guaranteed stream of profits for iron casters like military contracting could. Hence, the competition for growing naval and ordnance contracts escalated in lockstep with the size and capital intensity of the contractors. Ironmasters were

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[77] 'Everywhere in these years the forge men were falling back before the steady march of the casters: in every iron producing area the production of war material was bringing large scale armament firms into being.' Coalbrookdale, Masbrough, Dowlais, New Bersham, Carron, Cyfarthfa and others became schools of instruction in the art of coke powered smelting and casting, "and each of them gave birth to a lusty progeny bearing a close likeness to the parent firm" (Ashton, 1968, 53).

engaged in a battle to reduce costs and amplify output in order to secure the standing defense contracts that covered their rising costs and insured a minimum level of regular profit. Over the course of the war, the need for better and cheaper transport and inputs became paramount to this struggle. Soon iron firms were reaching back into raw materials production and forward into shipping, buying and developing their own coalmines and shipping lines; Coalbrookdale, Carron, New Bersham, Dowlais, and Cyfarthfa, amongst others, all began to expand firm operations backwards into raw resource production and forwards into transport during the 1760s. Some, such as Carron and New Bersham, even sought to control credit costs by attaching banking houses to their firms (Harris, 1988, 56; Ashton, 1968; Rule, 1992; Brown, 1991; Deane, 1965; Hyde, 1973, 411-413). It was the dawn of the vertically integrated industrial firm; and the vertically integrated firm would soon become the hallmark of industrialism the world over (Chandler, 1977; Harvey, 1990).

As Anderson (1972:16) cogently points out 'economic factors were such that the establishment of large integrated iron firms was facilitated, perhaps permitted, only when war inflated demand conditions prevailed.' But once such vertically integrated firms were created, they perpetuated themselves. Sunk and circulating costs were tremendous; production had to be expanded regardless of current demand. If demand was low, then raw material, transport, labor, and credit costs had to be rationalized; for lower prices would bring increased market share. Or alternatively, cast iron had to be applied to ever widening sectors of economic

production. A self-sustaining positive economic feedback loop initiated in the War of the Austrian Succession and strengthened during the Seven Years War now began to reverberate throughout the entire British iron industry and economy (Deane, 1965; Ashton, 1968; Harris, 1988).

To be sure then, lower interest rates stimulated by Pelham's conversion when combined with massive military expenditure and war production in an environment of low inflation largely accounts for the astounding transformation of the British iron sector that obtained during the Seven Years War. Similar could be said of British transport infrastructure. As discussed, in the early 1750s there began a sustained upward swing in the number of privately financed public works initiated in Britain.[78] In the 1750s investment in public works such as turnpikes and canals on average returned 5% per annum and sometimes far more (Rule, 1992, 244; Crouzet, 1990, 165). With government debt returning a relatively disappointing 3% per annum between 1750 and 1758 (a result of Pelham's mid-century conversion) there emerged the first public works boom in Britain (Rule, 1992; Brown, 1991; Ashton, 1968; Deane, 1965; Pressnell, 1960, 169).

By 1756, conditions of easy money combined with a blistering economy, intense wartime optimism, and heavy military expenditures, to send the British public works / capital goods boom into the stratosphere:

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[78] Britain had an interesting and rather unique market-based method of raising capital for public works. In fact, the public government was barely involved at all. Parliament would legislate the formation of trust companies, but the trusts were entirely private. Once they came into being, they raised capital by offering stock on the London exchange, used the capital to build the public work, charged users of the finished public good through the application of tolls and the like, and then returned dividends to their shareholders.

> "Perhaps because the success of British arms went to men's heads, grandiose schemes were concerted for the exploitation of far parts of the earth... It was in these conditions of easy money that there occurred what was probably the biggest building boom of the century, fed, as the figures show, by a rapid expansion in the import and output of materials" (Ashton, 1959, 99).

Newspapers of the time commented profusely on the building boom. Between 1758 and 1761 figures for the production of glass were greater than any previously recorded, pointing to a brisk pace of construction. There were big developments in 'Town Planning' throughout Britain, and Parliament was hard pressed to pass new building regulations. Turnpike construction occurred at a rapid pace and new highways were being constructed everywhere; in the latter half of the 1750s Parliament incorporated nearly 50 new turnpike trusts per year. New bodies of private commissioners were set up by acts of Parliament to institute paving and better lighting, especially in Westminster and London. In 1760 an act was obtained for widening and improving the streets of London, in 1761 an act was passed to improve the London Bridge, and bridges at Blackfairs and Chelsea were authorized (Little, 1976, 90; Ashton, 1959, 97; 149-150; Landes, 1969, 64).

The enhancements to British waterways during the Seven Years War were even more remarkable. Private parties sponsored a spate of river improvement acts throughout the war years (Little, 1976). And suddenly canals began to enter the picture. Canals were perhaps one of the most potent British technologies of the time, and this ability to bring waterways to where they were needed was initiated during the Seven Years War (Rule, 1992, 239). The Duke of Bridgewater's famous

improvements to Worsley Brook were completed in 1759, at the height of the war. The second British canal, at Sankey, was started in 1755 and completed in 1760. And there are numerous other examples of river improvements and canal constructions initiated during the war years. Indeed, by 1772 Britain had secured a linking of the major English river systems. It should also be mentioned that cast iron played some role in 1760s canal, aqueduct, tunnel, turnpike and highway construction (Little, 1976, 87; Rule, 1992, 232-239; Brown, 1991).

There can be little doubt that preparation for capital intensive war helped to drive the 1750s-1760s public works boom in Britain. The largest batches of ships, cannon, and stores the world had ever seen were being produced throughout Britain at the time of the Seven Years War, and these shipments had to be transported to the Navy and Naval Dockyards, thus increasing the likelihood of profit for privately owned and financed turnpike, canal, and river trusts. As merchant builders built ever larger warships, they sought improvements to local harbors and highways. For example, the considerable number of road improvements in Kent during the interval 1756-1758 coincides exactly with the extensive building of men-of-war by privately owned shipyards in these years (John, 1955, 334). Additionally, as iron contractors reached back into raw materials production, they became main shareholders and organizers of public work trusts. Abraham Darby III and John Wilkinson were noted trustees in various Shropshire turnpike trusts. Richard Reynolds, who took over as master caster at Coalbrookdale c.1760, organized the float leading to the Shropshire canal. Staffordshire, a major site of

cast iron production, became a central hub in the British canal system (Brown, 1991, 132-136; Rule, 1992, 234). Indeed, according to Deane (1965: 79), it was the need to move iron ore and coal to the casters in the industrial midlands that spurred the 1760s British canal boom. This point is echoed by later researchers: "Canals linked the main industrial regions, back to their sources of supply and forward to their outlets"; growth in industrial coal use, mostly for iron, was both cause and consequence of the rise of the canals (Rule, 1992, 231-238; Brown, 1991, 99; Little, 1976). And as mentioned in chapter 2: Of 52 acts for inland waterway improvement passed by 1774, 33 were in the Midlands and north and a further five in the Scottish lowlands, which were the budding industrial epicenters of iron production, and, of course, home to numerous iron defense contractors (Rule, 1992, 231-232; Brown, 1991, 99; 136; Ashton, 1968).

The notion that military procurement helped shift effective demand in favor of capital goods in mid-18th century Britain is thus quite evident during the years of the Seven Years War. Driven by contracting, heavy capital goods intensive cast iron production became the most dynamic, growing, vertically integrating, and influential sector of the British economy; and investment in public infrastructure in and around iron and naval defense contractors suddenly returned outstanding profit. Moreover, the 1750s and 1760s capital goods / infrastructural boom seems to have permanently changed the structure of the British economy. As Ashton (1968b: 115) aptly expressed "after 1760 a larger proportion of the labor force of Britain came to be employed in constructing roads, canals, harbors, ships, factories and

machines, and a smaller proportion in producing food and drink, boots and clothes, furniture and houses." In fact, by the middle 1760s, investment in public works and capital goods had become so profitable and popular, that the nation as a whole became quite reticent to turn away from capital goods / infrastructural investments; the boom continued right through to the War of American Independence when interest rates on public debt suddenly shot up above average rates of return on public trust investments; but more on that later. At the end of 1763, peace was ensuing and long rates stood just under 4%, with canal, turnpike, highway, and harbor construction proceeding apace (Rule, 1992, 234; Ashton, 1959, 61; 1997, 48).

But what of the now heavily capitalized cast iron industry, how did it fair in the postwar years? Naturally, these were anxious years for ironmasters. With the exit of the Ordnance and Naval Offices from the market, iron contractors found themselves saddled with high fixed capital costs along with extreme output capacity in the face of declining demand; not an auspicious situation. But, as the 'military expenditure impetus to mode of development shifts theory' would predict, some auspicious innovations developed from this inauspicious moment. As one ironmonger of the time, Josiah Tucker, put it, "Almost every Master-Manufacturer hath a new invention of his own, and is daily improving on those of others" (Little, 1976, 71). Cast iron began to be used as tubing in mining shafts, thus allowing for greater depths of coal mines during the interwar period. Importantly, the use of iron rails for transport was innovated at Coalbrookdale in 1767, as a direct result of

the post war collapse in iron demand. With more cast iron than he knew what to do with, Reynolds decided to link Coalbrookdale's ironworks to the Severn by cast iron tracks furnished with flanges to hold wagon wheels in line.[79] This innovation caught on and dispersed like wildfire in the blossoming capital goods intensive sectors of the British economy; especially in mining where transport was a perennial problem. Indeed, between 1768 and 1771 800 tons of rails were cast at Coalbrookdale alone, and with this activity went the casting of iron wagons and axle-trees. By the early 1770s multiple hundred ton orders for rails, wagons, and axles were piling up (Ashton, 1968b, 53). A proto-railroad infrastructure was taking shape in increasingly industrial Britain. All that remained to complete the picture was the development of the steam engine.

Here too, the interwar years provided fertile ground for research and development. In 1765 James Watt finished a beta version of his steam engine. "Until the sixties of the 18th century Newcomen's engine remained a contrivance for the useful but limited purpose of pumping water." The engine lost too much energy for it to power manufacturing equipment efficiently. James Watt realized

> "that the chief defect of the atmospheric engine arose from the alternate injection and condensation of steam: in order to keep the steam from condensing before the piston had completed its upward stroke, it was necessary to keep the cylinder warm; but, equally, in order to condense the steam for the return stroke, it was necessary for it to be cold. The sudden changes in the temperature of the cylinder wall meant that a great amount of potential energy ran to waste" (Ashton, 1968b, 56).

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[79] "The price of pigs became very cheap after the Seven Years War. Darby's works were so great, that in order to keep the furnaces on, they thought it was best to stock the pigs in a new way. Lay it on the wooden railways, as it would help pay the interest by reducing the repairs of the rails. If iron suddenly rose in price, they could always take it up again" (John, 1955, 332; Ashton, 1968b, 134).

There needed to be a separate chamber for condensing 'which could be kept permanently cool, while the cylinder could be kept permanently hot.' The steam engine that emerged in 1765 from this realization was hardly commercially applicable, it was large and the cast iron pieces did not fit together well; the engine shook uncontrollably and a tremendous amount of energy still ran to waste. Clearly more research and development was required (Ashton, 1968).

Watt however needed capital to continue his R&D, for by the year 1767 he had contracted debts worth over £1000. John Roebuck, founder of the famous defense contracting Carron Company, fat with profits from the Seven Years War, aided the soon to be great industrial pioneer. In return for the payment of Watt's debts, and the provision of the capital necessary to complete the invention, Roebuck obtained the right to two-thirds of the prospective profits of the steam engine. Also, in the late 1760s, Roebuck took a shine to Matthew Boulton and his company; Boulton had started Soho Ironworks in 1765, not a particularly propitious moment to start a large iron enterprise. In attempting to initiate a failed partnership, Roebuck became indebted to Boulton to the tune of about £1000. Rather than pay the debt, Roebuck, who was looking toward retirement, opted to transfer his share of Watt's steam engine patents to Boulton; the famed partnership had begun. In 1774 Boulton and Watt set up shop next to Boulton's Soho Ironworks in Birmingham; the partners intended to cast a commercially viable steam engine capable of powering rotary motion (Ashton, 1968b, 56; Ashton, 1968,

61-62; Rule, 1992, 122; 167)

The first order of business was getting the various cast parts of the steam engine to fit each other snuggly. Boulton and Watt turned to the master caster and defense contractor Darby III at Coalbrookdale for a solution, but the boring machines at Coalbrookdale were simply not precise enough for the task. Indeed, the leading canal and transport engineer of the day, John Smeaton, "predicted that Watt would not be able to build his engine because it required more accuracy than the techniques of the day permitted" (Landes, 1969, 103). Smeaton, however, had underestimated the fecund talents of the great researcher, developer, and cannon maker, John Wilkinson. Wilkinson spent countless hours during and after the Seven Years War working on a novel cannon boring machine that would accurately ream solid-cast cannon in a standardized fashion. Wilkinson realized that such a lathe would not only assure naval contracts galore; with minimal adjustments, it could also usher in an age of precisely cast and bored iron machinery. With the 1774 advent of Wilkinson's 'cannon lathe' a new era had commenced. In 1775, one year before the Declaration of American Independence, and ten years after the initial beta version, Watt patented a commercially viable steam engine with a separate chamber for condensing by using parts bored on a modified Wilkinson cannon lathe. In turn, Wilkinson increased the efficiency of his boring machine by using Watt's improved steam engine to power it; the progressively complex economic feedback loop leading towards British industrialization was gathering steam (Mokyr, 1993, 56; Forward, 1924, 36; Musson and Robinson, 1969, 445;

Tann, 1974, 84; Mann, 1993, 95).

Notably, the iron industry wasn't the only sector stimulated to innovation during the interwar years. For the first time patent counts clearly indicate a postwar boon to invention; thus providing quantitative evidence backing the theory outlined in chapter one – that mode of development shifts occur in the intervals of peace following years of intense conflict as human and productive capital, enhanced during hostilities owing to extreme military expenditure, are released back into the commercial economy. Before the mid 1760s the number of patents granted in any certain year rarely exceeded 12, but in 1766 grants rose abruptly to 36, a three fold gain (Mitchell and Deane, 1962); "The decisive break in the patent series comes in the 1760s when for the first time there are over 200 in a decade" (Deane, 1965, 135; Brown, 1991, 83). The British economy had indeed transmogrified over the course of the Seven Years War; whereas economic growth had been largely based on commercial trade in everyday consumables before the war, growth increasingly came to stem from innovations and developments in patentable capital goods production after the war (Deane, 1965; Ashton, 1968b; Rule, 1992).

Keep in mind that the Seven Years War was the first major conflict to occur after the completion of the English Financial Revolution, and it is during this war that the operation of 'the military expenditure impetus to mode of development shifts theory' is most evident. Britain accrued massive accumulations of capital on domestic and international capital markets. As the war progressed this capital was unleashed into the British economy via the defense department – capitalistic

contractor synergy previously described. The domestic consequences were simply profound; the international effects were perhaps even more so. Britain emerged from the 1763 Peace of Paris with France expelled from Canada and Nova Scotia, and Spain excluded from West Florida. Britain now had near total control of the North American continent. France had suffered a series of humiliating defeats in India at the hands of the British military. Britain's dominance in the Mediterranean was also strengthened, while Senegal was taken to increase its presence in West Africa, and four major islands were acquired in the West Indies. Britain fortified and expanded its global empire while thwarting all of the hostile ambitions of its enemies; it is hard to express the enormity of Britain's military triumph during the Seven Years War (Kennedy, 1976, 107).

And now Britain's incipient industrial mode of development shift in feedback loop fashion began reverberating throughout its worldwide empire: Cheap raw materials were fed into Britain's increasingly capital intensive domestic infrastructure. There they were processed and products were manufactured by quicker, cheaper, and more efficient means. Large batches of finished goods were then spit back out to the British Empire, and the resultant profits were then fed back into the domestic infrastructure, thereby increasing its capital intensive efficiency. Boosted by military expenditures during the Seven Years War, crucial dynamic and infrastructural aspects of the British economy had become qualitatively industrial. Soon the rest of the domestic and global economy would be drawn into the intensifying British industrial feedback loop, thus propelling Britain to sustained

quantitatively significant macroeconomic industrial growth (Kennedy, 1976; Deane, 1965; Mokyr, 1993).

CHAPTER 7: THE WAR OF AMERICAN INDEPENDENCE – 1775-1784

The War of American Independence marks the only British defeat of the 18th century (Kennedy, 1976, 97). Ironically, British victory or defeat has little direct bearing on the object of interest in this study; how victory or defeat affected the burgeoning defense propelled industrial mode of development shift of course does. Given that the British Isles remained untouched during the war, one might expect that the domestic centered defense driven feedback mechanisms facilitating British industrialization continued to progress during the war; which, for the most part, they did. Nonetheless, Britain was defeated (at least temporarily). This war was different from other 18th century wars in some significant respects. First, other nations viewed it as a kind of fratricidal civil war. More importantly, Britain was diplomatically isolated during the war. The daunting victories of the Seven Years War had left Britain with few noteworthy allies; Britain was now an undisputed hegemonic power with wary nations seeking to reestablish strategic balance (Brewer, 1988, 176; Kennedy, 1976).

The main reason that Britain lost the American War, however, was that France shifted tactics. In a 'defeat Britain or bust' sort of move (as we shall see later, both occurred), France channeled colossal resources into its navy while avoiding expensive and diversionary continental warfare (Brewer, 1988, 177). With a much enlarged and empowered navy, France was more easily able to disrupt British supply lines, which had grown somewhat unwieldy given the massive gains

Britain had achieved during the Seven Years War. There was also for the first time an extremely hostile colonial population in Britain's main theatre of war. In the end the colonies were politically lost. However, they were immediately reincorporated into the British dominated Atlantic trading system. The war therefore cannot be said to have greatly diminished the prospects for enduring economic development in Britain, which, as we have seen, was now becoming industrial in nature (Brewer, 1988, 177-8).

Nonetheless, an alteration in the mechanisms of interaction between conflict and emerging industrial production in Britain did surface during the War of the American Independence. In the words of Paul Kennedy (1976: 98), "The country by (1775) was well into the first stages of an industrial revolution which would enable it to outdistance all other rivals" (Kennedy, 1976, 98; Mathias and O'Brien, 1976, 607; Mokyr, 1993). Prior to the Seven Years War such an assertion would not hold. But with the intense modifications to British iron manufacturing and transport infrastructure that occurred during and after the Seven Years War, British industrialism was by 1775 taking on a life and pace of its own; one separate from, albeit still linked to war. Over the course of the American War, trade in industrial goods such as steam engines, cast iron rails, and iron machines, continued to grow, but now less and less had any direct, or even indirect, connection to defense procurement. To be sure, a good deal of capital goods production and development were still war related, but ever more was not. To a crucial degree then, by the end of the American War, the positive economic feedback loop propelling British

industrialization could proceed apace with no hostilities and little if any military spending. In fact, as will be shown below, military expenditures during the War of American Independence for the first time may have disrupted the growth potential of the newly industrializing British economy. The economic slack that had allowed for extreme military expenditure without the detrimental crowding out effects of heightened interest rates and inflation had been driven from the economy in the revolutionarily developmental years preceding the Declaration of American Independence (Ashton, 1959; Deane, 1965). Industrialism was ripening, and in doing so, war now affected it differently. To put it somewhat succinctly: where once market disruptions in effective demand brought on by intense procurement had led to a search for new financial, technical, and infrastructural innovations, all to the benefit of the burgeoning mode of development shift; now trade disruptions, inflation, and higher interest rates began to interfere with the enhanced pace of accumulation made possible by the manifesting industrial mode of development. This new dynamic will now be explored as we conclude the British Case with the War of American Independence.

WAR OF AMERICAN INDEPENDENCE EXPENDITURE OVERVIEW:

Aggregate state expenditure averaged £20,272,700 per annum during the War of American Independence, totaling £202.7 million over the course of the war. Thus between the Seven Years War and the War of the American Independence per annum public expenditure rose 28% while the total cost of the American War was

some 60% higher than the aggregate costs of the Seven Years War in nominal terms (inflation was a problem during this war).[80] Tax revenue yielded £12.2 million per annum on average during the American War; some 41% higher than average per annum tax revenue during the Seven Years War. But this still left Britain with an £8,118,500 per annum deficit, which was 40% of revenue, although nominally only 9% higher than the annual deficit that obtained during the Seven Years War. Obviously tax revenues were improving along with the expanding British economy at this time, thus shrinking the rate of growth of the deficit. Nonetheless public deficit finance was again crucial to meet the deficit gap occasioned by military expenditure, pushing the British national debt from £127 million in 1775 to £242 million in 1784, an impressive gain of 91% to a cumulative total some 83% higher than the national debt figure that had obtained at the end of the Seven Years War (Brewer, 1988, 89, 30; Mann, 1986, 485; Mitchell and Deane, 1962).

As might be expected, military spending during the American War was not small in terms of the overall British economy. In the year 1780[81] military expenditures totaled £19.79 million, which was approximately 12.5% of total national income; while exports totaled £12.3 million; some 38% less than military expenditure. Meanwhile, total private investment expenditure in the economy was still less than half of military expenditure (roughly £8.86 million in 1780); and

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[80] Civil expenditures still accounted for an awfully small percentage of total state expenditure; around 5% in the year 1780 (Mitchell and Deane, 1962, 390; Brewer, 1988, 30; Mann, 1986, 485).
[81] Five year average centered on 1780.

although private investment expenditure prior to the war had been lower than it was during the war (approximately £6.71 million in 1770), other statistical data do indicate crowding out in the latter half of the war, as interest rates on the national debt soared and inflation was enduringly stoked (O'Brien, 1991, 34-5; Mann, 1986, 485; Ashton, 1959; Brewer, 1988, 41; Williamson, 1984).[82]

THE STRUCTURE OF TAXATION DURING THE WAR OF AMERICAN INDEPENDENCE:

Sardonically, Britain met the costs of a war about poor tax collection in its colonies by intensifying its increasingly burdensome and yet highly efficient indirect tax collection system at home. Excise receipts totaled £5.7 million per annum over the course of the American War; a figure some 39% higher than that which obtained during the Seven Years War, allowing excises to account for 47% of total tax revenue. Returns in customs revenue modestly improved as compared with the prior war, now bringing in an average £2.7 million per annum, or 22% of total revenue (Mathias, 1979, 287; Deane and Mitchell, 1962, 388). Land tax revenue yielded an average £2.4 million per annum during this war, hence accounting for around 20% of total revenue, down from 26% during the last war (Mathias, 1979, 288). Additionally, investment in debt, stock, and fixed capital remained untaxed during the hostilities, and the state still avoided taxing those

[82] Williamson (1984: 696) has calculated an interesting figure estimating that in Britain net additions to war debt were 6.5% of national income in the 1780s. America achieved a 3.7% rate from 1980-1982 "when crowding out and capital scarcity began to attract attention."

manufacturing sectors most germane to war efforts (Rule, 1992, 284-5; Deane, 1975, 95; Ashton, 1959; 1968).

Thus during the American war, the regressive redistributive incidence structure supportive of defense-inspired economic transformation remained in place in Britain; but after the war this rapidly changed as a rudimentary form of direct income tax known as the 'assessed taxes' was put in place. Wealth was rocketing in Britain, but so were charges on the national debt, and the First Lord Treasurer, William Pitt, decided to go after that new wealth directly in order to reduce the national debt and its charges. Therefore, after the American war, it can be said that a major pillar of the 'military expenditure impetus to mode of development shifts theory' in Britain was progressively eroded (Mathias and O'Brien, 1976; Rule, 1992, 284-5; Deane, 1975, 95).

PUBLIC DEFICIT FINANCE DURING THE WAR OF AMERICAN INDEPENDENCE:

Although in procedure little had changed in public deficit finance between the end of the Seven Years War and the onset of the American War, British capital markets did not shoulder the increasing burden of debt imposed by the American War as well as they had previously. Interest charges on the national debt rapidly climbed, moving from approximately 4% before the war to almost as high as 7% after the war. Such high interest on long rates precluded private borrowing at the legal 5% level while also drawing capital away from investments that may have returned substantially less; economic growth at the aggregate level did slow as a

consequence (Schumpeter, 1938, 28; Ashton, 1959).

There are two main reasons for the rapid rise in interest rates during the War of American Independence. As previously mentioned, the slack had gone out of the British economy. Savings and resources which had been underutilized in previous wars and were therefore available to fund deficit expenditures were now being employed in the developing and dynamic business sectors of the British economy; sectors such as iron, transport, and increasingly cotton textile manufacture (Williamson, 1984; Mokyr, 1993; Ashton, 1959). Additionally, in the two previous wars, foreign capital had flowed into the British debt system at escalating rates thus keeping interest on the national debt down and freeing up domestic capital for investment in the transforming sectors of the British economy. Not so during this war; after Holland entered the fray in 1781, new debt came to be held mainly by British nationals. Although the rapid repatriation of Dutch capital did, in the long-run, hasten the transition to London as the global financial center for international loans, it also helped to dampen domestic investment in the dynamic commercial sectors of the British economy (Ashton, 1968b, 6, 86-7; Dickson, 1967; Deane, 1965; Pressnell, 1960, 172).

Moreover, and not unconnectedly, inflation picked up significantly during this war. Inflation can be extremely damaging to an economy if it causes inhibitions to investment and consumption due to 1) uncertainty, 2) the high cost of money, 3) the high cost of producer goods, or 4) the high cost of consumer goods. Because of the lack of slack in the British economy amidst heavy debt-financed

defense expenditure, along with the uncertainty accompanying the imperiled war effort, all four of these negatives cropped up during the early 1780s. Also, as a consequence of war born fiscal pressures, the Bank unwittingly stoked inflation with some of its debt policies: The Bank was allowing investors to fund their long-term consol purchases with short term credit instruments issued by the Bank itself. Additionally, it was practice at this time to use government securities as collateral for loans at local banks; and with the onset of modern style economic development, local banks were multiplying in number. Meanwhile, augmented amounts of domestically circulating government debt securities were allowing local banks to extend their loan operations, thus rapidly expanding the money supply (Schumpeter, 1938, 31; Pressnell, 1960).

In other words, what we see happening to Britain during the American War is a pattern more typical to a modern day economy operating at full capacity and financing military expenditures at rates equal to some 12% of national income; the consequence is bound to be higher interest charges, increased inflation, and sub-par growth in certain sectors of the economy (Williamson, 1986; Buchanan and Wagner, 1967). Nonetheless, as will be shown below, war industries, such as iron, were still profiting and transmogrifying as public deficit expenditures were directed to them; thus demonstrating that crowding out is not necessarily bad for economic development over the long run if public expenditures devolve to capitalists in dynamic leading sectors of the economy who choose to use the funds to fundamentally enhance capital infrastructure.

Still, when peace was finally signed in 1784, Britain was smarting – economically, politically, and militaristically. As normal trading patterns resumed, Pitt was able to consolidate most of the high yield credit stemming from the later war years into a funded 5% stock (Rule, 1992, 284-5). Notice this rate is some 40% above the 3% rate that Pelham was able to consolidate to thirty years earlier. Yet another sign that the British miracle epoch, wherein military expenditure multiplied as interest rates imploded, had come to a definitive close.

DEFENSE CONTRACTING DURING THE WAR OF AMERICAN INDEPENDENCE:

In form and procedure both naval and ordnance contracting remained the same as it had in previous wars, with advertisements in national and local papers (now there were many more papers than the Gazette, and the Boards utilized all of them), leading to a haggling process. There was again an increased reliance on standing contracts. Most importantly, the circle of market-based military contractors continued to widen for both the Navy and the Ordnance Office during the war, with the Navy contracting ships to private builders in 16 new towns scattered throughout Britain and many new ordnance casters lighting furnaces, in South Wales especially (Pool, 1966, 91; Ashton, 1968).

The general difficulties of public deficit finance were mirrored in the payment of naval contractors during the War of American Independence. The Naval Office spent £5.7 million per annum, some 21% more annually than what it spent during the Seven Years War (Mitchell and Deane, 1962, 390-391). By

January 1779 the discount on naval bills had reached 11.5%, and never decreased to below 10% for the rest of the war (Pressnell, 1960, 172-173). In 1783, the last year of the war, naval debt reached as high as £13 million, giving rise to a discount rate of 21% on naval bills; levels not witnessed since the early 18th century (Pool, 1966, 108). This then is yet another indicator of the undue economic burden imposed by procurement during the American War; a burden which had not at all materialized in the previous two wars when military expenditures unambiguously contributed to an industrial mode of development shift.

The Ordnance Office, on the other hand, was, surprisingly, readily able to pay on its bills regularly throughout the American War. Thus ordnance bills continued to pass as cash, even though over the course of the war the Ordnance Office spent £1.03 million per annum, a considerable 66% gain from the levels witnessed during the Seven Years War (Mitchell and Deane, 1962). Certainly this enhanced secure expenditure contributed to sustained economic transformation in the iron sector during the American War, as will be detailed precisely below. For now, suffice it to say, that in the year 1783 approximately 3,418 cannon were made for the Navy.[83] This would have been an impossible task in the 1740s and 1750s when an output of 700 cannon per annum was considered brisk (Pool, 1966, 79-80; Lavery, 1987). The Seven Years War had radically changed the productive capacity of the British cast iron industry, and its development continued through

[83] In 1783 the new construction program for the Dockyards included three 100 gun ships, six 98s and five 74s. Adding these to the number of cannon built for the 30 ships contracted out to the merchant yards in 1783 brings the total number of artillery cannons made for the Navy (all by contract) in the year 1783 to 3,418 (Pool, 1966, 91).

the American War. By the late 18th century what had once been a lagging and deficient sector had been transmogrified by military expenditure into the premier casting industry in the world and the epicenter of a technological revolution of incalculable historical consequence (Deane, 1965; Hobsbawm, 1968).

THE MATURING INDUSTRIAL REVOLUTION AND MILITARY EXPENDITURE:

As the British nation initially geared up for war, all appeared well with the flourishing domestic economy (Ashton, 1959, 131; 161-2). By 1778 however, three years deep into the war, long rates were already moving past 5% (Ashton, 1959, 105). Tellingly, such high rates, which were effectively communicated throughout the British economy (as previously described), brought the mid 18th century capital goods boom to a screeching halt. Construction rates of all sorts rapidly declined (Ashton, 1968b, 119). Interestingly, this strongly suggests that Pelham's conversion down to 3% on the national debt did release capital into the private sector looking for long-term returns around 4-5%, as formerly discussed; for when returns on long dated government paper reached a level above the approximate average rate of profit on long-term private sector projects (4-5% at this time), we see capital begin to flow out of the private sector. It is the same process described in the section on Pelham's conversion, but now in reverse (Pressnell, 1960, 177; Deane, 1965, 78; Dickson, 1967).

Furthermore, after 1778 the Bank's cash ratio fell, with note issues and deposits declining; while bankruptcies mounted from 471 to 623 (Ashton, 1959,

66). Interest rates continued to move upwards as the Dutch repatriated their capital and by 1780 a deep commercial recession had set in, with residential building and overseas trade bearing the brunt. In fact, from 1778 to 1783 exports and imports experienced their first sustained decline of the 18th century (Ashton, 1968b, 119).[84] Industrialization had quickened during and after the Seven Years War, and a modern business cycle was evolving; war was now either disrupting this process or deepening what would have been a more normal slowdown in economic activity (Ashton, 1959, 162-165; Deane, 1975; Little, 1976, 37; Schumpeter, 1938, 26).

This however should not suggest that the American War did not at all propel the ongoing British industrial mode of development shift to further multiplicative heights. The state was still amassing enormous accumulations of capital and then directing this to market-based contractors in the private sector. War related industries were extremely robust during the American War (Pressnell, 1960). For example, the shipbuilding sector thrived, with the overwhelming majority of new naval ships being contracted to builders in the northeast of Britain. Indeed, by the end of the war, the northeast was increasingly the epicenter of shipbuilding rather than the Thames region (Rule, 1992, 127).

More important, however, were the momentous changes the American War

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[84] "Certainly the statistics of overseas trade lend support to the view that the American War exerted a break on the progress of the British economy. Even leaving aside the lucrative North American trade, which fell away almost to vanishing point, British imports and exports declined over the period of the American war: and the spectacular upsurge in the international trade figures which dates from the end of the war further emphasizes the wartime recession" (Deane, 1975, 92).

fomented in the British iron industry. The late 1770s saw a rash of new coke powered furnaces fired up, so that by the 1780s, charcoal furnaces were a rare and dying breed (Hyde, 1973, 416; Ashton, 1968, 53; Crouzet, 1990, 202). Meanwhile, the established coke-powered iron firms continued to grow and extend their vertical integration; particularly those heavily involved in military contracting, such as the aforementioned Coalbrookdale, Carron, Dowlais, The Ironworks of Masbrough, New Bersham, and Crowley Company (Brown, 1991, 96, 120; Harris, 1988, 68).[85]

Wilkinson's New Bersham Company probably experienced the most outstanding expansion of the American War. Cannon production swelled; even the French Government ordered large batches of cannon from New Bersham during the American War. Early in the conflict, A. Darby III at Coalbrookdale installed a Wilkinson boring machine, as did the Walkers at Masbrough. Soon Wilkinson's boring machine was appearing at all of the major iron firms, especially those engaged in military contracting. Demand for the machine arose not just because it produced better cannon, but also because of its use in parts manufacture for Watt's steam engine (Trebilcock, 1969, 477-8; Ashton, 1968, 45-6). By 1780 Wilkinson himself had four of Watt's 'furnace engines' erected, which in turn led to new

[85] The size and vertical integration of Crowley's iron factory in 1776 was impressive. There were more than 1000 workers on the annual wage bill of £12,000. Gigantic cast iron wheels powered huge furnaces, forges, and vast bellows. "The whole process is here gone through from digging the ironstone to making it into cannons, pipes, cylinders, etc. All the iron used is raised in the neighboring hills, and the coal dug likewise" (Rule, 1992, 117). The Walker owned Masbrough Ironworks, which was founded during the War of the Austrian Succession in order to cast cannon and ordnance for the Navy, was similarly now vertically integrated and huge. The firm's contracting operations were so profitable during the American War that the capital value of the company doubled in less than a decade, moving from a value of £62,500 in 1774 to £128,000 by 1782 (Ashton, 1968b, 98).

steam engine orders from other ironmasters. Moreover, Wilkinson applied the steam engine to ever widening aspects of the iron production chain during the war. For example, in 1776 Wilkinson was the first to directly apply steam power to the cast iron blowing cylinder (innovated at Carron in 1760), thus allowing furnace size to expand further (Landes, 1969, 89). In 1782 Wilkinson introduced a steam powered forge hammer that could strike 150 blows per minute (Deane, 1965, 112). Also in 1782 Wilkinson used a complicatedly enhanced furnace engine to power his boring machine more effectively. All of these inventions quickly dispersed throughout the highly competitive iron defense contracting industry during the American War, causing orders for steam engine parts to pile up at Wilkinson's factory (Musson and Robinson, 1969, 445; Tann, 1974, 84; Ashton, 1968). In short, nowhere was the ongoing defense propelled industrialization feedback loop more evident during the American War than at John Wilkinson's famous New Bersham Company, which now boldly stood at the profitable intersection between British state defense expenditures and the increasingly successful capitalistic domestic iron industry (Ashton, 1968; Deane, 1965).

Wilkinson of course was a caster, perhaps the best ever, but now for the first time, we also see military expenditures directly effect innovations in wrought iron production. Even with the improved casting techniques of the day, iron goods that required meticulous detail and precision continued to be made at forges in the 1770s. At these forges, ironmasters worked with charcoal to craft their final wrought iron wares. This made wrought iron goods prohibitively expensive vis-à-

vis cast goods, but for many naval needs, such as rigging, locks, chains, clasps, moving hooks, precision bolts, specialty tools, etc, wrought iron goods were an absolute necessity. Upon the outbreak of the American War, wrought iron rapidly increased in price as demand skyrocketed and foreign imports were choked off. Witnessing the spiraling costs for wrought iron goods with much chagrin was a naval purchasing agent, Henry Cort, posted at Cyfarthfa Ironworks, which had been built by defense-contractor Anthony Bacon towards the end of the Seven Years War, and was now one of the Navy's principal iron contracting firms. At the same time wrought iron prices were rising, cast prices were declining as a result of the progressive application of coke and steam to production processes; moreover, coal itself was falling in price as cast ironmasters worked to improve mining and transport techniques. Finding a method by which coal could be used to produce wrought iron hence became a sort of Holy Grail quest for the totally patriotic and somewhat obsessive Henry Cort. With official Admiralty Office sanctioning, Cort took up residence at Cyfarthfa starting in 1776, using his 'free' time to pursue his quest. In 1783 and 1784, the final two years of the war, Henry Cort patented the techniques that soon came to be known the world-round as 'puddling and rolling' (Harris, 1988, 55; Ashton, 1968, 53, 92-93; Deane, 1965, 110; Mokyr, 1993, 56; Rule, 1992, 117). From that time forward, the Navy restricted its wrought iron purchases to only that which was coked 'puddled and rolled', but the true significance of the invention is entirely more momentous. In the stirring words of T.S. Ashton (1968: 92-93),

> "Cort's method was first to re-heat the pig iron with coke until it was in a pasty form, then stir it with iron rods until much of the carbon and impurities had been burnt away, and finally to pass it between iron rollers which pressed out the dross that remained. His discovery was one of the outstanding events in the history of technology. It had the effect of freeing the forge-masters from their dependence on the woodlands, just as Darby's discovery had freed the furnace owners... It drew the forge branch of the industry from its scattered haunts to the coalfields, where the making of finished iron could be carried on in close proximity to the furnaces... The output of iron increased vastly... the hardware industries expanded their range of products; and there was hardly an activity – from agriculture to ship building, from engineering to weaving – that did not experience the animating effects of cheap iron" (Ashton, 1968, 92-3).

Puddling and rolling sped the output of wrought iron 15 fold, and when the steam engine was applied to drive the heavy rollers, which occurred across the wrought iron industry with a rapidity rarely matched in the history of technology before or since, throughput was increased another ten fold (Church, 1994). As a result, Britain's domestic iron production doubled within ten years as prices plummeted; "And by grooving or otherwise pre-forming the rolls, one could now turn out an almost unlimited range of those standardized crude shapes – beams, bars, rails and the like – that have come to constitute the framework of industry, construction, and transport" (Landes, 1969, 91; Crouzet, 1990, 23; Mokyr, 1993, 23; Deane, 1965, 103).

The American War sputtered to a close in 1784, and once again, as 'the military expenditure impetus to mode of development shifts theory' would predict, there is unequivocal quantitative data indicating a postwar boon to invention as enhanced human and fixed capital were released from the defense sector back into the general economy. In 1783, with peace clearly on the horizon, the number of

new patent issues jumped 64%; in the five years following the war patent issues were 40% higher than the five years during the war, and over 100% higher than the five years previous to the American War. The only period of the 18th century that rivals this rate of growth in patent issues is that immediately following the Seven Years War (Mitchell and Deane, 1962, 268).

With the Naval and Ordnance Offices largely exiting the market, the innovative and transformative spirit of the postwar domestic iron industry again quickly emerged. This time, the path forward for ironmasters was crystal clear – puddled and rolled wrought iron when combined with the steam engine would decidedly transform the entire edifice of British manufacturing. First, postwar ironmasters applied these combined innovations to the growing, and suddenly fashionable, consumables iron industry (buttons, toys, wall-hangings, knockers, locks, hinges, etc.). For example, Birmingham rapidly became a bustling metropolis for and about steam engine powered puddled and rolled iron consumables in the second half of the 1780s (Rule, 1992, 199-120; Ashton, 1968, 68-9; 1997, 93). Next the capital goods machine tools industry was entirely transmogrified, with Crowley Company, Coalbrookdale, Carron Company, and New Bersham becoming premier global market leaders in the production of new fangled machine tools and hardware of all sorts (Ashton, 1968b, 33-34; Brown, 1991, 97).

At that point it of course became evident that untold profits could be derived from applying puddling and rolling and the steam engine to economic

sectors outside of iron, especially to the exploding business of cotton textile manufacture. After the war increasingly heavy and durable textile machinery, such as Arkwright's frame (1768) and Crompton's mule (1779), came to be constructed entirely from puddled and rolled wrought iron (Mokyr, 1993; Landes, 1969, 87; Musson and Robinson, 1969, 435). Moreover, both these crucial textile machineries came to be powered by steam engines in the years directly following the War of American Independence. Prior to the American War, the steam engine 'remained a single acting device for producing a reciprocating stroke.' In order for the steam engine to become an effective source of perpetual motion for textile production, the to and fro action of the steam engine had to be converted into a rotary movement capable of turning machinery. Throughout the war, the casting of a steam engine capable of rotary motion was Watt's main obsession. A patent for such an engine, made possible by the 'sun and planet' innovation, was taken out by Watt in 1781. In the following year came the double-acting rotary engine patent, in which the expansive force of steam was applied to both sides of the piston. In 1784 the parallel motion double rotary engine was patented by Watt; "and in 1788 the beautiful device of the governor, which gave the greater regularity and smoothness of working essential in a prime mover for the more delicate and intricate of industrial processes." To say Watt's wartime inventiveness had much to do with the American War would of course be stretching the dissertation's argument to unsustainable lengths, but it is interesting to note that history has recorded 1785, the year following the close of the War of the American Independence, as the year

when the steam engine was first used to power textile production (Ashton, 1968b, 57; Landes, 1969, 102; Brown, 1991, 103).

The story of course continues from there: After 1790 "when steam power was used to drive the mules, it became possible to put up large factories in towns" (Ashton, 1968b, 60; Deane, 1965, 90).[86] As factories with iron machinery powered by steam engines spread, there developed a new market for the machinery engineer, and this too then became a high growth employment sector in which ironmasters and former defense contractors could apply their war born talents (Musson and Robinson, 1969, 432-435; Rule, 1992, 133). Suffice it to say there was no shortage of work for those with ironworking credentials.[87] Indeed, "By the 1790s British international dominance in the production of iron was unchallenged, as it would be for nearly 100 years" (Church, 1994).

Thus by the 1790s the novel dynamic of engendering productivity gains by converting heat into motion through engines and then applying engines to manufacturing via distributed machines was proliferating throughout the British manufacturing edifice. Coal smelted iron became the overwhelmingly preferred constitutive constructional element for factories of all sorts, power mechanisms of all sorts, machinery of all sorts, tools of all sorts, piping of all sorts, engineering

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[86] Notably, investment in steam engine powered textile factories marks the first time that textile manufacturers had to invest heavily in expensive fixed capital. Here too the British matrix of credit built up around military expenditure played an indispensable role (Crouzet, 1973; Mokyr, 1993, 100; Brown, 1991, 197).

[87] For example, in the late 1780s Wilkinson built the first of many iron barges, Darby III spent the 1790s casting large iron bridges and canal aqueducts, and all of the military contractors of the 1780s caught a large share of the exploding water pipes and gas lamp markets of the early 1800s (Brown, 1991, 92).

gears of all sorts, transportation infrastructure of all sorts, machine beds of all sorts, barges of all sorts, etc. (Harris, 1988, 57). And every schoolboy and girl knows the hallowed tale of the dominant 19th century British Empire, sustained by dint of its mass produced manufacturables. Thus we have entered into the industrial age proper; the industrial mode of development was fully operative in the 1790s, both qualitatively and quantitatively (Landes, 1969; Deane, 1965; Crafts, 1987; Crouzet, 1990; Mokyr, 1993; Rostow, 1960). Our story regarding the ways in which military expenditure helped to bring the industrial mode of development into being is therefore at its end. Of course, military expenditure continued to interact with the mature industrial mode of development, starting again soon after France's post 1789 descent into utter chaos. But that essentially 19th century military expenditure / economic interaction chronicle falls outside the purview of this dissertation; a dissertation which aims to illuminate the role that long-term large-scale military expenditure plays, given certain institutional and structural conditions, in causing one mode of development to transition into another.[88]

Importantly, however, the ways in which military expenditure interacted with the economy of Old Regime France prior to its collapse does fall within the

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[88] Interestingly, economic historians who have previously studied the effects of war on industrialization have tended to focus upon the Wars of the French Revolution and the Napoleonic Wars (c.1793-1815) (notably Patrick O'Brien, 1989; Phyllis Deane, 1975; and Jeffrey Williamson, 1984); simply because there is better statistical data for these later conflicts. Their findings however have been largely equivocal – war continued to stimulate the iron industry in these years but the overall economic effect was primarily negative due to crowding out. By shifting the focus of the discussion to the time when the British mode of development transitioned from agrarian to industrial, a process that necessarily had to principally occur before the 1780s inception of sustained industrial expansion (Mokyr, 1993, 10), I hope that I have unequivocally demonstrated that military expenditure helped to foment the British industrial mode of development shift.

purview of this study. For we have seen the transformative force of the dynamic mechanisms embedded within 'the military expenditure impetus to mode of development shifts theory' in action in France's main rival. But we have yet to analyze why these potent mechanisms so rarely emerge. Thus we now turn to Old Regime France (1689-1784) in order to comprehend why the conjunctional causal variables that compose the 'military expenditure impetus to mode of development shifts theory' seldom gel, coalesce, and interact to transform the extant mode of development, as they so powerfully did in the British case.

CHAPTER 8: THE CASE OF FRANCE – 1689-1784

In the 1670s France had real advantages over its European rivals: a large and growing population, a coherent national territory, a state apparatus capable of raising large sums through taxation, and a powerful army. These advantages diminished during the 1680s and 1690s: the population stopped growing, the alliance between England and the Netherlands created a powerful fiscal opponent with greater capital resources than France, and competing armies carried out reforms enabling them to challenge the supremacy of French military tactics (Collins, 1995, 123; Minton, 1975, 27).

Throughout the 18th century, the institutional structure of France was sorely tested, especially during the successive episodes of conflict with Britain. As we have seen, the British economy generally fared quite well during these wars; some of its largest growth spurts came during or just after hostilities, and over the long run, war stressed the British economy in ways that caused it to positively transmogrify, thus propelling a technological revolution of incalculable consequence. Not so in 18th century France; there, periods of war tended coincide with either economic stagnation or outright decline, and over the long-run, the rising expense of unremitting warfare ultimately collapsed the state (Collins, 1995, 195). Below it will be argued that these differences in political economic performance can be attributed to the institutional structures that supplied and supported military expenditure and procurement in both nations.

Although Old Regime France managed to basically match Britain in military spending for the better part of a century, it lacked many of the theoretical prerequisites fundamental to the 'military expenditure impetus to mode of development shifts theory' as explicated in chapter one. No electoral body had control over French finances, and there were only weak checks on the French sovereign. Old Regime France relied on a tax structure that was inhospitable to economic growth and development, especially during wartime. The debt system of Old Regime France remained entirely unsound, ultimately precipitating the collapse of the regime in 1789. The French form of warfare was not particularly capital intensive, and the organizational forms that military contracting took were not at all market-based. And to top it all off, Old Regime France failed to institute effective property laws, while cross-regional transaction costs were allowed to remain elevated. Thus military spending had an enervating rather than energizing effect upon French economic development. The mechanisms underpinning the 'military expenditure impetus to mode of development shifts theory' were not at all operative in Old Regime France, and accordingly, 18th century France did not generate a mode of development shift, as will now be evidenced.[89]

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[89] There is a line of thought running through certain historical literatures averring that growth in the British and French economies was about even for most of the 18th century (Crouzet, 1990). I accept that the quantitative growth of some non-capital-intensive sectors was more similar than different. However, the French economy plainly grew within the same organizational and techno-productive infrastructural framework. Regardless of aggregate growth rates, it is clear that the French economy did not achieve industrial style technical innovation and / or vertical integration in any economic sector during the 18th century (Price, 1975). "On the eve of the Revolution, the French economy was not basically different than what it had been under Louis XIV" (Crouzet, 1990, 26). "Structurally the (French) economy had undergone no basic change in the course of the 18th century" (Kemp, 1971, 66).

AUTOCRACY AND PATRONAGE IN OLD REGIME FRANCE:

As already demonstrated, parliamentary control over taxation and spending was a linchpin in the successful British system of war finance. Parliamentary oversight widened the body of lenders willing to invest in public deficit finance because public debts now obliged the entire nation rather than just the King. Moreover, wealth holders were brought into the structure of power thus establishing 'checking' mechanisms thereby curtailing the arbitrary power of the sovereign (North and Weingast, 1989).

In theory, the King of Old Regime France was an absolute monarch deriving his powers from god and sharing them with no legislative body. He alone had the right to legislate, tax, and declare war. This of course stands in direct contrast to Britain where limitations on autocratic power were many and codified. The principal limitation on the King's arbitrary power in France was the uncodified notion that he should not unjustly interfere with his subject's property (Price, 1995, 10-11). The courts, led by the 'thirteen parlements', with the Parlement of Paris at its head, presented another weak limitation on the King's power in France. Historically, the parlements were staffed by nobles who had privilege and interest in the King's rule; unlike Britain, the courts in France were not at all independent from the King. Moreover, parlements did not make law in France, they merely opined upon the King's edicts (Collins, 1995, 212). Royal edicts did have to be registered in official books by the parlements in order to become law, and each new loan and each new taxation measure specifically required parlementary action of

this sort (Riley, 1986, 209). But parlementary action was, for all intensive purposes, assured. When parlements bristled at registering a royal edict there were two options to the King. The first was a 'letters de jussion', which was simply a letter ordering the parlements to register the edict without further discussion. The second option was a 'lit de justice' which was a sitting of the parlements attended by the King. At a lit de justice the King held "a ceremony reminding the parlemantaires that the right of judicial review was delegated and could be withdrawn" (Riley, 1986, 209; Minton, 1975, 98). In the King's presence the parlements could not lawfully object to his legislation. Typically then, some monarchal attention sufficed to bring the parlements into line (Collins, 1995, xxvii). The result of this structure was that the King became solely responsible for all types of legislation (fiscal, criminal, etc.); in specific regards to finances, the result was that public debt in France obliged the King and the King only (Collins, 1995; Riley, 1986).

Another aspect of the 18th century French political system that contrasted poorly with that of Britain was the overwhelming importance of privilege. In France the main motor of social action was patronage, and this tended to confuse and hinder the raising of finances, amongst other things. Privilege affected every aspect of life and governance in France; patronage, clientage, and the use of public power to advance relations and friends were not abuses, they were political currency. The King of France sat at the head of a bewilderingly complex system of social privilege, and all state-related activities, from corporate charters, to tax

exemptions, to the ability to hold an office, to the right to receive interest, were particularistic privileges granted by the King (Alder, 1997).[90]

The importance of privilege and patronage deeply affected the prospects for economic development in France. 18th century France had plenty of surplus capital floating around, potentially available for investment, but this capital tended to be diverted into the social orbit of status and privilege, where it purchased offices and titles rather than expanding and improving upon output. In such a social milieu, military expenditure merely stimulated competition for offices and sinecures amongst state clientele, rather than spurring productive capital goods investments (Kemp, 1971, 34; 40-41).

Additionally, in France's patronage centered society, the development of Weberian bureaucratic administration was entirely unlikely, and indeed, did not occur. Meanwhile, in 18th century Britain Weberian type bureaucratic administration came to predominate, especially in regards to excises, banking, finance, and naval operations; which were of course the organizational foundations to effectual military expenditure (Pritchard, 1987, 29; Dickson, 1967; Kiser and Kane, 2001; Brewer, 1988; Pool, 1966). Sans the trappings of modern bureaucratic administration, governance in Old Regime France often deteriorated into confusion.

> "The governing coalition could provide no continuity of policy, because that coalition was always ephemeral. The constantly shifting power relationships were Byzantine in their complexity. The historian dissects

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[90] "The King was the greatest patron, setting the pattern for the rest of society by dispensing the highest places, honors, and pensions according to his own pleasure and the pleasure of the royal family, or of an influential group or individual at court. Lower in the social scale, anyone with influence could be king to those beneath them" (Bosher, 1994, 89-90).

> them in vain, for they possessed no more logic than permanence. In the words of a contemporary, all was 'moving sand" (Kennett, 1967, 10).

Hence, as the 18th century progressed and modernity developed, the Old Regime found itself increasingly unable to cope with the growing number of functions it was expected to assume, especially in regards to war – moving sand proved to be a terribly poor foundation for 18th century interstate competition (Dull, 2005; Riley, 1986).

For example, unlike the British Prime Minister, the French King did not have a cabinet as such. The major heads of government departments met separately with the King in a series of councils organized around various government functions; they never met together. All discourse was mediated through the King, which led to compounded rivalries and persistent confusion (Dull, 2005, 22). "In the absence of an effective King, council, or any other form of constitutional restraint, power was monopolized by the King's ministers, who were in practice accountable to nobody and were able to take arbitrary decisions virtually unchecked" (Price, 1995, 42). Thus, 'ministerial despotism' arose as a response to the Byzantine nature of French governance, and in turn, ministerial despotism eventually became grist for the French Revolution. Whereas the British form of parliamentary governance came to be a model for modern states, battle drove the intricacies of the Old Regime patrimonial system into the annals of history (Tilly, 1990).

PROPERTY RIGHTS AND TRANSACTION COSTS IN OLD REGIME FRANCE:

In 18th century France, property rights generally (and in knowledge in particular) were insecure, transaction costs were extreme in a relative sense (as compared with Britain), capital and economic markets were far from integrated, and the productive apparatus was burdened with a backward looking medieval guild and regulation system (North and Thomas, 1973; Crouzet, 1990). Thereby creating an inauspicious environment for economic development of any sort (North, 1990), let alone defense inspired economic transmogrification.

In regards to property rights in knowledge, in France the monarch did grant exclusive rights to producers for various periods of time, but only for artistic or luxury goods, and only for a limited market area rather than for the whole of France. Commodity related inventions were typically deemed entirely unworthy of protection. Furthermore, no new invention could conflict with previous monarchal grants; such grants tended to be simple monopolies in already existing markets and techniques. Thus, if a new invention would harm any one of the multitudes of earlier issued monopolies, the Crown would not protect it. Established monopolies also made it extremely difficult for new blood to enter into old industries; many times royal patents, monopolies, and subsidies supported inefficient industries and companies, while more efficient producers found it impossible to survive without royal favor (North and Thomas, 1973, 126-127). Moreover, inventors in France competed to obtain awards granted by governmental committee, and these awards were typically distributed based on patronage; the market was merely a secondary

thought (Mokyr, 1993, 42; Crouzet, 1990, 26-7; Kemp, 1971, 32). Thus military expenditure did not propel innovation in productive processes in Old Regime France because innovation itself was usually a rather pointless exercise in currying Kingly favor.

Another drag on invention and economic improvement in 18th century France were the guilds and their associated regulations on production. In France the guilds were 'the universal model for the structure of trade not only in the cities but also in the market towns and even in the country.' Guilds in France tended to be conservative, and were therefore an impediment to the introduction of new techniques. "In a wide variety of industries (textiles and metallurgy included) the state claimed the right to set standards of production" (Alder, 1997, 167). "Regulations were created after consultation with guild officials and generally mirrored medieval production techniques" (North and Thomas, 1973, 126). Furthermore, guilds jealously guarded their markets, restricted output, and presented yet another barrier to entry in most French economic sectors (North and Thomas, 1973, 126; Crouzet, 1990, 28; Kemp, 1971, 32; Price, 1975, 160).

An additional institutional obstruction to the development of industrialization in France was the segmented marketplace for goods and trade, and the large transaction costs imposed on interregional trade via an elaborate internal taxation system.

> "The fiscal policy of the French crown, whether intentionally or not, did almost everything conceivable to thwart the spread of an extensive market and thereby surrendered the gains that lay therein. Regions were artificially

> separated, isolated from one another by a system of internal tariffs… France during the Ancien Régime should be considered as composed of more than thirty separate market areas" (North and Thomas, 1973, 122-123).

Moreover, most French natural resource endowments were ferociously protected by privileged local social hierarchies, thus making utilization by extra-regional entrepreneurs difficult and burdensome. Segmented markets naturally meant segmented production as well; since the market was fragmented, the location of manufacturers was widely dispersed, and demand was strictly local in character. Therefore, French production did not enjoy the returns that might have come from interregional competition, and projects leading to expanded output proved irrational (Crouzet, 1990, 34-35; Alder, 1997, 168).

For the above reasons then, the 18th century French political economic system did not provide a sound environment for capital goods investment, technical innovation, or vertical integration. In short, military expenditures, no matter how great, could not have induced or contributed to industrialization in Old Regime France; in fact, it seems unlikely that anything could have. Nevertheless, much can be gained from analyzing the other independent variables in the 'military expenditure impetus to mode of development shifts theory' in the context of Old Regime France, for the comparisons highlight just how unique and special the synergies and dynamics that endowed military expenditure with extreme transformative force in 18th century Britain were.

TAXATION IN OLD REGIME FRANCE:

The overriding thesis guiding the following section reads simply: the tax structure in France was, for various reasons, not at all conducive to industrial economic transformation, especially during wartime, when the greater burden of taxation put heightened stress on overall economic performance. The taxation system of Old Regime France was complex (to put it mildly).[91] The complexities lay in the variety of forms applied to different regions, the disparity between theory and practice, and in the multiplicity of tax types (Riley, 1986, 46). In general terms, "Pre-revolutionary French tax administration was a mix of privatized collection of indirect taxes (tax farming) and decentralized, locally controlled collection of direct taxes" (Kiser and Kane, 2001).

Direct taxation will be explored first, for direct taxes composed the majority of state revenue in Old Regime France. In fact, during wartime the state tended to augment direct taxation in order to fund the extraordinary costs of hostilities, rather than augmenting indirect tax revenue, as was the case in Britain. Direct taxes in Old Regime France included the taille,[92] the capitation,[93] and during wars the

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[91] "The problems of analyzing the structure and incidence of taxation in France are considerably greater than for Great Britain. Data has not survived nearly as completely, and was not collected and formulated subsequently in the same way as the public accounts of Britain... Where taxes were farmed, as they were for almost all indirect taxes (in France) the fixed annual rent... conceals the actual amount collected... As always with tax farming, the loan operations of the farmers, and the servicing costs paid for this borrowing by government became inextricably mixed up with the tax levies and rent of the farm, to the frustration of historians seeking to isolate and assess the costs and effects of taxation and borrowing as distinct functions of state" (Mathias and O'Brien, 1976, 624-625).

[92] The taille was the main and oldest direct tax in 18th century France. Originally created in the late fourteenth century, the taille was assessed primarily on income from land, but also counted other income. The tax actually was a series of direct taxes; including sur taxes, a garrison tax, and special military taxes. Tax officials divided the taille by parish. Within the parish, the parishioners

dixième and vingtième.[94] All direct tax administration was decentralized and venal in Old Regime France.[95] "The fact that officials had purchased their offices made them difficult to control and even harder to remove, as the price of the office would have to be returned. Venality was not only a source of high corruption, but a significant barrier to reform" (Kiser and Kane, 2001). Hence it should not surprise that although the venal 'receivers-general' controlled 90% of direct tax income in

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themselves divided and collected the tax; if individuals could not pay, the parish had to pay for them. Royal officials could seize property in order to force payment. Parish proceeds from the taille moved onto a local receiver (receveurs des tailles) who paid wages, rentes, and other charges settled on those receipts, and then sent the balance to the receiver general, who maintained central accounts and paid charges assigned at that higher level (e.g. certain military expenses) (Riley, 1986, 48; Collins, 1995, xxxiii; 20).

[93] The capitation, introduced in 1695, was, in theory, more so than in practice, levied on all French lay people. Assessment was divided into 22 classes loosely based on income. The tax was designed to be progressive with the highest classes paying the most; 2000 livres for each individual per annum, those in the 22nd class paid only 1 livre per annum. The highest class of individuals included princes, the controller general, and the Farmers General. "The capitation involved the nobility and townsmen, although many towns, provinces and corporations purchased exemption" (Collins, 1995, 200). The capitation was first levied in order to raise financing for the Nine Years War. During the war it raised approximately 24 million livres per annum, but was ended in 1697 with the close of hostilities. When war broke out again in 1702 the capitation was reintroduced. This time the tax was levied not by class but by region, and therefore became little more than a supplement to the taille (Collins, 1995, 167-168). The tax was expected to produce 30 million livres but due to exemptions produced something more like 23 million livres. The capitation remained in force throughout the War of the Spanish Succession, although it yielded diminishing sums as time went on (Lossky, 1994, 280; Collins, 1995, xx; Riley, 1986, 51).

[94] Like the capitation, the dixièmes and vingtièmes were intended to raise capital for war efforts. The main difference between the taille and the capitation on one hand and the dixièmes and the vingtièmes on the other is that the former were levied according to an assessor's judgment and the latter according to declarations by taxpayers. The dixième (or a tenth) was first applied in 1710 during the height of the War of the Spanish Succession. It was a 10% tax on income derived from property and universally applied. The dixième lapsed in 1717, but was reestablished between 1731 and 1737 (as a result of the relatively small War of Polish Succession), and again between 1741 and 1749 (as a result of the War of Austrian Succession). The dixième was superseded by the vingtième in 1750. The vingtième aimed to raise 5% of the income of all businesses and individuals. From 1756 there were two vingtièmes in force, and from 1760 to 1763, three (as a result of the costly Seven Years War). Vingtièmes persisted to the end of the Old Regime (Collins, 1995, xxii; Riley, 1986).

[95] Duties were in the hands of agents that were appointed and controlled locally. The administration remained venal throughout the 18th century (Markoff, 1996, 237; Kiser and Kane, 2001).

Old Regime France, only 15-20% found its way into central government coffers (Collins, 1995, 107).

Most importantly, direct taxation did not effectively tap the wealth and income of Frenchmen. Assessment was terribly inexact, mainly because the state had no real means of assessing the value of assets or income; either corrupt local officials estimated wealth and income, or tax payers assessed property values themselves. Such inexact assessment was ostensibly a product of the hazy legal notion that family finances were private and therefore not subject to unjustly interference by the King. In reality, inexact assessment opened up the system to profitable abuses (Lossky, 1994, 281). To make matters worse, all forms of direct taxation in Old Regime France were riddled with exemptions based on privilege. Assessment rates also remained stagnant even as incomes and wealth grew.[96] Indeed, after 1739, when poor war finance caused inflation to gather pace in Old Regime France, unchanging assessment rates bred a collapse in the real revenue derived from direct taxation (Collins, 1995, xxxiii, 20; Riley, 1986, 49). To worsen matters further, as the century progressed, legally sanctioned tax avoidance (exemptions) gave way to rampant tax evasion, as the state continually failed to implement measures that would allow it to adequately assess wealth or monitor collectors (Riley, 1986, 59).

In short, although the state in Old Regime France relied on direct taxation, especially during hostilities when new varieties of direct taxation were imposed in

[96] For example, throughout the 18th century the taille was pegged at a nominal sum less than that used in the middle 17th century (Collins, 1995; Riley, 1986).

order to fund the extraordinary costs of warfare, direct taxation did not at all provide a suitable basis for crown finances. Due to exemptions, local assessment, local collection, venality, corruption, stagnant assessment rates in the face of war born inflation, and outright evasion, direct taxation allowed a land rich in resources to be poor in finance (Riley, 1986, 50; Collins, 1995).[97] Poor finance, in turn, made military spending an albatross around the neck of the French economy. Hence, direct taxation in France did not provide adequate fuel to the public deficit finance system to either initiate or further economic transformation in the nation, industrial or otherwise; during peace, but even more so, during war (Lossky, 1994, 280; Collins, 1995, xx, 168, 201; Riley, 1986, 51-70).

Recall that in Britain indirect taxes composed the base of the pyramid of funds involved in the successful system of public deficit finance. What of indirect taxation in 18th century France? In France there were four main types of indirect taxes – gabelle (salt taxes),[98] aides (sales taxes),[99] douanes (customs taxes imposed on international trade), and traites / octrois (taxes imposed on interregional domestic trade). Before the administrative organization of indirect taxation in Old

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[97] For example, a real 10% levy on income should have brought in approximately 135 million livres at the beginning of the century; while a 5% levy on income should have brought in some 255 million livres in the 1780s. But the revenue from dixièmes and vingtièmes combined maxed out at approximately 23 million livres in the 18th century, a mere fraction of the expected revenue based on estimates of 18th century French national income (Riley, 1986, 59).

[98] The gabelle was the oldest and most despised tax in Old Regime France. The gabelle was "a state salt monopoly in which the price was fixed at different levels in six regions of the royalty." In order to boost revenue the state would often set a minimum of salt that had to be purchased by the individual. This minimum would often be over and above what the average French person required, thus stoking resentment (Riley, 1986, 53).

[99] Aides were indirect taxes on sales and manufacture established in the 14th century; they lasted until the end of the Old Regime. Income from the aides came primarily from taxes on wine, fish, and wood (Collins, 1995, xix).

Regime France, along with concomitant effects, are summarized and analyzed, allow me to say a special word in regards to the traites and octrois. Traites were transit fees collected by the state on goods moving inside the Kingdom from one province or region to another while octrois were levied on domestically produced commodities as they moved between towns and cities. The imposition of such transit levies led to a complicated system of policed internal trade, thus raising transaction costs, thereby surrendering gains from trade that may have otherwise materialized, as alluded to above (North and Thomas, 1973; Collins, 1995).[100]

Now onto the summary of indirect tax administration in Old Regime France, and the analysis of concomitant effects. In the 18th century all indirect taxes in France were farmed (tax collectors paid the King a fixed sum in return for the right to assess, collect, and hold indirect taxes) with the consolidated General Farm administering the various taxes (Collins, 1995, xxv; Kiser and Kane, 2001). For France, a large nation with poor internal transport, such a non-bureaucratized administrative structure actually made sense (Kiser and Kane, 2001). The General Farm, centralized at the top, employed an army of local agents to collect the multitude of taxes in its lease; 'according to one source 10,000 agents operated in 1750.' The localized character of assessment and collection at the bottom of the administrative hierarchy circumvented the need for widespread travel, while centralization at the top of the administrative hierarchy enabled the General Farm to develop techniques that improved efficiency. For example, General Farm

[100] "Between Orleans and Nantes on the Loire, for example, boats had to stop more than twenty times to pay local transit fees" (Mathias and O'Brien, 1976, 631; Collins, 1995, 19).

accounting procedures were better than those used by the state, and detailed personnel records were kept (Kiser and Kane, 2001). As a result, revenue from indirect taxation increased at a faster pace than direct taxation revenue throughout most of the 18th century (Riley, 1986, 52-54).[101]

This is not to say that indirect taxes in Old Regime France effectively tapped French wealth; clearly they did not. To begin with, the General Farm charged the King dearly. Costs for collection ran at around 16% of total indirect tax revenue, while collection costs for direct taxation ran at a significantly lower 10% of total direct tax revenue (Riley, 1986, 62). Secondly, the Farm often hid profits from the Crown, levying more in taxes than was actually recorded. At mid century contemporaries estimated that the Farmers lined their pockets with at least 10-20 million livres in unreported collections per year, which was approximately 10-20% of mid 18th century indirect tax revenue (Riley, 1986, 54). Due to corruption along with high costs of collection it can be asserted that the General Tax Farm passed only a third of what it collected to the King (Collins, 1995, 233). Interestingly, the King's court allowed this to go on for they were in collusion with the farmers. The great tax farmers sold shares in their syndicate to a wide range of people, including the highest nobility (Collins, 1995, 110-111). Elites received gifts and shares while the farmers received secret profits. In short, tax farmers paid

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[101] The tax farmers in Old Regime France were motivated by the structure of their leases to collect more than their lease required (for they kept the extra) and the court understood this. Thus each lease raised the expected revenue the farmers were to collect. In this strange way, taxes collected by the General Farm were the only taxes that kept pace with the growth of national income in France. Hence, the state came to rely in ever greater ways on the taxation collected by the General Farms as the 18th century progressed (Riley, 1986, 70).

far less for the privilege of collecting taxes than they should have, and they were not the only party to profit from this situation (Riley, 1986, 62-63; 70-71).

In Britain, on the other hand, indirect taxation was assessed and collected by a proficient professional bureaucracy. As a result indirect tax revenue in Britain grew by leaps and bounds over the course of the 18th century. Its growth was most notable during conflict when British prime ministers relied on indirect taxes to fund the British war machine. In France, indirect tax revenue grew, but slowly. Moreover, the King consistently chose to augment direct taxes rather than indirect taxes to cover extraordinary expenses during hostilities.[102] This was a far less effective strategy in the 18th century when consumption was rising and the formation of an effective infrastructure for centralized assessment of fixed wealth and income was, for all intensive purposes, impossible. Thus the French public deficit finance system was left with a dearth of foundational revenue, especially during wartime (Riley, 1986; Brewer, 1988; Kiser and Kane, 2001).

Another interesting aspect of the British / French taxation comparison queries whether the overall tax burden was greater for Englishmen or Frenchmen during the 18th century. This is an important question because, as previously explicated, tax revenue provides the base for the credit structure involved in public deficit finance; if that base grows, so too does the potential for expanded public deficit finance operations. Thus if per capita tax burdens are higher in a nation, the

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[102] In France, direct taxation provided half of total tax revenue during peace and upwards of 60% during war; this was between two and three times greater than the proportion derived from direct tax revenue in 18th century Britain (Mathias and O'Brien, 1976, 625-626).

nation can have a larger public deficit finance system in relation to overall population; a larger public deficit finance system means more fuel for economic transformation as outlined in chapter one. In France, the burden of taxation was in fact much lower than it was in England; and for most of the 18th century it did not increase, especially in relation to the growth of the French economy (Mathias and O'Brien, 1976, 606; 634; Riley, 1986, 56-58).[103] As shown, the per capita tax burden borne in Britain multiplied rapidly as an effect of conflict and was therefore double that borne in France throughout most of the 18th century. Indeed, by 1793, meagerly populated Britain was producing more nominal revenue per annum than heavily populated France (Mathias and O'Brien, 1976, 608-611).

The preceding points are not the only relevant French / British comparison in regards to their respective tax structures and whether they provided a sound basis for economic transformation during wartime. Recall that in 18th century Britain a regressive tax structure freed the capital of middle and upper classes for investment in either manufacturing or public deficit finance thus aiding incipient industrialization. What about in 18th century France, was the structure of taxation regressive or progressive? At first glance this appears to be a silly question; the weight of historical opinion regards the tax incidence in Old Regime France as highly regressive (Mathias and O'Brien, 1976, 627). But was it, and was it more so than Britain's? Of course, the very richest groups in France largely escaped

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[103] Indeed, in France, physical output increased faster than real tax income, so relative to the size of commodity output, taxation falls from levels of 15-17% in 1735 to levels of 10-11% by the end of the century (Mathias and O'Brien, 1976, 608-609).

taxation, transferring only a small proportion of their income to the state. Nevertheless, finance ministers of the Old Regime did try to tax income and wealth in proportion to the ability to pay, especially during wartime. The capitation, dixièmes, and vingtièmes certainly aimed at doing so, and can be viewed as more progressive levies than the more commonly studied taille. In fact, as the 18th century progressed, French leaders became ever more interested in progressive taxation. Accordingly, the taille decreased in its share of direct tax revenue from around 50% in 1725-1726 to less than 30% in the 1780s. Additionally, a local study by Lizerand (1958) finds that poorer parishes contributed a lesser proportion of their income in direct taxes than richer parishes; while Morineau (1972) finds that the poor paid low proportions of their income as capitation and vingtième (Mathias and O'Brien, 1976, 629). Moreover, indirect taxes in France were less regressive than those in Britain for Britain taxed not only alcohol, tobacco and salt at high rates, but also widened the range of indirect duties to include all the necessities of the poorer classes, such as 'sugar, tea, soap, candles, coal, leather, certain textiles, and building materials.' Hence the argument can be made, and has been successfully by Mathias and O'Brien (1976), that "the overall incidence of direct taxes in France probably bore more heavily upon the wealth and incomes of the more affluent classes than comparable taxes in Britain." Hence, the tax incidence in Old Regime France, counterintuitively, curbed the savings and investment potentials of the classes that would have been involved in any type of industrialization, more so than was the case in 18th century Britain (Mathias and

O'Brien, 1976, 629).[104] This discrepancy likely rose further during wartime as the British tended to boost indirect taxes to pay for war, while the French relied on new dixièmes and vingtièmes, which explicitly aimed at directly taxing accumulating wealth. Also, the French state did not exempt defense contractors from indirect taxation (as was the case in Britain) and direct taxes fell heavily upon wealthy French military contractors (Pritchard, 1987, 155-6). In summation, the tax incidence in France was unquestionably inhospitable to defense expenditure inspired economic transformation.

PUBLIC DEFICIT FINANCE IN FRANCE:

The main thesis girding this section of the French case reads as follows: the poor organizational structure of public deficit finance in France limited, if not destroyed, any of the beneficial economic effects that might have devolved from military spending. Throughout the 18th century, France's financial institutions were at least a century behind those of Great Britain. Public debt was still construed as the King's personal liability, and parlement was not a legislature in control of taxation and debt, it was simply a promulgator of the King's edicts (Minton, 1975, 67-68). Indeed, the Crown attained a well deserved sordid reputation in regards to dealing with public debt. The 17th and 18th centuries witnessed many repudiations, partial bankruptcies, and re-coinages in order to fleece those who had lent to the King (Bosher, 1994, 298). In fact, repudiations were so common that creditors to

[104] "In terms of social incidence, the burden of taxation in constitutional, bourgeois, parliamentary Britain was more regressive than in absolutist France" (Mathias and O'Brien, 1976, 633-635).

the French Crown expected to receive only half of the interest rate to which they had subscribed. Moreover, continual manipulations of currency scarred France for generations.[105] Owing to re-coinage, partial bankruptcies, and regular defaults on payments, interest rates charged on moneys advanced to the King were often 20%, and sometimes reached 50%, during the 17th and 18th centuries (Riley, 1986, 132; Lossky, 1984, 247; Bosher, 1994, 298; Collins, 1995).

Additionally, due to the extreme likelihood of default and repudiation, creditors forced the Crown to enter into poorly structured loan agreements. In Old Regime France all types of annuity packages were termed 'rentes.' Prior to the Regency (1715-1723), the main form that rentes took were perpetuity loans, wherein the King never paid back the principal but paid interest to the creditor or their family forever. French Kings traditionally asserted that the proper rate on perpetuity loans was 5%; although creditors often demanded rates as high as 9%. Given these rates, total payments surpassed the amount of the principal in 10 to 20 years, and then continued on from there. After the Regency, Louis XV preferred loans that were not paid into perpetuity but ended, such as lifetime annuities. As discussed in the British case, life annuities paid interest until the assignee died. Creditors traditionally demanded an interest rate of 10% on life annuities; a level French Kings supported as proper. Of course, Britain had stopped issuing life annuity loans early in the 18th century, and stopped issuing perpetuity loans before

[105] When tax revenues fell short the King would often issue an ordinance revaluing money. For example, between 1690 and 1715 France revalued its coinage some 40 times; "The controller general's office simply declared that all coins in circulation were worth a different amount" (Minton, 1975, 35).

that, for the traditional 10% and 5% interest charges were proven irrational by uncomplicated mathematical expectation and compound interest tables. Moreover, as discussed, Britain had discovered the concept of refinancing loans to make use of lower market interest rates, and life annuity and perpetuity loans could never be refinanced. France nevertheless continued to regularly utilize life annuity loans with a 10% (or more) interest rate right up to the end of the Old Regime; creditors would accept no less from the untrustworthy and unchecked King. It should also be noted that there was not a liquid market for rentes in Old Regime France, so rentes were not easily transferable to third parties. This too then kept French public interest rates at wildly inflated levels (Riley, 1986, 176; 186-188; Collins, 1995, 31).

Budgetary confusion also loomed large in Old Regime France; in fact, the regime did not operate on a budget in any modern sense. The government could only vaguely estimate both its revenue and expenditures and sometimes the errors were massive. For example, in 1758 the deficit was estimated at 133,000,000 livres; later it was found that this estimate was probably 84,000,000 livres below the actual figure. Venal administrators were given two years to submit their accounts, three years during wartime, and in many cases these generous deadlines were not met. For instance, the office in charge of extraordinary expenses did not close the accounts on its books for 1758 until 1766 (Kennett, 1967, 88-89; Collins, 1995). Moreover, payments on annuities were supposedly guaranteed by revenues held by the town government of Paris or by liens on indirect taxes. However, since

there was no exact accounting on expected and received revenue, it would be entirely mistaken to label these liens an earmark (Collins, 1995, xxxi). Furthermore, "In the case of expenditures... the destination or governmental department to which they should be attributed was frequently not known." Louis XV, for example, made extensive use of 'secret' pay orders that merely contained the phrase "I know the purpose of this expenditure." At one point in Louis XV's regime these vague pay orders reached a sum of 100,000,000 livres outstanding (Kennett, 1967, 89).

To further complicate matters, ministerial despotism was most pronounced and mercurial in the vital area of finance, thus hopelessly muddling the public accounts. Power devolved to the 'controller general', and his subordinates, the 'intendants des finances' – a small group of venal appointees, each responsible for one or more sources of crown revenue. Below the intendants des finances sat the venal 'treasurer-general intendants';

> "Who, though legally mere accountants, were de facto private bankers possessing royal authority to carry on the financial business of the state. They did not simply manage the government chests, but controlled their own private chests in which funds belonging to the crown were held on account together with other private accounts" (Collins, 1995, 108).

The entire arrangement for the payment of government expenditure was built around the assumption that treasurers-general had authorized revenues in their chests (caisses), but this was rarely, if ever, the case. The treasurers-general, who paid out government expenditure, were entirely separate from the administrators maintaining collected government revenues, known as the 'receivers-general.' As a

consequence, "the government's receipts were scattered in the chests of hundreds of accountants"; accountants who utterly confounded their public and private financial responsibilities (Pritchard, 1987, 188). Unsurprisingly, the capacity of caisses to provide funds at the appropriate time repeatedly surfaced as a major encumbrance. Treasurer-intendants high up in the venal hierarchy would often issue 'assignations' (payments) on revenue chests that were either light or empty (Pritchard, 1987, 188-189). Caisses were usually light or empty because the receivers-general and treasurers-general had liberty to use the funds and credit of the government in their own personal business affairs. Thus government funds were often diverted to risky private endeavors leaving revenue chests bare. The unregulated operation of the decentralized quasi-private caisses was an important aspect of the continual financial crises that plagued Old Regime France, especially during wartime. "In time of stress... individual treasurers could fail and fall because they were not mutually sustaining, not part of an articulated financial organization." This decentralized, poorly coordinated, and entirely unregulated quasi-private treasury system remained in place until the death of the Old Regime, contributing substantially to its ultimate collapse (Bosher, 1994, 86, 348; Collins, 1995, 108).

The arrangement of quasi-private caisses also bred an unwieldy currency system. The preponderance of bills and notes in the French economy were issued by various treasurers-general and receivers-general with no central oversight (Pritchard, 1987, 188). These bills were issued for short-terms and in haphazard

manners; even more so during hostilities (Bosher, 1994, 352). For example, during conflict, receivers-general would many times cover their own short-term costs by issuing what were called 'rescriptions.' Rescriptions relied on the individual credit of the receiver and often circulated at heavy discounts. The decentralized haphazard issuance of rescriptions compares, in some small way, to the centralized well-managed issuance of exchequer, naval, and ordnance bills in Britain during wartime; one main difference being that discounts on rescriptions during 18th century wars typically ran to well over 30%, while discounts on exchequer, ordnance, and naval bills in Britain during 18th century wars tended to fluctuate between 0% and 10% (Collins, 1995, 67; Dickson, 1967).

A further faulty aspect of the Old Regime's financial structure was its reliance on a very small number of aristocrats for most of its credit. These aristocrats often held positions of authority in the financial dealings of the state (such as treasurers-general and receivers-general) (Lossky, 1994, 98).

> "The fact that the monarchy's financial officers were also its chief short-term creditors was bound to give rise to numerous abuses. The most notorious of these were the so called jeux de caisses, by which the treasurer, taking advantage of the complete lack of distinction made between the caisses through which he handled his private funds and those of the crown, lent the crown its own money before it was needed for expenditure at an enormously inflated rate of interest" (Price, 1995, 89).

The most notable financiers of the Crown were the tax intendants of the General Farm. As would be expected, the controller general and the General Tax Farm were always closely interrelated through personal ties, loyalties, and bribes (Collins, 1995, 204). In fact, bribes to the controller general were viewed as a right

of office. Truth be told, the operations of finance throughout the entire Kingdom were hopelessly riddled with corruption. Treasurers-general acted practically independently of any government control; the 'Paris Chamber of Accounts' had some oversight responsibility, but they did not tackle questions of a budgetary nature. Of course, all questions relating to public finance are of a budgetary nature, thus the Chamber of Accounts had little power (Pritchard, 1987, 187). The controller general's venal hierarchy also left little room for appeal against unjust acts by revenue collectors or treasurers-general. The most senior intendants des finance sometimes judged financial appeals, but when they did so, they did so solely and arbitrarily. As a result, treasurers-general and receivers-general often operated their semi-private chests for the King with malevolent intent (as quoted above – the jeux des caisses) (Price, 1995, 43-45; Collins, 1995, 108).

Many of the additional troubles that arose in the French financial system can be attributed to the practice of staffing the financial ministry with jurists whose careers had begun as counseillers to the Parlement of Paris or other privileged positions. These men had no training in finance, and most had extremely short tenures (as opposed to the lengthy apprenticeships which bankers and financiers experienced in Britain). Additionally, due to the system of privilege, when one controller general left, his entire staff was forced to leave with him, only to be replaced by men who were even greener. Most ministerial time was therefore devoted to mastering the intricate and many times impenetrable financial system of France, 'a system that has so baffled historians that is said to have been muddled

and likened to an opium den' (Riley, 1986, 158-159). Not only were financial officers clueless, but the royal chain of command in regards to finance was often erratic and unpredictable. Depending on their personal status with the King, non-financial ministers were able to demand and receive funds for their departments without oversight from the controller general. In fact, the controller general was officially the lowliest of all the King's ministers (Collins, 1995, 108).

The problems with 18th century French public deficit finance did not end there. In 18th century Britain, changes in interest rates followed from the demand for credit. This was true in both the public and private sector and by the mid 18th century public and private credit markets were largely integrated (i.e. private interest rates and public interest rates moved in tandem) (Dickson, 1967; Pressnell, 1960; Brewer, 1988). Not so in Old Regime France, where private credit markets remained entirely separate from public credit markets. In fact, private interest was not allowed to be charged in Old Regime France. What was allowed was termed a 'rente constiuee.'[106] Each separate province in France had its own ceiling above which a rente constiuee could not rise. In the 18th century most of France had a ceiling of 5%. This mirrors the ceiling imposed on private interest rates in Britain. However, in Britain, military spending and operations on the public debt created an integrated credit market with interest rates on public debt typically yielding well under 5%, thus freeing capital for financially intensive projects in the private

[106] Rentes constiuee specified an interest rate, but the term of the loan was, by law, necessarily left unspecified. Hence, whereas private rates in 18th century Britain keyed off length in loan, such a natural process was legally prohibited in Old Regime France (Riley, 1986, 30-31).

sphere (Thompson, 1973; Crouzet, 1972; Dickson, 1967; Pressnell, 1960; Deane, 1965; Ashton, 1958). Additionally, recall that in Britain military contracting familiarized firms, which were also producing for the private marketplace, with expensive capital intensive projects. In Old Regime France, not only were public and private credit markets entirely separate, so were public and private producers; i.e. firms that produced for the state had no private market interests, while firms that produced for the market were usually prohibited from producing for the state. Therefore, the state and its associated non-market-based patrimonial companies were the only entities dealing with large public projects in Old Regime France; smaller private projects drew from an entirely different and ultimately smaller pool of capital (Riley, 1986; Bosher, 1994). As a consequence, 18th century French private sector companies rarely undertook capital intensive projects. As previously discussed, sound public deficit finance when combined with market-based defense contracting spurred numerous private British firms to invest in capital intensive projects, especially during the middle 18th century (Ashton, 1968b; Deane, 1965; Pressnell, 1960, John, 1955). As will be discussed more below, entirely unsound public deficit finance practices, and a completely segmented market for government credit and production, contributed to the perpetuation of small localized consumer oriented non-capital-intensive private companies in Old Regime France (Riley, 1986; Bosher, 1994).

Furthermore, during 18th century conflicts, the difference between public and private market interest rates in France became increasingly pronounced

(whereas in Britain rates moved in tandem). Thus high public interest rates would drain all capital away from private borrowing as lenders sought to capitalize on the usurious rates being charged to the King. This, in effect, was an extreme form of crowding out, where large public borrowing completely eclipsed private lending and investment (Riley, 1986, 102; 156; 91). The adverse implications for defense expenditure inspired economic transformation in Old Regime France should be fairly obvious. For example, in France, where the King was not trusted and where private and public capital markets were not integrated, long-term public annuity rates during the Seven Years War averaged 14%, while short-term public paper (rescriptions) yielded well above that. This almost certainly crowded out borrowing for private investment at the 5% rente constiuee level. As a result, Old Regime France experienced a moribund economy during the Seven Years War (Bosher, 1994; Collins, 1995, 227-229). Meanwhile, both public and private rates remained below 5% in Britain throughout the Seven Years War, thus propelling an economic boom of monumental consequence (as previously evidenced).

The final, and perhaps most intractable, problem with French public deficit finance in the 18th century was the absence of a central bank. Recall that in Britain the Bank of England served the public by pooling wealth and lending it to the government at non-usurious rates, most crucially, during wartime. Additionally, modern accounting and professional bureaucracy met in the administration of the Bank, which over the course of the 18th century joined with Parliament to become an important financial check on the propensity to over-issue paper debt and

monetary instruments (Minton, 1975, 68; Bosher, 1994, 349; Dickson, 1967). Such crucial economic governance was entirely absent in France. There was no central bank managing bills and notes; nor was there an electoral legislative body to oversee one if it had emerged (Collins, 1995; Lossky, 1994; Bosher, 1994; Price, 1995; Pritchard, 1987; Riley, 1986).[107]

In summation, to suggest that the French financial system was murky and ineffective is beyond an understatement (Collins, 1995, xxxi). Due to poor organization, the lack of a real budget and precise accounting, the lack of an integrated credit market for public and private loans, a reliance on short-term credit provided by a small number of individuals, corruption, unknowledgeable leadership, and the absence of a central bank, French public deficit finance could not have possibly provided a sound financial infrastructure for long-term large-scale military expenditure. Hence, no benefits accrued from heightened military spending; indeed heightened military expenditure caused augmented economic stress. In fact, historians have time and again cited pecuniary pressures occasioned by the Seven Years War and the American War as the primary factor precipitating the collapse of the Old Regime in 1789 (Alder, 1997, 52; Collins, 1995; Bosher, 1994; Price, 1995; Pritchard, 1987; Riley, 1986). The financial structure of 18th century France could not sustain the increased pace of military spending necessary

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[107] It should be noted that in the early 18th century John Law attempted to establish a central bank in France, but due to French institutional deficiencies, his endeavor ended in abject failure. Unregulated printing of paper money resulted in a speculative bubble and collapse of epic proportions. As a consequence, the idea of central banking was thoroughly discredited in Old Regime France. For a more detailed description of John Law's folly see Minton, 1975; Garber, 2000; and Collins, 1995.

to fight a fiscally sound Britain, let alone foment a defense expenditure propelled mode of development shift. In Britain there emerged from public deficit finance a virtuous cycle which girded economic development, especially during periods of conflict; in France there emerged from public deficit finance a vicious cycle which destroyed economic prospects, eventually leading to the liquidation of the Ancien Régime.

MILITARY EXPENDITURE AND DEFENSE CONTRACTING IN FRANCE:

Now that the deficiencies with French public deficit finance have been covered, let's explore more closely the precise organization and functioning of military expenditure and military contracting in 18th century France; here too the potential for a defense expenditure inspired mode of development shift was entirely muted by the organizational configurations adhered to by the Old Regime. During 18th century wars, state spending in France tended to peak around 15% of national income, which is similar to the levels witnessed in Britain. However, owing to the extra costs borne by France for ordinary expenditure, Britain actually ended up spending nominally more to prosecute 18th century wars than its much larger and more populous rival (Riley, 1986; Brewer, 1988).[108] For example, the War of the Austrian Succession, the Seven Years War, and the War of American Independence

[108] At the level of aggregate expenditure, it is clear that 18th century France spent more than Britain on ordinary affairs of state; approximately 9% of national income in France vs. well under 5% of national income in Britain (Riley, 1986, 145; Mitchell and Deane, 1962).

cost France a combined 3.5 billion livres, while Britain spent the equivalent of approximately 5.8 billion livres on these three wars (Dull, 2005, 254).[109]

Nevertheless, war born costs wrecked the finances of France thus deterring economic transformation; while in Britain the financial system remained quite sound, underpinning a mode of development shift. We have reviewed many of the reasons why this was so above, and more reasons will be discussed below, but first it is important to note that 18th century France expended its war chest quite differently than did 18th century Britain. While Britain spent the overwhelming majority of its defense funds on naval warfare, France spent disproportionately on land based field and siege warfare.[110] This dissimilarity is important, for the disparate forms of conflict required very different things from each economy. As discussed, 18th century naval warfare was highly capital intensive, with the main costs being immense warships and heavy iron cannon (Lavery, 1987; Glete, 1993). Land based warfare, on the other hand, was significantly less capital intensive in the 18th century. Some artillery was deployed during land based warfare; however, artillery pieces remained few in number, mostly owing to mobility difficulties. 'Siege trains', for instance, occupied miles of roadway, and were towed at a snails pace by tens of thousands of horses. In fact, a grand siege army contained perhaps half the number of cannon present on a single mid-18th century British warship.

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[109] The conventional (and necessarily approximate) conversion rate for 18th century livres to pounds is 24:1 (Riley, 1986, 7).

[110] The ratio of army expenditures to naval expenditures in France during the first half of the 18th century at times reached an astounding figure of 10:1; later in the century this disproportion fell significantly, but still favored army expenditure (Kennett, 1967, 28).

The same applies to land based field armies; long vast field battles were typically fought with less cannon combined than was present on one British warship. Additionally, in the mid-late 18th century, land based cannon were light and inexpensive as compared with their sea-based cousins. Moreover, owing to their relative unimportance and ineffectiveness, artillery aspects of armies made very little progress between 1689 and 1784; whereas ship based cast iron cannon progressed by leaps and bounds over the course of the 18th century, ultimately culminating in the carronade. Of course, muskets were utilized in 18th century land warfare. However, muskets were manufactured easily and cheaply via traditional means, especially as compared with evolving cast iron heavy cannon.[111] Simply put, the main costs in waging land battle were labor rather than capital intensive. Thus, owing to its non-capital intensive reliance on large numbers of men rather than proficient weapons, French military expenditure did little to stimulate enhanced capital goods production or infrastructural development during the 18th century (Childs, 1982, 109; Lavery, 1987; Kennett, 1967, 28-30).

The French system of finance in place for military expenditure also compares unfavorably to that of Britain, making economic development as a result of military expenditure even more improbable in France. Due to unwieldy organization, much French military expenditure ran to waste. During the 18th century, the French military had a strange two tiered organizational structure for

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[111] Muskets were hand made and required little fixed capital for their production (Parker, 1979, 128-129). The production of muskets was 'hopelessly tradition bound' in France throughout the 18th century (Alder, 1997, 175).

procurement, where financial oversight and purchasing remained separate. 'Military intendants' were responsible for procuring all materials, but they were often left in the dark in regards to debts or current expenditures, for venal 'military treasurers' oversaw defense finances (Pritchard, 1987, 96-98; 189; Price, 1995, 53). In the Navy,[112] the Bureau of Funds was an intermediary between the military intendants and treasurers; it prepared the formal releases that enabled creditors and contractors to receive funds, thus adding yet another confounding layer to the procurement system. Given chronic under funding and opaque accounting procedures, "smooth operation of the Funds Office proved difficult if not well nigh impossible... formal releases were issued up to fifteen months after stores had been delivered and receipts were often eighteen months late" (Pritchard, 1987, 101; 106). To make matters worse, the venal treasurers of the Navy worked a system of private caisses, where their own private funds constantly mixed with the naval funds emanating from Paris; disaggregating the public and the private is therefore impossible when it comes to the payment systems of the French military (Pritchard, 1987). As a rule, treasurers-general of the Navy were not to use the funds entrusted to them to engage in private commercial trade. But treasurers-general often did, many times illicitly, thus drawing government funds into questionable private trading practices (Bosher, 1994, 292). Moreover, due to the system of private

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[112] Because Army intendants did not procure much in the way of capital intensive equipment, naval procurement will now be the main focus. Army expenditures occurred largely within a similar system but were even more wasteful because of the increased patrimonial aspects of the national army. "In a very real sense the army was not royal property, but the possession of proprietary colonels and captains who trained, equipped, and led their own men" (Kennett, 1967, 35; Alder, 1997, 29).

caisses, naval intendants and treasurers negotiated payments and budgets outside the purview of the controller general. In other words, the Navy (and Army for that matter) operated on numerous uncertain mini-budgets, and not at all on a general budget (Price, 1995, 53).[113] Without a general budget there was no way of knowing precisely how indebted the military had become; "Nothing could be more certain than the existence of these debts and nothing less certain than the figure of their total" (Bosher, 1994, 343). For example, no statement of naval expenses exists for the last two years of the War of the Austrian Succession, and the aggregate naval debt attained during the war remains uncertain to this day. Hence, reduction of the mass of old, unpaid, wartime expenses was never accomplished easily in Old Regime France, thereby impeding reconstruction and economic development in postwar periods (Pritchard, 1987, 102, 188-191; Bosher, 1994, 339-341). In short, the odd and complex mechanisms of military finance in Old Regime France prevented military expenditure from becoming an effective force of demand.

Most of the other difficulties with military equipment and supply encountered in 18th century France can be traced to the non-market-based patrimonial organizational structure of military contracting and the poor wording and administration of military contracts. The 18th century French state did not usually own the means of military production outright; although sometimes it did.

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[113] The controller general had little statistical knowledge of the Navy's needs or the nation's naval budget, 'and was in a poor position to match government revenue to naval expenditure' (Pritchard, 1987, 185).

Generally, the state tried to let private merchants and local producers absorb the risks involved in intermittent military markets. Nonetheless, French military contractors all relied heavily on state encouragement, assistance, grants, and patronage of various kinds for their survival. Contractors were cloaked in a series of social and legal privileges that allowed them to reap heady if intermittent profits regardless of efficiency. Such rights were won and retained through court intrigue and bribery (Kemp, 1971, 37; Alder, 1997, 130). Also, French military contractors were granted royal monopoly rights to produce their particular military wares, thus effectively eliminating competition. Moreover, in France there was no bidding process for military contracts; intendants let contracts to those producers to whom they had patrimonial ties (Pritchard, 1987). Pricing therefore tended to be founded on winks, nods, and handshakes rather than competitive haggling (Kennett, 1967, 108; Pritchard, 1987, 162). Additionally, as suggested above, major French military contractors did not produce at all for the civilian market, in fact, many times they were forbidden from doing so; therefore, even if innovations had arisen as a consequence of military production in Old Regime France, these innovations would not have been easily communicated to the civil marketplace (Alder, 1997; Kennett, 1967; Pritchard, 1987). Such uncompetitive, non market-based, contracting practices present the antithesis to the British system of military contracting. In fact, it can be said that the traditional methods of subsidizing and encouraging large scale military contracting Old Regime France led to 'artificial creations which in no real sense were the precursors of modern capitalist industry'

(Kemp, 1971, 37); as previously evidenced, competitive and market-based military contracting provoked a rather opposite effect in 18th century Britain.

To cap off this section regarding the many problems with military expenditure and contracting in 18th century France, it should be noted that French military contractors were known to be deplorably corrupt; but so were the state officials that dealt with them. Contractors 'escaped effective control by the intendant'; compliance was difficult to obtain since liability was circumscribed owing to state supported patronage (Kennett, 1967). Obscure contract wording and procedures insured that the military paid exorbitant prices and remained open to sharp, often fraudulent, business practices. Suffice it to say, the more honorable the contractor, the less considerable were his gains, and the majority of French contractors were taken to be 'a league of bloodsuckers' (Kennett, 1967, 108; Pritchard, 1987, 162). Nevertheless, the Crown many times 'succeeded in getting the better of its business partners' (Pritchard, 1987, 171; Bosher, 1994, 303). During wars payments were perennially delayed and uncertain as there were few clauses in contracts that related to swift or complete payment. Hence, military contractors often found themselves shouldering heavy financial burdens, holding paper that was difficult if not impossible to parlay at a profit; many were bankrupted as a result. But this merely cleared the way for yet another patrimonial privilege to be extended by the King (Pritchard, 1987, 162; Kennett, 1967, 111). In short, the contrast between the smoothly functioning competitive market-based

British defense contracting system and the now seemingly archaic French system of military contracting could not be anymore stark.

FRENCH MILITARY CONTRACTING AND THE IRON SECTOR:

Now that the mechanisms and machinations of 18th century French defense contracting have been surveyed, let's look more closely at concomitant effects, focusing on the key 18th century sector of capital goods related technological change – the iron sector. Unsurprisingly, the methods of awarding military contracts in Old Regime France did nothing to spur technological development in this important leading sector of the industrial revolution, as they plainly did in 18th century Britain. During the reign of Louis XIV most iron for the military was produced 'par regie', which meant that the state owned and operated the factories outright. This system of organization failed early in the 18th century due to a lack of capital and poor transportation. Afterwards, the state began to award iron contracts to private producers, but only in the form of royal monopoly grants. Predictably, the wording of the contracts conveying monopoly grants in French military production was terribly imprecise. For example, 18th century military iron contracts specified only agreed prices and quantities of weight. Thus ironmongers benefited from ignoring the military's needs and supplied only those goods of heaviest weight as quickly as possible regardless of quality; "The procedure practically ensured that a great deal of unwanted iron arrived at the arsenals" (Pritchard, 1987, 171).

On the other hand, iron contracting could be a ruinous business. Iron production for the military was completely segmented from iron production for the market in France. Recall that in 18th century Britain, market-based iron contractors would search for ways to adapt their products to the civilian market once military contracts ran out. The century-long interplay between the public and private sectors that obtained in the British iron sector was entirely absent in 18th century France. Add to this the long time between orders and payments, the latter made with insecure and steeply discounted paper, and the frequent poverty of French naval iron contractors is explained.

> "Far from holding the navy in fee, iron manufacturers were prisoners to be paid when possible but certainly not ahead of anyone else. The navy exploited the entrepreneurial skills and credit resources of its iron contractors, engineered their ruin if necessary in order to confine government financial failure as close to home as possible, and moved on with promises of generous advances and favorable prices to encourage new sources of credit in order that the (naval) department might continue" (Pritchard, 1987, 171).

That being said, what does the historical record regarding the fates of some of the more well known 18th century French iron contractors tell us about the importance of the structure of contracting in stimulating 18th century iron industry development; or as the case was in France, why did military contracting not spur 18th century French iron contractors to augment fixed capital and innovate upon production processes? Here again we will focus upon naval procurement, for such procurement was naturally more capital intensive than other forms of military procurement (Lavery, 1987; Glete, 1993; Kennett, 1967). From the mid 1730s,

most wrought iron goods and cast iron anchors for the Navy were produced by one contractor, Babaud, who became "the first 'Iron King' to emerge in 18th century France." Notably, none of Babaud's product ever appeared on commercial markets (Pritchard, 1987, 168; Parker, 1979, 127-128). "Although Babaud may have ruled over the largest iron empire in France, his establishment was not on a sound financial basis." Babaud was paid in rescriptions on which he lost at least 6% through discounts; often he would be paid in government paper that was significantly harder to negotiate. Two years into the Seven Years War (1756-1763), Babaud, starved of secure finance, was unable to expand sufficiently to keep up with heavy naval demand. Interestingly however, there were no real alternatives for naval wrought iron. Babaud had been granted monopoly rights, thus the French iron market had not benefited from years of interplay between competitive commercial market forces on one hand and military demand on the other, as was the case in Britain. Hence, private French iron manufacturers were not advanced enough to take on naval demand. In any case, even if Babaud's monopoly rights had been revoked, the funding just wasn't there for new firms to enter into naval iron production. Indeed, as the Seven Years War progressed "naval payments became more difficult to obtain." By February 1760 the Navy was basically experiencing bankruptcy and all iron orders were suspended; "To all intents and purposes Babaud was ruined" (Pritchard, 1987, 169; Parker, 1979, 127-128).

What of naval cannon production? (Babaud produced wrought iron and anchors, not cannon.) During the first half of the 18th century one family was given

sole right to provide cannon to the Navy, their name was Landouilette. "The decline of the fleet after 1715 and the quasi monopoly enjoyed by Landouilette's heirs led to the loss of skilled labor at other forges and failure to develop additional (cannon) production capacity elsewhere. By 1748 (Landouilette's) forges were badly neglected." Given family Landouilette's failures, naval intendants sought to widen the market for cannon manufacture as early as 1739. Their failed attempts provide a more detailed depiction of the middle 18th century French iron industry and its intersections with military contracting (Pritchard, 1987, 143).

During 1739 a yawning gap in naval ordnance supplies appeared. Nonetheless, few civilian market ironmasters were willing or able to transition over to military production. The problem lay in the structure of the French cannon market. "French cannon prices may have been too low to provide sufficient incentive to manufacturers." They were lower than British cannon prices, even though the British cast iron industry was more efficient, competitive, and technically advanced.[114] Unfair pricing seems to have been an effect of patrimonial French contracting practices. In Britain contracts were openly bid on by the entire British foundry market. In France, naval intendants sought out certain known ironmasters and used court power and interpersonal relations to agree to a price. Prices therefore tended to be lower than those that would have obtained in a free contracting market. To make matters worse, whereas cannon manufacturers in

[114] For example, between November 1748 and February 1763 the British Board of Ordnance paid an average of £21.6 per ton for cast iron cannon. Between 1748 and 1758 the French paid the equivalent of £19.6 per ton for cast iron cannon (Pritchard, 1987, 144-156).

Britain found themselves unhindered by heavy taxation and enabled by low interest rates for road construction, French cannon manufacturers found their requests for relief from the taille and corvée completely ignored, and were further burdened with governance by royal intendants that did not have cause to improve roads in and around foundries. Moreover, when a civilian ironmaster entered into state contracted military production, he immediately became subject to a whole range of stipulated production regulations. Additional difficulties militating against the entry of civilian ironmasters into cannon production in mid-18th century France include court based rivalries, tensions arising from different jurisdictions of the royal government, and the still medieval structure of the French iron industry itself (Pritchard, 1987, 144-156).

This sustained medieval structure was also a partial consequence of the monopolistic and noncompetitive nature of 18th century French iron contracting. In England, military contracting stimulated development in the early-mid 18th century iron industry, shifting it away from its medieval roots. In fact, as discussed earlier, it is not clear that anything else would or could have (Anderson, 1972; John, 1955; Harris, 1988). By the 1760s, market-based iron contractors in Britain were becoming vertically integrated. They were also increasingly utilizing steam-power and coke smelting to produce both their military and commercial wares (Ashton, 1968; Harris, 1988). In 1760s France, iron production for the civilian marketplace, which was entirely segmented from monopolistic military contracting, still exhibited dispersed forges, small enterprises, and narrow horizons.

> "Of feeble capacity, badly designed, and provided with only primitive bellows driven by water power, the (French) iron smelter was truly a rustic implement. The rhythm of work was slow and irregular, punctuated by long delays brought on by depletion of ore and charcoal, variable water levels of rivers, and seasonal demands on the labor force to work in the fields... Production methods were inexact and extremely wasteful... Moreover, the average (civilian) furnace could not cast any of the navy's four heaviest guns" (Pritchard, 1987, 147).

Additionally, the segmented nature of regional markets in 18th century France insulated all French ironmasters from any type of real competition; there simply was no such thing as a capitalistic iron market in France in the middle 18th century (Pritchard, 1987; Kemp, 1971). To further worsen matters, small private sector ironworks were many times owned by nobles who made money in other more profitable ways. These nobles were more concerned with carrying the title of 'ironmaster' than actually being a successful ironmaster. Such owners had little interest in entering the draconian world of cannon manufacture, and most refused to (Parker, 1979, 125; Kemp, 1971, 46).

Nonetheless, by 1748, the French Navy was desperate to find new sources for ordnance, owing to a new shipbuilding program that was getting underway. The Naval Minister had planned for an unrealistically large fleet requiring 4,099 new cannon – this would have been a difficult task for the British market at the time, in France it was impossible. In the spring of 1748 the lessee of Landouilette's works and an owner of a smaller ironworks agreed to supply the Navy with 1200 cannon in four years in a contract worked out by a naval intendant. (The largest British iron contractors together could produce this amount of cannon in about a

year at this time.) The Naval Minister (and his venal administration) additionally contracted for cannon from a noble-owned forge where naval guns had never been cast before (Pritchard, 1987, 145; Glete, 1993).[115]

Predictably, the newly minted contracts of 1748 proved insufficient to keep up with French naval demand. Landouilette's foundry quickly needed an extra 100,000 livres to assemble charcoal and iron ore. Then, Landouilette's foundry delivered only 68 guns in the first year of its contract, 13 of which were rejected upon proofing. From the beginning of 1749 to the end of 1754 the two foundries that had contracted to provide 1200 guns in four years were able to provide only 485 guns, many of which were rejected. The noble-owned forge, on the other hand, did not complete a single gun before 1751. Such meager productivity left the French fleet short by thousands of cannon. "In 1750 the navy had only about two-thirds of the guns required to arm the authorized fleet of sixty of the line and forty frigates." And the guns they did have were poorly constructed. The earlier grandiose plan for 4,099 cannon was scratched and reduced to 2,745 cannon. Still new production facilities would need to be found. The size of orders was yet again reduced in order to seek out smaller producers but there were few realistic or patrimonially acceptable offers for production forthcoming (Pritchard, 1987).

In fact, one noble French founder who let a contract to produce 400 guns in the early 1750s defaulted having not produced a single cannon. Concurrently, the

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[115] At this time the Naval Minister turned down offers from two non-noble ironmasters who were willing to cast cannon for the Navy; the impenetrable patrimonial nature of French military procurement would not allow for it (Pritchard, 1987, 145).

Naval Minister let the largest outstanding contracts for cannon production to a different ironmaster of noble-status named Montalembert. Montalembert had strong patrimonial credentials, but he had never cast cannon before. A contract for 800 of the Navy's three largest cannon was let to Montalembert who at the time owned neither a furnace nor a forge (Pritchard, 1987, 147). As would be expected, Montalembert's efforts at developing operations cut into the labor force and raw materials needed by the traditional ironmasters; monopolies had effected the structure of the French iron market at every level, and there was little room for new government producers, even poor ones. In the first quarter of 1752 only 13 of the 36 guns delivered by Montalembert were accepted. By May of the following year 26 more cannon had been delivered and half of these were rejected upon proofing. The problems with the guns were numerous, leading James Pritchard (1987: 148) to declare that "Montalembert's production efforts had been disastrous." By November 1753 "the navy had advanced 1,200,000 livres to Montalembert and received less than 200,000 livres worth of guns." Montalembert was forgiven for his failures owing to his court connections, but the Navy was left in dire straits. With hostilities breaking out in late 1755, the French Navy could only arm 18 of the line and 7 frigates (Pritchard, 1987, 149); while the British were effectively arming well over 125 state of the art battleships (Glete, 1993). Is it any wonder that the French Navy was all but obliterated in the first three years of the Seven Years War?

During the rest of the Seven Years War, "the large number of rejected guns,

large number required, scarcity of raw materials, and failure to find additional entrepreneurs", along with the ongoing thrashing by Britain, provided the Navy with incentives to seek technical innovations in the iron industry in order to increase efficiency and the number of acceptable guns. In the early 1760s, hollows and bubbles were still regularly appearing in French cannon; "The chief means to obtain greater solidity and density, using coke iron and re-melting pig iron in a reverberatory or air furnace, were unknown to the French", although well-known to British cannon casters, at this time (Pritchard, 1987, 151). With naval ordnance shortages in full bloom, the Secretary of the Navy, Rouille, sought out a famous inventor, Jean Maritz, who had recently successfully installed British methods of smelting while also developing a horse-driven solid cast boring apparatus for the King's pleasure. It should be noted that British ironmaster John Wilkinson was contemporaneously developing a Newcomen engine driven hydraulic cast iron waterwheel powered cannon lathe (Ashton, 1968). All the same, Maritz was solicited to erect horse-driven boring machines in all of the foundries currently providing cannon to the French Navy. At the state's expense, Maritz's new methods were forced upon Montalembert and the other naval cannon founders, each of whom surely resented the disregarding of their patrimonial status. Ironically, Montalembert was still unable to produce usable cannon; immediately following the installation of Maritz's machine, Montalembert's ironworks produced 81 cannon, only 9 of which were accepted by the Navy. Montalembert was now 1.9 million livres behind in his deliveries. On the grounds that the Crown had paid

for the new technology, Montalembert was forced to place his foundries directly under state control, and Maritz became the overseer. This shift to partial production 'par regie'

> "was an act of desperation and the subsequent signing of additional contracts was sheer expediency... no alternative existed but to obtain cannon from anyone offering to produce them... But traditional methods of smelting, inflexible market structures, and ingrained acceptance of the existing order could not be overcome in such a brief period of time" (Pritchard, 1987, 158).

Despite Maritz's innovation, production persistently fell short (Pritchard, 1987, 153-155; Alder, 1997). The trouncing by the British therefore continued; France was shellacked at sea and abroad during all seven years of the Seven Years War (Kennedy, 1987).

The final Old Regime attempt to improve and expand production of naval cannon occurred during the War of American Independence, and further displays just how little contracting procedure and iron production processes changed in France over the course of the 18th century. In the late 1770s, the Navy sent an intendant into the countryside to locate an area suitable for large-scale technologically advanced cannon manufacture based upon the British ordnance model. In fact, the French Navy hired John Wilkinson's younger brother, William Wilkinson, to supervise the construction of the new foundry. The intendant and Wilkinson found the perfect site – superior coal and iron deposits were close by and the region was easily accessible by two major rivers. The question that immediately arises (at least for me) is; in 1780, how was such a region not already

being exploited for advanced cast iron production? Again, the answer lies in the nature of the French contracting system along with France' underlying economic institutions. Owing to the patrimonial, monopolistic, uncompetitive, and inefficient methods of French iron production and defense contracting, ironmasters tended not to move locations in search of better resources or processes. Their production areas were government designated, their resources were government protected, and for contractors their markets were state assured. Additionally, a new plant in a new area would likely be burdened with new tolls, fees, and duties stemming from the onerous internal taxation system. Plus, there was no competition in the 18th century French iron market, certainly not any fostered by military contracting. Why would any iron contractor front the expenses involved in switching locations, or techniques for that matter? France clearly had the raw resources necessary for advanced iron production, but its institutions prohibited them from being exploited; capital intensive development was just not a rational option in Old Regime France (Parker, 1979, 132; Kemp, 1971, 39; Price, 1975, 115).

So, in the late 1770s, when the French Navy sought to produce cannon by British methods, it was entirely upon the government to make it happen. The Le Creusot ironworks was commissioned by the government in 1781 with the state directly providing the lion's share of its initial financing. The majority owners were ostensibly private, but they were also, of course, very wrapped up in the spoils of the Old Regime; rather than being entrepreneurs of a modern type, they pushed

their way forward through the use of court intrigue (Kemp, 1971, 39; Price, 1975, 115). Under William Wilkinson's watch amid the court's baneful gaze, the government subsidized the construction of the first vertically integrated, coke-smelted, and internally railed ironworks in all of France. And French cannon production proceeded better than ever during the American War, thus sustaining French victories at sea. Importantly, however, this major ironworks was again completely isolated from the civilian market. Hence, with the end of the war, demand immediately ceased. And as the French government fell on hard financial times, the state grants and subsidies that had enabled profitable production at Le Creusot gradually disappeared. The demise of Le Creusot then parallels the demise of the Old Regime (Parker, 1979, 133; Price, 1975, 110).[116]

In summation, owing to the poor institutional configuration of defense contracting, the segmented and monopolized nature of production, and the insecurity of military financing, the cast iron industry in France remained hopelessly backward vis-à-vis its rival British counterpart. By the end of the 18th century the French iron industry was over 100 years behind that of Great Britain and still closer to medieval rather than modern (Kemp, 1971, 32, 44-46; Parker, 1979, 125; Price, 1975, 145; Pritchard, 1987; Alder, 1997). Thus it is not surprising that when French artisans attempted to recreate Watt's steam engine

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[116] A discussion of French artillery production for land warfare has been omitted here because artillery cannon were lighter and far less capital intensive than naval cannon. Moreover, innovations in artillery production in France were stymied by the same set of factors that encumbered naval cannon production. For a wonderful analysis of how patrimonialism, archaic institutional configurations, and non-market-based military contracting combined to minimize innovation and fixed capital investment in artillery production in 18th century France see Alder, 1997.

from detailed drawings they found that the pieces did not fit; French cast iron technology was simply not adequate to the task (Alder, 1997, 146). In large part, it is backwardness in this key sector that delayed industrialization in France (Deane, 1965; Crouzet, 1990). Hence, via the French comparison, it becomes apparent that military expenditure, and the concomitant organizational configurations of defense contracting, did indeed play a critical role in the mechanisms propelling the British industrial mode of development shift forward.

In conclusion, the overarching question driving the French case analysis has been as follows: France spent nearly as much on warfare in the 18th century as Britain did; if military expenditure helped pave the way for industrialization in the British case, why were there not the same returns to economic development in the French case? To answer this question, French autocracy, French property rights and transaction costs, French public deficit finance, the methods of French military expenditure and defense contracting, and the way said methods effected the French cast iron sector, have been examined. What clearly emerges from the analysis is that the 'military expenditure impetus to mode of development shifts theory' and all of its complex related corollaries were not at all operative in 18th century France. Accordingly, Old Regime France did not generate a mode of development shift; in fact, heightened military expenditure eventually consigned the increasingly antiquated and still largely agrarian Old Regime to the dustbin of history (Kemp, 1971, 66; Collins, 1995; Bosher, 1994; Price, 1995; Pritchard, 1987; Riley, 1986).

Perhaps it can be said that non-industrial petty commodity production

reached some sort of apogee in late Old Regime France, but the British industrial feedback loop was already powerfully gathering momentum; France had clearly missed the boat (Kemp, 1971, 30; Collins, 1995, 220; Crouzet, 1990). For the next century Britain would lead the world ever deeper into the industrial era. Then, around the turn of the 20th century, the mantle gradually passed to Germany in Europe and the United States across the pond (Kennedy, 1987; Modelski and Thompson, 1996). Thus igniting a decades long, albeit highly intermittent, political and economic conflagration that slowly gestated the conditions in which a novel gelling of the mechanisms underpinning the 'military expenditure impetus to mode of development shifts theory' would again occur. It is to the WWII era, then, that we now turn, when military competition rather suddenly shifted towards a form of mega-expensive capital intensive informational warfare previously inconceivable (DeLanda, 1991). Eventually, this shift would transmogrify the economic and social bases of global production in ways no less profound than the initial genesis of industrial production had in Britain. This time, however, the United States of America would furnish the crucible (Castells, 1996; Cortada, 2002; Freeman and Louca, 2001; Dertousos, 1998; Modelski and Thompson, 1996; Harvey, 1991; Beniger, 1986).

Infrastructures of Aggression: Military Expenditure during the British Industrial and American Informational Mode of Development Shifts

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Volume Two

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CHAPTER 9: THE THEORY AS APPLIED TO THE US CASE

The causal role that military expenditure played in the genesis of an industrial infrastructure in 18th century Britain has been thoroughly analyzed. Also, a discussion highlighting the institutional components that were absent in the 18th century French case, thus making the 'military expenditure impetus to mode of development shifts theory' not operative there, has been completed. The dissertation now switches temporal epochs in order to analyze the causal role that military expenditure played in the genesis of an informational infrastructure. Here the focus will be the United States of America, 1940-1999;[117] the site where decades-long massive military expenditures interacted with the contracting market and the economy more generally to produce the technologies which now compose the infrastructural foundation for the informational mode of development. Although the generalized theory guiding the dissertation remains unchanged, its precise application to the American case differs owing to the particulars of the new case and time. Thus, before the comparative historical narrative commences, an overview of the theoretical variables, and the way in which they interacted in this new era, is in order.

To begin with, the object of interest now modifies from an industrial mode of development shift to an informational mode of development shift. Chapter one defined the informational mode of development as a globally extensive regime of

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[117] The years 1940-1999 are generally accepted as the temporal interval wherein the development and wide diffusion of digital information technologies occurred and the advent of a global infrastructure for informationalism appeared (Ruttan, 2006; Cortada, 2002; Dearnley, 2001; Castells, 1996, 1998).

accumulation wherein digital information technologies are harnessed to derive productivity gains from economic enterprise in new and flexible manners. Dubbed informationalism by some (Castells, 1996, 1998) and flexible volume production by others (Borrus and Zysman, 1992, 20-1; Piore and Sabel, 1984; Harvey, 1990), the literature on this new mode of development is vast, containing wide ranging topical discussions relating to technologies, methods of manufacturing, systems of management, inventory control, the rise of service industries, marketing techniques, network geometries, finance, and more. Clearly though, the one common thread that binds the many facets of flexible volume production entails the novel application of information technologies to all sorts of commercial endeavors (Cortada, 2002; Dearnley, 2001; Greenwood, 1997; Castells, 1996, 1998; McKenney, 1995; Harrison, 1994; Borrus and Zysman, 1992; Harvey, 1990).

As discussed in the introductory chapter, the literature on flexible volume production tends to have a rather narrow focus regarding causal descriptions of the rise of the new regime of capital accumulation: The consensus is that a deep profit recession brought on by increased competition and the oil crisis caused corporations worldwide to seek cost-saving rationalizations in their applied business models. Outsourcing increased, offshore production increased, and information technologies were integrated into corporate practices at the process, managerial, and organizational levels, thus enabling profit maximization and the globalization of economic production (Piore and Sabel, 1984; Harvey, 1990; Harrison, 1994; Castells, 1996, 1998; Cortada, 2002).

Certainly, this causal description is persuasive, but it is also narrow in that it ignores two exceedingly crucial questions. First, what were the causal processes that led to the coordinated development of the radical new infrastructural information technologies that corporations adopted en masse in order to globalize and rationalize production during the 1970s corporate profit recession? Second, what causal processes drove the pace and timing of the rise of the *new* firms which commercialized and manufactured information technologies? Causal descriptions pertaining to the advent of flexible volume production that attribute causal primacy to a corporate profit recession are obviously more concerned with large already established firms than with the small new firms that managed to offer up innovative informational devices at prices traditional corporations were willing to pay. Moreover, a profit recession would constrain new capital investment expenditure and present a barrier to the rise of new firms, and yet both occurred. Thus it becomes apparent that the profit recession causal impetus leaves much to be explained.

Interestingly, there is an extant historical literature which traces the 20th century developmental roots of the critical infrastructural information technologies and the firms that eventually came to commercialize them. One simply cannot escape the defense-related[118] nature of both the technologies and the firms (Ruttan,

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[118] Throughout the American case, when the term 'defense-related' is applied to technologies it refers to any device that initially played a prominent role in the advanced military hardware of the day. When the term is applied to bureaucracies, it includes any agencies that fall under the auspices of the DOD, the armed services, or NASA (see note 128 for more on NASA as an important defense-related agency). When it is applied to projects it refers to any project that has or had

2006; Campbell-Kelly, 2003; Abbate, 1999; Cerruzi, 1998; Flamm, 1988). But there is a wide disconnect between this historical literature and the sociological literature which discusses the manifestations of flexible volume production. The following American Case will remedy this disconnect by demonstrating that military expenditure not only propelled the emergence of the central infrastructural informational technologies, but also, through its vicissitudes, affected the timing, pace, and quality of the transition to flexible volume production (i.e. the informational mode of development).

Owing to the diverse nature of the informational technologies underpinning the informational mode of development shift, and the complex developmental roots of each, any project that sought to include all defense expenditure induced informational infrastructural technologies would surely collapse under its own weight.[119] Thus the American case will focus on three critical, fundamental, and essential infrastructural informational technological sectors: the semiconductor sector, the computer sector, and the computer networking sector.[120] These three

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primarily national security rationales for its initiation. When it is applied to firms it includes any company that regularly acts as a defense contractor and receives a fair proportion of revenue (at least 15-20%) from its defense contracting activities.

[119] The following are among the important information technologies with defense-related roots that will not be covered in the American case: satellites, wireless communication, cellular networks, GPS, geographic information systems, lasers, photonic communication, infrared remote control, AI technologies, robotics, machine vision, programmable machine tools, computer-aided manufacturing, a myriad of complex health care technologies, long-range digital photography, digital-analog converters, chips for portable communication devices, data compression, and advanced data encryption (Ruttan, 2006: DeLanda, 1991; NRC, 1999; Gavaghan, 1998; Day et al, 1998; Smith, 1985; Noble, 1985; Tirman, 1984; DiFilippo, 1990; Hecht, 1999; Hecht, 1984; Goldstein, 1991, 31-41; Vernez et al, 1996).

[120] Since it is many time difficult to separate software and hardware when discussing computers and computer networking, the computer and computer networking sector analyses will include discussions of software as necessary or appropriate.

sectors capture the informational infrastructure at the micro, meso, and macro levels: the semiconductor is the indivisible micro unit of informational infrastructure, the Internet is the macro-level holistic global organizational unit of informational infrastructure, and the computer is the meso level unit of action in the informational infrastructure. It will be shown that US military expenditure was indispensable to the coordinated genesis and diffusion of these three interrelated informational 'general purpose' technological sectors.

GENERAL PURPOSE TECHNOLOGIES AND MILITARY EXPENDITURE IN THE 20TH CENTURY:

The notion of general purpose technologies (GPTs) is somewhat new, and a hearty literature has recently sprung up to analyze them. The concept is being introduced here because a working knowledge of GPT theory is essential if one is to comprehend the contemporary causal processes embodied in 'the military expenditure impetus to mode of development shift theory' as applied to the American Case. A GPT can be defined simply as a technology that 'exerts a pervasive impact across a number of industries' (Ruttan, 2006, 5; Helpman, 1998, 10).[121] GPTs also tend to be heavy infrastructural capital goods vertically and horizontally linked to many other technological sectors thus increasing their

[121] "GPTs are characterized by the following features: (1) They are extremely pervasive; that is, they are used as inputs by a wide range of sectors in the economy. (2) Their potential for continual technical advances manifests itself ex post as sustained improvements in performance. (3) Complementarities with their user sector arise in manufacturing or in R&D technology" (Helpman and Trajtenberg, 1998, 55).

potential for application in a number of different industries (Ruttan 2006; Helpman and Trajtenberg, 1998; Lipsey et al, 1998; Bresnahan and Gambardella, 1998).

In a limited sense then, cast iron manufacturing technologies, along with puddling and rolling, the steam engine, and even shipping technologies, could be considered GPTs in late 18th century Britain. Such application of the term though is anachronistic in that an additional crucial definitional feature of a GPT relates to the institutionalization of innovation and the international environment for rapid technological diffusion that evolved over the course of the 20th century; such a technological milieu, wherein novel inventions swiftly circulate, can hardly be said to have existed in the 18th century world-economy (Mokyr, 1993; Bell, 1973).[122] Because general purpose technologies can, in the contemporary era, be applied to production and R&D in numerous diverse and variegated settings and sectors, gains from GPT innovation are, by definition, highly diffuse; many firms can and will capture their gains, usually quite quickly. However, the capital intensive, technically advanced, infrastructural nature of general purpose technologies also makes them incredibly expensive to develop. Hence there is a disconnect between the high costs of innovation and the diffuse gains from innovation that could be expected by any contemporary firm if it were to develop an advanced capitally intensive GPT (Ruttan, 2006; Helpman and Trajtenberg, 1998).

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[122] Also, a key aspect of a modern GPT is that "productivity of R&D in a downstream sector increases as a consequence of innovation in the GPT." Given that pre-20th century inventions involved diminutive R&D, such a theoretical definitional component makes little sense when applied to the 18th century (Helpman, 1998, 3).

GPT theory avers that, in the modern era, this high cost / diffuse benefit disconnect has been surmounted only through the conscious application of state funds. For example, electric power generation was one of the first infrastructural GPTs to emerge in the early 20th century (Lipsey et al, 1998). In order to benefit from this potent transformative force, states around the world necessarily subsidized the construction of electric power infrastructures. Individual firms were then able to profit from developing inexpensive electrical appliances without any one firm having to assume the high cost / diffuse benefit risks intrinsic to power grid development (Helpman, 1998, 4; Lipsey et al, 1998, 27; Ruttan, 2001). In this case, however, there were numerous clear and immediate economic and social advantages that would devolve to any nation with a power grid, and numerous disadvantages that would obtain for a nation without one. The informational technologies that form the objects of interest in this leg of the study were different. In each case, there were no overwhelming or immediate economic or social justifications for their development. Ultimately globally useful and widely applicable infrastructural informational GPTs initially represented a radical departure from current technological and economic practices, and years of R&D along with multiple billions of dollars were required to bring them to commercial maturity (Ruttan, 2006; Ceruzzi, 1998).[123]

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[123] Currently favored theories of technical change, such as induced innovation (Ruttan, 2001), evolutionary advance (Nelson and Winter, 1982), and path dependence (David, 1985; 1990) do not specifically address the emergence of revolutionary GPTs. In the evolutionary revision to neo-classical theories of technical change, routine replaces profit maximizing as the overarching determinate of the pace and direction of technical change. Competitive pressures lead firms to

A crucial concept that guides the theoretical analysis in the American case then can be stated thusly: *The informational GPTs that coalesced to form the infrastructure of the informational mode of development were so complex, expensive, and radically new that their development required national security justifications in order to enact the long-term large-scale government expenditure necessary for their innovation.* An important corollary to this argument states that the private market alone would have proved insufficient to produce radically new infrastructural informational GPTs (Ruttan, 2006, 177; Markiewicz and Mowery, 2003).[124] Throughout the temporal period marking the American Case (1940-1999), it will be shown that private firms had to be induced by non-market forces to engage in the expensive, time-consuming, and uncertain R&D inherent in the invention of informational GPTs (Ruttan, 2006, 14). This is because "the bulk of commercial R&D activity involves relatively minor improvement or modification of existing processes" (Peck and Scherer, 1962, 45; 534-5); not work on radically new and expensive inventions and products (Ruttan, 2006; Nelson and Winter, 1982). Cost consciousness, immediate profit potential, and process adaptations to rather small market changes govern R&D expenditure in a modern capital market

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search for technical alternatives, but satisficing behaviors lead firms to reduce search costs and eschew independent research costs as much as possible. This leads to path dependent technical change that favors small process innovations over the development and implementation of radical technical innovations. Thus, in the private sector, the technical condition of industry in the prior period is the main determinant of the innovations that are adopted in future periods (Ruttan, 2006, 11-12; Helpman, 1998, 2; Nelson and Winter, 1982; Goldstein, 1991, 29).

[124] In the words of Vernon Ruttan (2006; 177); "Can the private sector be relied on as a source of major new general purpose technologies? *The quick response is that it cannot!* When new technologies are radically different from existing technologies and the gains from advances in technology are so diffuse that they are difficult to capture by the firm conducting the research, private firms have only weak incentives to invest in scientific research or technology development."

(Vayrynen, 1992, 105; Goldstein, 1991, 29; Ruttan, 2006, 178). Additionally, most private-sector R&D tends to be aimed at short-term projects. "Decision makers in the private sector almost never have access to the patient capital implied by a 20 year, or even a 10 year, horizon" (Ruttan, 2006, 177; Fox, 1974, 21). Moreover, in the commercial sector profit gains from the introduction of a radical technology must be large enough to justify writing off investments in previous technology. Therefore, it becomes highly improbable that a private firm will independently pursue an R&D effort if 1) the costs are high, 2) the risks of failure are great, 3) the project's ultimate profitability is uncertain, 4) the application of resulting innovations are likely to be uneconomical, and / or 5) the development timeline is apt to be protracted (Conca, 1992, 246). Clearly, as will be shown, the R&D projects that led to the revolutionary informational technologies being analyzed here scored off the charts on each of these measures (Flamm, 1988; Cerruzi, 1998; Abbate, 1999).

If endogenous private market processes were insufficient to generate the R&D efforts that resulted in the technologies that form the infrastructural core of the informational mode of development, how did US military demand during the Cold War differ? To begin with, in the modern age, the US military not only tolerates revolutionary technological advances, it welcomes and encourages them.[125] In fact, "a sizeable step forward must be offered in order to justify the

[125] Many economic historians have found that military organizations have historically been conservative in their approaches to and acceptance of new technologies. However, in the US, since at least the inception of the Cold War, "there is an empirically established general tendency among

great cost of creating a new generation of weapons systems" (Fox, 1974, 469). Over the course of the Cold War such innovation-centered policies led to a weapons industry wherein the single most important determinant of firm survival was the ability to adapt to and incorporate radical changes in technology over the long-term (Scherer, 1964, 80; Fox, 1974; Weber, 2001). Additionally, obsolescence leads to immediate amortization in the military sphere. The DOD therefore casts a wide net, looking for projects that will yield inventions likely to drastically improve a broad variety of weapons systems over a long period of time (Peck and Scherer, 1962, 283; Ruttan, 2006).[126] Any technology that may convey a strategic advantage in the coming decades is pursued and funded vigorously (Peck and Scherer, 1962, 236-237; Ruttan, 2006; Stowsky, 1992). Which points to another crucial difference between endogenous private market processes and exogenous US military demand; the time and fiscal horizons of the US military are far longer and larger than the horizons of market firms. The DOD has nearly unlimited access to patient capital, and is willing to wait decades for major R&D breakthroughs. Such a patient, persistent, and flexible orientation devolves from the fact that the DOD is not governed by profit logic (Vayrynen, 1992, 105; Smith, 1985, 9; Boies, 1994, 26; Kovacic, 1990b, 106).

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soldiers, bureaucrats, and politicians in charge of procurement to favor the most sophisticated technologies" (Farrell, 1997, 84). The ever present threat of total annihilation helped to foster this reorientation (Vayrynen, 1992, 17).

[126] In the commercial sector, on the other hand, slow amortization impedes technological diffusion; it is "the market's means for assuring balanced growth and orderly economic development" (Clark, 1966, 216).

Furthermore, as a new weapons technology moves from R&D to production, the military's incessant focus on testing and developing testing rigs, which are themselves technological achievements, reveals information about design weakness, detects trouble-spots, observes technical performance under varying conditions, and pinpoints the stages in manufacturing where defects and bottlenecks occur; at costs and expenses seldom if ever incurred in the private sector (Smith, 1985, 18; Ruttan, 2006, 6). Procurement then provides initial markets at premium prices before the technologies have reached commercial viability. Such an insulated and guaranteed market for revolutionary new technologies "allows manufacturers to improve their products and reduce costs by gaining production experience, a phenomenon known in the field as coming down the learning curve" (DeGrasse, 1984, 78; 86; Ruttan, 2006, 6; Smith, 1985).

This is not to say that there are not numerous problems with the American system of defense-induced development. The tribulations are copious; the pertinent ones will be discussed below. It is also not to say that a heavily funded and coordinated government effort directly aimed at creating civilian technologies is less desirable than the military focused technological development programs that obtained in the US over the latter half of the 20th century. This author strongly believes that the global economy would be indescribably enhanced if a similar amount of time, capital, and effort (over 10% of the world's largest GNP for more than four decades) were expended in an effort to coordinate private firms to develop GPTs that have no security justifications, just civilian ones. However,

such a grand civilian effort has never been undertaken by any nation, and the prospects for the US government undertaking one anytime soon seem dim (Vayrynen, 1992, 27).[127] A national security effort driven by fear, political intrigue, and crisis may not be the most efficient method of creating radically new developmental trajectories and infrastructural GPTs for the civilian economy. But, as will be shown, national security does lie at the crux of the processes which enabled the core infrastructural technologies of informationalism to emerge in commercially viable forms.

The above discussion has hopefully illuminated the theoretical reasons why heavily funded military demand materialized as a critical component in the processes that led to the development of informational GPTs. But little has as of yet been said in regards to why the GPTs that did obtain were informational in nature. They were so owing to the changes in methods of warfare that occurred immediately prior to, during, and after WWII. Although information analysis had long been an important component of warfare, during WWII it became the crucial component conveying triumph upon the victor (DeLanda, 1991; Ceruzzi, 1998, 8). The pace, scope, geographical space, and tactical options involved in battle exploded exponentially during WWII. Formulating strategy came to involve countless variables, possibilities, contingencies, and environments; the human mind

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[127] One may be tempted to fall into creating some opportunity cost equation exploring what would have happened had defense funds been spent on civilian technological development (such as in Dumas, 1995, 7-10). But in the real world there is no indication that defense funds for military R&D would have in fact been spent on civilian technological development had they not been spent on defense (Stowsky, 1992, 233; Clayton, 1970, 152; Smith, 1985, 33).

was incapable of fathoming all of the strategic options without the aid of mechanical information processing devices. The increased scope of warfare also generated a greater need for long-range reconnaissance and data transmission. Such data transmission, utilizing radio waves in a variety of formats, gave rise to intense cryptology battles wherein Axis and Allied powers played high-tech games of cat and mouse attempting to encode and decipher informational transmissions; and then hide the facts as to whether they had or hadn't broken the enemy's ciphers (DeLanda, 1991, 186). Cryptology then too came to rely on mechanical information processing machines during WWII. Additionally, the new rapidity and pace of aerial and ground combat during WWII made previous targeting techniques obsolete. Targeting now had to rely on self-regulated mechanisms of informational data processing and translate informational feed back into real-time action. Infantry weaponry also became more precise, thus spurring operational and tactical flexibility, which in turn required small mobile communicational devices to link field units with command and control centers (DeLanda, 1991, 43, 72; Vayrynen, 1992, 21). Together these developments brought information processing to the foreground of all aspects of warfare. The final development cementing informational processing as the lynchpin to triumph was the advent of nuclear warfare. Not only did the Manhattan Project require vast computational power to simulate the consequences of a nuclear explosion before the fact; but the prospect of total national annihilation gave rise to a form of cold war with a heightened need for real-time global reconnaissance wherein all strategy and many military

operations were relegated to the imaginary, and therefore informational, sphere. In brief, WWII and the Cold War created unique motivations for rapid and radical technological advances in informational systems development (DeLanda, 1991; Weber, 2001, 48). And in the end, it was America's heightened capacity for real-time information processing at the global level that enabled the United States and its allies to emerge from the 20th century victorious (DeLanda, 1991; Castells, 1996, 1998).

Crucial to the development of this capacity, a capacity which ultimately served as an incubator for the technologies which have come to create the infrastructural base for the informational mode of development, were all the elements involved in the interacting set of multiple conjunctional causal variables highlighted in both chapter one and the British Case: long-term large-scale military expenditure, capitalistic defense contracting, efficient taxation, sound public deficit finance, the institutional prerequisites to economic development, and insulation from attack. Since the size, nature, and vicissitudes of US military expenditure (including NASA expenditure figures)[128] over the years 1940-1999 will be covered

[128] NASA expenditures will also be included in military expenditure aggregates. This is common practice in literatures analyzing the military's role in technological development, because during the Cold War most NASA programs had some sort of major defense justification or use (Ruttan, 2006, 60). In fact, the main reason NASA was separated from the DOD and termed 'civilian' was because Eisenhower wanted to establish 'free' global space, which would endow the US with the freedom to float satellites over Soviet airspace; in other words, the civilian orientation of NASA has always been somewhat of a cover for defense-related efforts in indivisibly international space (Gavaghan, 1998). Since NASA expenditures inevitably find their way into the same contracting marketplace as DOD expenditures, and are disbursed to that marketplace via embedded autonomous bureaucracies similar in organizational form to those in the DOD, it seems reasonable to include NASA R&D and procurement expenditures in the analysis. Given their structure and purpose, such expenditures do fall under the rubric of the dissertation's general theory.

in detail in the following chapters, just one point needs to be made now in regards to this primary variable, and it is a key point: *Only a certain kind of military spending activated the 'military expenditure impetus to mode of development shifts theory' in the American case – expenditure on 'advanced weapons'*[129] *R&D and production.* Expenditure for advanced weapons development and procurement consistently pushed the state of the art in the high tech sectors that compose the objects of interest in the American Case; while conventional spending on troops, rifles, ordnance, buildings, and the like, did nothing to activate the processes that yielded information technologies.

Also, not much needs to be said at this point in regards to the 'institutional prerequisites to economic development' and 'insulation from attack' variables. The institutional prerequisites to innovation and economic growth remained constant between the 18th and 20th centuries (North, 1990; Rostow, 1975), and insulation from attack was a simple historical fact for the continental United States during the temporal interval being studied (although attack was possible it never materialized). Hence, little more will be said of these two variables going forward. The rest of the present chapter will thus be devoted to a discussion of market-based defense contracting, efficient taxation, and sound public deficit finance as applied to the American Case. One must keep in mind, however, that the raw invention of infrastructural informational GPTs is only half the story involved in America's

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[129] E.g. guided missiles, tracking systems, tracking avoidance systems, space-based weapons, satellites, smart bombs, long-range real-time communications systems, crypt-breaking and espionage devices, etc.

latter 20th century informational mode of development shift; the story of the diffusion of infrastructural informational GPTs into the global commercial marketplace, and the ways in which this diffusion was helped or hindered by military expenditure, composes the other half. The structure of American market-based defense contracting, taxation, and public deficit finance were important in different ways to both sides of the development / diffusion equation. In order to capture this effect, the theoretical analysis conducted in the rest of this chapter will be broken down into three main sections: The first section will discuss the organizational configuration of market-based contracting in the American Case. The second will outline the synergistic processes between market-based defense contracting and the market more generally that conditioned the pace, quality, and timing of the commercial diffusion of the informational GPTs undergoing analysis. The third section will tackle and dissect the funding variables (efficient taxation and sound public deficit finance), describing their causal and theoretical importance to both sides of the development / diffusion equation. The chapter will conclude with a brief dialogue addressing the long-standing debate over the relationship between military expenditure and productivity growth in the 20th century, and the ways in which this study contributes to and fits into this debate.

DEFENSE CONTRACTING IN THE AMERICAN CASE:

As stated in chapter one, Peter Evans' (1995) theory of embedded autonomy guides the analysis of the organizational structure of defense contracting

throughout the dissertation; it provides a theoretical orientation for evaluating the ways in which states and private firms can interact to develop new technologies and negotiate novel technological trajectories. Although Evans focuses upon civilian bureaucracies and high tech companies in developing nations, I argue that his theory is applicable to defense bureaucracies, defense contractors, and advanced technological development in the US; with one major caveat: In developing nations, civilian bureaucracies expressly chart technological trajectories based on already existing commercial technologies. Defense bureaucracies in the United States after 1940, on the other hand, charted a technological path for national security, and in doing so developed informational technologies previously unseen in the commercial sphere. The overwhelming effects these technologies then had on production as they diffused into the commercial sector were largely unintended and mostly unexpected. Nevertheless, the parallels between the methods and organizational structures that have successfully activated high tech IT production in the developing world and successfully created advanced information technologies in the United States are absolutely striking.

First, let's briefly review Evan's conception of embedded autonomy. According to Evans, state led technological development in a market milieu requires 'intimate connections' between firms and states, with developmental state agencies being autonomous and at the same time 'embedded' in industrial capital (Evans, 1995, 32). The crucial dynamic mechanism in embedded autonomy arises from dense formal and informal social networks tying state bureaucracies (which

approximate Weber's ideal type) to private industrial capital; these links allow for the exchange of ideas, information, knowledge, and personnel between the two otherwise autonomous sectors. Informational feedback traverses the embedded links as autonomous state bureaucracies and connected private firms negotiate the technological trajectories that serve the state's goals along with private firms' bottom lines (Evans, 1995).

Let's now explore the state-centered aspects of the theory as applied to the American defense complex, focusing on the operative structure rather than on the system's historical roots. [130] At the top of the bureaucratic hierarchy sits the Department of Defense (DOD) and its' associated Office of the Secretary of Defense (OSD). Beneath these offices there exists a multitude of bureaucratic armed service procurement agencies. In fact, hundreds of bureaucratic organizations participate in any one advanced weapons procurement decision in the United States. Volumes have been devoted to their description.[131] Listing all of the agencies here is neither possible nor necessary. In regards to state side autonomy what chiefly matters is the Weberian character of the bureaucracy (Evans, 1995, 41). It is abundantly apparent that at both the macro and micro levels the American defense bureaucracy conforms to Weber's bureaucratic ideals; there is strong internal coherence, healthy hierarchical chains of command, meritocratic hiring and promotion, and incredibly robust internal, external, and

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[130] The history of the formation of the American defense establishment has been covered in depth elsewhere. See Scherer, 1964; Purcell, 1972; Beaumont, 1977; Kovacic, 1990 and 1990b.
[131] Peck and Scherer, 1962; Fox, 1974; and Weber, 2001 should get the interested reader started.

even congressional, monitoring mechanisms (Peck and Scherer, 1962; Fox, 1974; Higgs, 1990; Hooks, 1990).

As will now be detailed, autonomous bureaucratic US defense agencies are densely linked to various private 'prime' defense contractor systems integrators.[132] Some of the links generating embeddedness are quite formal. For example, in a process akin to the 18th century British residential Naval and Ordnance Overseers, the DOD many times establishes field offices at contractor plants (depending on the number and size of contracts going on there). Such offices are overseen by the Defense Contractor Administration Services (DCAS) and manned by 'field officers.' Field officers keep the DOD informed as to whether the contractor appears to be conforming to the contract specifications; field officers also assist in negotiating contract changes. Since longevity provides some cooptation opportunities, field officers are rotated at least every 3 years, thus increasing the breadth of the formal networks created through the use of DCAS field offices (Fox, 1974, 218; Peck and Scherer, 1962, 85).

Another formalized embedded connection arises from the appointment of program managers on both the armed services and prime contractor sides. Program managers and their large administrative staffs work closely together to negotiate and renegotiate timelines, cost schedules, technical changes, subcontracting

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[132] The US uses a 'prime' contractor approach which delegates coordination and integration responsibilities to one primary contractor. Each of the many independent subsystem vendors which also participate in a weapons development project then become subcontractors to the prime. The prime integrates, and retains contractual and economic powers to enforce final decisions regarding component integration (Weber, 2001, 15; Peck and Scherer, 1962, 85).

structures, and performance specifications. In so doing, dense social networks linking private firm and public defense agency managers and their respective bureaucracies are created (Fox, 1974, 173-80; Melman, 1970, 45).

More important than the formal networks however, are the numerous informal links and contacts that endow autonomous defense bureaucracies with embeddedness. The advanced technical nature of weapons acquisition in the post WWII era has caused the relationship between the armed services and their various prime contractors to become downright 'intimate' (Fox, 1974, 67). Numerous paid contractor representatives stay in constant touch with the key bureaucratic agents involved in formulating advanced weapons strategies in order to place the contractor in a competitive position to win a contract. Daily visits to procurement agencies are commonplace, where conversations range from the mundane to marketing, peppered no doubt with the occasional solicitation for inside information (Fox, 1974, 290-2).

Here we now come to the perniciously perceived and oft decried 'revolving door policy'; an informal practice so common it requires a formal name. The concept is simple enough: state and military personnel formerly involved in the procurement process end up working for defense contractors, typically in an advisory role. And former employees of defense contractors find themselves manning influential posts in defense procurement agencies.[133] In the theoretical

[133] There were over 3000 retired military officers working at defense contractors in the 1980s; this figure excludes the many civilians involved in defense procurement on the state side that eventually find employment in the private defense sector. For example, around 30% of the R&D secretaries

light of embedded autonomy, the far left's decades-long preoccupation with the revolving door policy seems quaint at best, ill informed at worst. First of all, revolving door exchanges happen at the precise levels and positions that embedded autonomy would suggest: at the liaison level where social networks lubricate the interactive give and take through which new technological trajectories are forged, mapped, and agreed to; at the advanced technical level where employees with the relevant knowledge and skill sets are few and far between; and at the procedural level where familiarity with arcane procurement regulations can only be established over a period of years or decades. Moreover, several pieces of legislation regulate this process (Boies, 1994, 34).[134] The fact is that numerous studies have found little to no wrongdoing by retired military officers or former state officials working for contractors, or by former defense contractor employees working for state agencies (Fox, 1974, 73; Baumgartner, 1970, 24; Boies, 1994, 34; Higgs, 1990; Hooks, 1990).

Another incredibly important dense and extensive social network that embeds defense bureaucracies in the contracting marketplace forms around the many university and non-profit laboratories engaged in defense work throughout the United States. Such laboratories hold an intermediate network position, acting

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that have been employed in the OSD came from defense firms and returned to defense contracting work after relinquishing their public positions (Boies, 1994, 34; Higgs, 1990, xxviii; Fox, 1974, 77).

[134] E.g. "Federal regulations require that senior appointees divest themselves of all stocks, bonds, and interest in profit-sharing plans of any firm doing more than $10,000 in defense business" (Baumgartner, 1970, 24). Also the DOD has the authority to cancel a retirees' pension if he goes to work for a contractor and / or engages in activities deemed as potentially injurious to the Pentagon (Fox, 1974, 73).

sometimes in a formal contractor capacity,[135] and at all times as a formal and informal social repository for scientists, engineers, company men, and armed service representatives interested in obtaining or distributing the ample R&D funds emanating from the defense sector (Hughes, 1998; Saxenian, 1994; Campbell-Kelly and Aspray, 2004, 199).

> "In several regions of the United States, universities have formed the nucleus for large aggregations of military research and production. Two of the most important of these are around Boston, along Route 128 (near MIT), and in Palo Alto, California, in the industrial park that adjoins Stanford University. At Stanford as in Boston, there is crossing over between military-industrial and university posts. In some cases, members of the faculty initiate enterprises. More often, faculty members serve as consultants or... board members of military industrial firms" (Melman, 1970, 101).

Now that the principal embedded links among autonomous procurement agencies and private defense contractors have been sketched, let's take a closer look at the contracts which pass between them; for it is the contracts that enable the DOD to steer its market-based defense contracting corps as these two autonomous, embedded, and distributed organizational sectors negotiate, establish, and traverse novel technological trajectories. The contracts used by the DOD and the armed services mainly fall into two categories: Fixed Price (FP) and Cost Plus a Fixed Fee (CPFF). FP contracts correspond to the type of contracts that tend to obtain in most regular market environments (such as home remodeling). "The contractor promises

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[135] At times industrial primes have turned down systems integrator roles on the hardest projects. Prime responsibilities in this case may devolve to a university (often MIT or Stanford) or a non-profit laboratory (Hughes, 1998, 62, 91). These 'not for profit' laboratories largely get the same contracting deals and rights as 'for profit' contractors, although they of course distribute their funds and patents in ways that accord with their non-profit missions (Melman, 1970, 98).

to supply certain specified goods or services at a price which, after agreed upon by a buyer and seller, is not subject to adjustments reflecting the seller's actual cost experience" (Scherer, 1964, 132; Baumgartner, 1970, 71-75; Fox, 1974, 224-244). In a CPFF contract "the buyer and seller initially agree upon a fee or profit amount related to an estimate of total costs. The cost estimate is not binding; the buyer agrees to reimburse within limits all allowable costs incurred by the contractor in executing the contract. Consequently the price in a CPFF relationship is almost completely flexible." But the fee is fixed regardless of costs, so although a certain level of profit is guaranteed, the profit rate as a percentage of costs declines as costs escalate (Scherer, 1964, 133; Weber, 2001, 60; Fox, 1974, 224-244).

Prior to WWII, when the government did contract with private enterprise for goods, it was usually for products already in the commercial marketplace. FP contracts sufficed for such a situation, and were the main form of contract the government used. During WWII weapons acquisition became increasingly characterized by a unique set of uncertainties which differentiated it from other economic activity.[136] It quickly became clear that FP contracts were insufficient to induce private firms to participate in the new ambiguous brand of advanced weapons procurement; costs had become indeterminable and increasing

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[136] Weapons development came to involve more complex and numerous technically advanced subsystems, and engineering problems relating to their interaction exploded exponentially. Weapons systems, and the capital equipment used to make them, also became subject to rapid and sudden obsolescence. Moreover, as military expenditures and weapons costs spiraled upwards, weapons acquisition became more subject to the vicissitudes of budget formulation with its staggered election cycles and changeable congressional committees. To make matters worse, there were simply no yardsticks by which to measure costs and value for entirely new and unique weapons systems that crystallized over the course of lengthy negotiated developmental efforts (Peck and Scherer, 1962, 42-50; Weber, 2001, 48; Farrell, 1997, 181; Fox, 1974).

technological uncertainty had created an unbearable level of risk for private defense contracting firms (Fishback, 1993, 10; Peck and Scherer, 1962, 219, 518, 535; Weber, 2001, 65). Therefore, the government had to manufacture a number of formal institutional inducements if it was going to marshal private industry to the advanced weapons acquisition cause. The aforementioned CPFF method of contracting quickly emerged as the primary method through which the government reduced risk for private firms participating in advanced weapons development (McNaugther, 1989; Weber, 2001; Markusen and Yudken, 1992).[137] The more technologically advanced, urgent, and uncertain the weapons program, the more likely was the use of CPFF contracting. This is because CPFF contracts transfer the burden of cost uncertainty to the government which has a superior ability to bear risk than any one firm. CPFF contracting also institutes flexibility in weapons development by enabling daily, sometimes hourly, changes in the technical and engineering designs of a weapons system with no added costs or risks to be borne by the contractor. Hence, the government is able to induce private industry to perform R&D activities it would not otherwise engage in through the use of CPFF contracting (Weber, 2001, 139; Williamson, 1967, 222-3; Scherer, 1964, 145); which for obvious reasons, is quite pertinent to the 'military expenditure impetus to mode of development shifts theory' as framed above.

CPFF contracting was not the only risk reducing measurement provided by the government in order to induce firm participation in radically new weapons

[137] In early 1940 87% of defense contracts were FP; by late 1940 74% were CPFF (Fishback, 1993, 10).

development projects during WWII and after. The government also induced defense contractors to invest in technically innovative (and therefore risky) fixed capital by providing expedited tax amortization and interest cost reimbursement on loans aimed at financing advanced weapons production equipment and facilities (Beard, 1993, 37; Weber, 2001, 61-2; Peck and Scherer, 1962, 539). Given the rapid rate of technological change in products, plants, and equipment employed in defense production, such measures at times proved insufficient to sustain the level of capital turnover necessary for the provision of national security during the Cold War. Hence, the government resorted to constructing production facilities for defense contractors outright whenever necessary. These facilities were designed by and fully transferred to defense contractors (Weber, 2001, 60-62). This process not only heightened the pace of technical advance in the defense industry, affecting especially the nascent electronics and communications sectors, but also rapidly familiarized large chunks of the American engineering corps with novel and complex weapons related technologies (Misa, 1985; Peck and Scherer, 1962; Ruttan, 2006).

The government has sought to induce technological change in the weapons sector via generous patent policies as well. In the commercial sector, patent rights tend to be assigned to financial sponsors. Not so in the defense sector. Procurement regulations include the statement: "It is the policy of the DOD to encourage inventiveness and to provide incentives therefore by honoring the proprietary data resulting from private developments" (Scherer, 1964, 114). Under

DOD procurement regulations contractors generally obtain patents on inventions conceived under government contracts "subject only to a royalty-free license for government use" (Peck and Scherer, 1962, 215). Nonetheless, contractors often do not patent findings made under government contracts in order to avoid giving royalty-free licenses to a major customer, or whenever possible will privately fund projects likely to yield patentable inventions (Berkowitz, 1970, 210; DeGrasse, 1983, 87; DeGrasse, 1984, 89; Scherer, 1964).[138]

Over the years, these inducements in aggregate have fostered a robust and competitive defense contracting market in the United States that adeptly advances the state of the art.[139] Nonetheless, many critics have assailed the American defense contracting industry for being fundamentally noncompetitive, and thus not as innovative as it should or could be (Melman, 1970; Pursell, 1972; Art, 1973; DeGrasse, 1984; DiFilippo, 1990). Detractors cite figures reporting that 90% of contracts are awarded via negotiation rather than through advertised bidding, while 60% of all defense contracts are awarded entirely noncompetitively (Lee, 1990, 29; Art, 1973, 252). In context, such figures actually do not justify disparaging

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[138] Hence it would be a stretch to suggest that the government's generous patent policies for defense R&D have had a significant impact on informational GPT development. Given that in the second half of the 20th century most patented inventions are not utilized, many utilized inventions are not patented, and most patents apply to incremental process change and not to radical invention, patent data at the aggregate level unfortunately tells us exceedingly little about the development and diffusion of infrastructural informational GPTs in the 20th century (Braun and Macdonald, 1982, 132; DiFilippo, 1990, 38; DeGrasse, 1984, 89; Berkowitz, 1970, 314-315). Therefore, aggregate patent data will not be discussed below.

[139] The primary determinant of revenue and profit growth for defense contractors in the US is evolving technical capacity (Scherer, 1964, 29, 162; Peck and Scherer, 1962, 128, 397; Weber, 2001); also, the gigantic size and intermittent nature of weapons programs makes defense contractor competition more intensely concentrated than that typically experienced in the commercial marketplace (Fox, 1974, 100-1).

conclusions. Although the DOD would undoubtedly prefer to use advertised bidding at all times, this clearly would be a less effective method of procurement for advanced weapons development than negotiated bidding. When pushing the state of the art, advertised bidding doesn't work because the government is uncertain about the final specifications of the proposed integrated weapons system (Peck and Scherer, 1962, 344). How can the services formulate advertisements, and then stick to the advertised requirements, when creating the indefinite? Thus, as previously suggested, advertised bidding naturally gave way to negotiated procurement as the arms race pushed weaponry into the realm of the unknown (Weber, 2001, 52).

More importantly, 'negotiated award' does not mean 'without competition.' When the need for and / or the possibility of a new weapons system is identified, the DOD initiates an open 'program definition' competition where defense agencies and interested defense contractors 'negotiate' back and forth (utilizing those previously highlighted embedded links) in order to determine what is ultimately feasible and preferable. Such program-definition competitions involve 'bloody' rivalry (Baumgartner, 1970, 39);[140] and also involve considerable expense, time, and effort on the part of contractors and procurement agencies. From that point

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[140] The services many times invite up to 100 firms to submit bid proposals during program definition efforts. Usually fewer than this actually submit bids for contractors are highly specialized, and are many times working at capacity. Program definition competitions on average involve 30 firms (Peck and Scherer, 1962, 337-356; Scherer, 1964, 40).

procurement follows a pipeline progression.[141] At each step of the way, competing defense contractors are winnowed down as the weapons system that will ultimately be procured comes into focus. Finally, one prime contractor is awarded the production contract (Peck and Scherer, 1962; Fox, 1974; Baumgartner, 1970; Weber, 2001; Higgs, 1990).[142]

This brings us to the not so thorny issue of 'sole-source' contracts. As the name suggests, such contracts are awarded without competition of any type. Up to 60% of defense contracts let in any one year are sole-source. This should in no way suggest that the defense contracting industry is for the most part noncompetitive. Generally, sole-source awards are used in only two situations. 1) When an entirely unique weapons system moves from the prototype phase to the production phase; in this case the prime has already won a series of competitions and now is the only contractor with the know-how and facilities to integrate and manufacture the weapons system. Or 2) Each time a weapons system under development is infinitesimally altered, a new 'design modification' contract must be signed; such contracts are of course sole-source, and also so numerous that they compose the bulk of the 60% figure (Ruttan, 2006, 168; Weber, 2001, 47-9; Peck and Scherer, 1962, 326-338; Baumgartner, 1970, 39; Fox, 1974).[143]

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[141] This pipeline progression is of course quite involved, and has been detailed elsewhere (Peck and Scherer, 1962; Fox, 1974; Baumgartner, 1970; Weber, 2001; Higgs, 1990).

[142] Typically, defense agencies adjudicate between contractors based on standard criterions that are worked up into a quantitative point tally. Criterions include contractor capability, technical attractiveness of designs, managerial effectiveness, appropriate R&D capacities, past performance, and available technical and physical resources (Scherer, 1964, 69-70; Fox, 1974).

[143] Great urgency for a weapons system or technology has sometimes led to 'second-sourcing.' Here two or more firms manufacture one advanced weapons system. Second-sourcing can easily

Another criticism that is consistently hurled at the American defense industry is that it is too concentrated to be adequately competitive and innovative; over the years 1940-1990 the top 25 prime contractors typically received between 45% and 55% of defense sector contract awards (Higgs, 1990, xx; Kovacic, 1990b). To be sure, the defense industry is concentrated, but criticizing it for being so smacks of polemics. Concentration is in fact no more prevalent in defense contracting than it is in any other mature sector of the US economy (Peck and Scherer, 1962, 117-118; Reich, 1973, 93-94). Moreover, blunt figures on prime contracting, like those above, grossly overestimate the level of concentration in the defense industry. The primes are systems integrators, and as such, subcontract heavily; however, all subcontracted dollars are officially reported as staying with the prime. In fact, subcontracting accumulates as one moves down the production hierarchy from prime systems integrator, to subsystems integrator, to component producer. In sum, at least 50% of all prime defense contractor dollars are subcontracted out in any given year, giving rise to a competitive defense industry composed of tens of thousands of smaller defense contractors (Peck and Scherer, 1962, 380; Higgs, 1990, xxix; Mayer, 1990, 220; Fox, 1974, 41; Weber, 2001, 20).[144]

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double the costs of procuring a weapons system, since the government often times has to subsidize the facilities for the second manufacturer. Thus second-sourcing is used sparingly (Scherer, 1964, 104-112; Stowsky, 1992, 122).

[144] Unfortunately, no governmental agency keeps records on defense sector subcontracting and "most companies consider subcontracting information to be proprietary or commercially sensitive and are reluctant to release it", thus data on subcontracting is scant (Goldstein, 1991, 53; Mayer, 1990, 219-20).

A few truisms about subcontracting are widely asserted. Subcontracting as a whole greatly decreases the administrative costs of weapons procurement to the government. The proportion of defense contracting money received by small and intermediate businesses is approximately doubled when subcontracting is taken into account. Competition to obtain subcontracting dollars tends to be more intense than the competition that arises for prime dollars (for there are many more companies with component producing capabilities than there are systems integrators). Turnover is rapid in the defense subcontracting industry. Much of the technical knowledge and capital, along with innovative potential, in the defense industry is maintained at the subsystems and component level. And subcontracting is more prevalent and competition more intense in the electronics segment of the defense industry than in any other sub-segment. In short, one is unlikely to know the names or be aware of the numerous subcontractors involved in any particular procurement project, but it is precisely these subcontractors that endow the American defense industry with a good deal of its flexibility and innovative capacity. Indeed, as will be shown, defense subcontractors were at times crucial to the innovative efforts that led to commercially viable informational GPTs (Bertelli, 1995, 83, 91-94; Bischak, 1995; Mayer, 1990, 219-220; Tuomi and Vayrynen, 1982, 65; Baumgartner, 1970, 78; Peck and Scherer, 1962, 152-155).

The succeeding chapters of the American case will demonstrate that the embedded autonomous market-based contracting system that operated in the American defense sector over the years 1940-1995 was highly successful in forging

the novel technological trajectories that led to commercially applicable informational GPTs. Defense bureaucracies effectively directed and coordinated vast numbers of competitive market-based defense contractors in huge multi-year advanced technological efforts. Indeed, by the 1980s the DOD was executing 15 million contracts per annum, or 60,000 per day (Scherer, 1964, 380; Kovacic, 1990b, 106). Generally, the negotiated process worked in this manner: Contractors stayed abreast of technical developments for competitive reasons and because they had the requisite knowledge and specialization. Contractors then persuaded defense officials to heed the new technical possibilities, and act on the advantages that would devolve from employing novel innovations. Defense officials and agencies then processed the evolving and emerging options (often using advanced computer-driven techniques) and incorporated them into a coordinated policy for advancing national security on a broad front. Open project design competitions aimed at precisely defining the weapons systems deemed worthwhile or appropriate by the defense establishment were then initiated. A prime contracting firm for manufacture was chosen via the aforementioned competitive pipeline progression system. The prime subcontracted as it saw fit, and eventually an innovative weapons system, along with all of its technically advanced components and subsystems, was produced, tested, and procured (Higgs, 1990, xxvii; Fox, 1974; Peck and Scherer, 1962, 241; Weber, 2001).

Given the enormous complexities involved at each of these steps, only an embedded autonomous system could have successfully maintained the flexibility

and rapid pace of technical change achieved by the United States during the Cold War. Government alone would have been incapable of both "managing the broad trends in weapons development while at the same time specializing in the numerous complex sectors necessary to produce the wide range of modern age defense needs"; while contractors alone would have been unable to overcome the demands of competition to provide clearly articulated and well formulated strategies for overall national security (Higgs, 1990, xxvii; Evans, 1995, 95; Peck and Scherer, 1962, 64; Weber, 2001). It was the combination of the two, and the formal and informal social networks between them, lubricated by the university system and driven by competitive incentives, that enabled the mutual interactions giving rise to the negotiated technological trajectories which served national defense by continually pushing the state of the art during the Cold War. There should be little doubt that this system was highly successful in achieving the US military's overriding goal of force multiplication through technological superiority. The proof is in the pudding – the US won the Cold War, and the supremacy of US defense technology in the second half of the 20th century vis-à-vis the USSR, or any other great power for that matter, is at this point entirely undebatable (Nincic, 1982; Ruttan, 2006).

Nevertheless, what works well for national security is not necessarily that which works best for the underlying economy, especially in the short-term. Although the Cold War did drive the US military to unprecedented and impressive technological heights, the lack of clarity regarding enemy capabilities and strategies

did inject a good deal of uncertainty and inefficiency into the weapons development process.[145] Each new intelligence missive, which themselves were given to wild uncertainties, led to discarded weapons programs and costly new ones that too were subject to cancellation at a moments notice (Fox, 1974, 103; Peck and Scherer, 1962, 45-47). Such a milieu could hardly be expected to yield cost-effective technological development; and as will be discussed further below, the US economy did at times buckle under the weight of its Cold War defense burden. This burden however did give rise to a unique form of 'shotgun' like development, where any and every potential trajectory was pursued no matter the cost. The long-term result of this shotgun method of technical advance was the opening of just a few key developmental trajectories, attained at incredible expense. Commercial technical trajectories would surely have been more 'rifle' like and cost effective, while economic undulations would surely have been more serene, without the

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[145] The procurement process in the US is subject to various inefficiencies that have not been covered here. These inefficiencies are not as copious as one might think after reading the literature on the 'military industrial complex.' Unfortunately space does not allow me to engage this literature in any substantial way here. Suffice it to say that most of the criticisms hurled at the 'military industrial complex' have proven overstated, oversimplified, or incorrect. For example, defense expenditure in the post WWII era has been considerably more flexible than entitlements, transfers, and social welfare spending. The fact that defense spending is more variable than other budget items suggests defense interests are no more powerful than other organized interests, and that they mainly compete with each other for a piece of a budget slice which is determined by forces largely outside their purview (Kelly, 2000; Baumgartner, 1970). Also, numerous studies have shown that profits from defense contracting are not at all large or out of the ordinary; in fact defense contractor profitability is less than that typically seen in commercial sectors (Kovacic, 1990b, 109-115; Scherer, 1964; Fox, 1974, 307-310; Baumgartner, 1970, 64; Weidenbaum, 1973, 267). Additionally, corruption in defense contracting is neither typical nor predatory in nature; like most government corruption in the US, corruption in defense contracting has been shown to be sporadic and non-systemic (Farrell, 1997, 68; 88; Hooks, 1990; Boies, 1994, 81; Baumgartner, 1970). I could go on, but I digress. For a fair and balanced analysis of the defense industrial complex and its many foibles see Merton Peck and F.M. Scherer's 1962 and 1964 exhaustive studies, which "quickly became, and remain today, the preeminent works in the field" (Kovacic, 1990, 71).

uncertainties and urgencies created by the Cold War arms race. As suggested above, however, and as will be demonstrated throughout the American Case narrative, the defense expenditure induced shotgun method of technological development, unbridled by cost, was a necessary element in the advent of the exotic and radically new information technologies that eventually came to compose the infrastructure of the informational mode of development. We now turn to a discussion of the feedback processes that moved information technologies from defense-induced artifacts to revolutionizing commercial devices, and the ways that military expenditure impacted upon their path.

THE DIFFUSION OF INFORMATIONAL GPTs AND MILITARY EXPENDITURE:

The main effect military expenditure had on the diffusion of informational GPTs in the American Case can be summarized thusly: diffusion occurred most strongly and rapidly during intervals when political events allowed for or called for a reduction in the amount of military expenditure going to advanced weapons procurement. The above theoretical proposition of course devolves from the causal mechanisms outlined in the introductory chapter. In the American Case specifically, it will be shown that rapid escalation of military expenditure aimed at procuring weapons relying on advanced informational processing systems propelled the development of the relevant infrastructural informational GPTs in a synchronized fashion that would not have been possible absent the defense expenditure impetus. Then intermittent advanced weapons funding draw-downs

released into the commercial economy human capital possessing experience relating to constructing, adapting, operating, and integrating the novel informational systems. The coordinated nature of development in advanced information processing systems fostered by Cold War defense expenditure, and the widespread and swift commercial diffusion of these militarily tried and tested technologies witnessed during draw-down intervals, contributed to a palpable transformation in methods of production and deriving productivity gain over a condensed period of time, thus giving rise to the informational mode of development shift.[146]

Note that the process outlined above is generally similar to the development and diffusion process that was operative during the British industrial mode of development shift. Also recall that in 18th century Britain, defense contractors, especially in the iron sector, were steeped in the larger commercial market where a majority of their revenues materialized (Ashton, 1968; Harris, 1988). At times this too was the case for the important carriers of diffusion in post WWII America – corporations that were both defense contractors and commercial marketplace leaders (like IBM and Bell Labs) developed important informational GPTs on the defense side of their business, and then carried and adapted the technologies to the commercial marketplace. More typically, however, such was not the nature of

[146] Taken alone, it is clear that the development of any one of the three radically new sectors that compose the objects of interest in the American case would have been delayed by decades sans the military expenditure impetus; also the pace of development in each sector would have been stochastic rather than coordinated (Ruttan, 2006; Flamm, 1988; Hughes, 1998). Given their synchronized development and diffusion, it becomes evident that military expenditure warrants causal primacy in theories seeking to account for the coordinated rise of commercially viable semiconductor, computer, and computer networking technologies.

diffusion in the American case. Many of the most successful prime contractors in the American Cold War defense industry remained highly insulated from the non-defense commercial sector. In fact, US corporate primes have been deemed 'a world unto themselves.' This owes to the many unique demands and arcane contracting requirements of American defense contracting; if the strange management techniques the arcane practices breed were carried over into the commercial sector, the results on profits and efficiency could prove disastrous. It is also for this reason that many prime systems integrators in the US tend to be 'irrevocably' committed to defense contracting; numerous prime attempts at converting from a mainly defense orientation to a mainly commercial orientation have failed (Gregory, 1993, 54; Weber, 2001, 51, 80; Borrus and Zysman, 1992, 35; Weidenbaum, 1973, 271).[147]

Hence the 'startup' company emerged as the principal mechanism through which defense-related informational GPTs were converted to commercial uses in the United States (Weber, 2001, 122; Goldstein, 1991, 37; Gregory, 1993, 101; Dumas, 1995, 16). Therefore, in terms of the dissertation's diffusion feedback processes as applied to the 20th century, there can be little substitute for a vigorous and dynamic startup sector. The startup sector itself of course relies on well capitalized and liquid stock and venture capital markets. Thus the main carrier of defense-related technologies to the commercial marketplace in the American Case was the intermediate mechanism of strong, well capitalized, flexible, and open

[147] In the 1980s McKinsey and Company reported that defense firms had an 80% failure rate when trying to penetrate commercial markets (Weber, 2001, 121).

financial markets. Here then we come back to the indispensability of capitalistic institutions to the 'military expenditure impetus to mode of development shifts theory.' In the American case, diverse and diffuse individual shareholders and entrepreneurs proved to be the best constituency for deciding the future of defense-related technologies, especially during those intermittent periods of declining defense expenditure when technical feedback into the commercial economy took place at a heightened pace (Weber, 2001, 135-6; Dial and Murphy, 1995).

Such an argument relies on the basic assumptions of efficient markets theory: There is a high correlation between firm value and its stock price, and shareholders flee stagnating sectors and flock to emerging sectors with high growth potential, thus providing liquidity and capital when and where it is needed most. In a perfect world, efficient markets produce sustained economic growth and development. But in the real world, financial markets are not perfectly efficient; faulty information, transaction costs, uncertainty, poor management decisions, over-speculation, along with a host of other factors, convey inefficiency to capital markets (Weber, 2001, 31-2; Fama, 1990). Hence there are some encumbrances associated with the market mediated form of technological transfer peculiar to the American case; i.e. the process was more frictional than would have been the case had defense contracting firms themselves been able to serve as the main conduit for commercialization of defense-induced technologies (Etzioni, 1973, 361; DeGrasse, 1984, 88; Berkowitz, 1970, 307). Nevertheless, American startup firms did

manage to achieve early leading market share in the radically new technologically advanced commercial sectors arising from defense-induced innovations in the United States during the Cold War. This was because American engineers were closest to the source of the inventions, and as such, were the first to obtain the knowledge required to successfully adapt defense-related inventions to commercial production (Norberg, 2002, 182; Flamm, 1988; Cerruzi, 1998).

The market mediated technological transfer argument employed in the American Case therefore necessarily assumes healthy fluidity and flexibility between defense and non-defense engineering labor markets in the United States. Financial markets may provide the requisite capital in the delineated startup diffusion mechanism, but the knowledge and technical know-how of course feeds through the labor market (Weber, 2001, 67). For example,

> "Engineers trained on the first computer projects (which, as will be shown, were indisputably defense-related) were largely responsible for the development of the industry. New products and firms can be traced directly to individual engineers who left the first projects, and using their accumulated experience, tried creating a commercial product. This phenomenon is by no means unique to the computer industry – the semiconductor industry has grown from much the same process" (Flamm, 1988, 218).

Thus it follows that the pace of exit from defense engineering labor markets should largely condition the pace of technological diffusion in budding commercial sectors relying on defense-induced innovations.

There has, however, been some debate as to whether there is flexibility and fluidity between US defense and non-defense engineering labor markets. Prior to

1970, fluid engineering markets in the US were a given.[148] Following the Vietnam debacle, 'military industrial complex' polemicists began to attack the notion of flexible American engineering markets, vociferously claiming "There is now a core of engineers in the US with a trained incapacity for functioning in the civilian economy" (Eaton, 1973, 190; Melman, 1991, xvii; Dumas, 1995, 13). As might be expected, the glaring problem with this polemicist thesis is that very little empirical evidence substantiating the position actually exists (Eaton, 1973, 190).

In fact, a good deal of evidence suggests just the opposite. In a wide ranging comparative study of defense engineering employment in the Boston and San Francisco areas conducted in the late 1960s, it was found that defense engineers had 'a less severe reemployment experience' than other types of engineers.[149] A large proportion of defense engineers transitioned quite smoothly to civilian employment (35% overall, 54% in the SF area, and 23% in the Boston area – the rest stayed in the defense industry), with few ensuing salary or productivity decreases (Eaton, 1973, 191-3). The results led the researchers conducting the study to conclude that "The evidence seems to indicate that there is not a great deal of difficulty involved in transferring from defense work to non-defense work. In fact, the concept of a defense worker does not appear to be very useful" (Eaton, 1973, 193-200; Mosley, 1985, 165; Berkowitz, 1970, 348). And such findings likely hold for the entire temporal period under analysis: Studies

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[148] For instance, "The very rapid flow of engineers and scientists from war work back to non-defense work at the end of WWII probably had a great deal to do with the rapid dissemination of that new knowledge throughout the non-defense industry" (Clayton, 1970, 156).
[149] Based on duration, salary loss, and subsequent labor market status.

conducted in the early '70s found that typical labor market variables had more effect on employment than any qualities specific to the professional military engineer (Eaton, 1973, 181). And a National Science Foundation database on engineers accumulated between 1980 and 1986 revealed that nearly one-quarter of engineers employed in the defense industry in 1982 had shifted non-problematically to commercial work by 1986 (Bertelli, 1995, 69).

Also facilitating knowledge transfer and economic feedback between the defense and commercial sectors in the United States are those many previously mentioned university milieus where defense engineers, scientists, and professors mingle. There tends to be smooth flow between research positions at these universities and engineering positions at defense contractors. Moreover, many scientists and engineers working on defense-related projects at universities later become thriving startup entrepreneurs, successfully applying the knowledge and skills they gained through defense work to innovative commercial tasks and opportunities. It is therefore no coincidence that Silicon Valley sprung up and flourished next to Palo Alto's Stanford University during the Cold War; Stanford attracted billions of Cold War defense dollars aimed at developing information processing machines and weapons, and many faculty who cut their teeth on defense-related projects at Stanford later migrated to commercial firms in Santa Clara Valley. The same logic applies to Boston's Route 128 high-tech corridor, located at MIT's doorstep. As the following chapters will indicate, the pattern of DOD expenditures during the Cold War combined with university social space and

ample venture capital to create a powerful technological revolution in these two microelectronics 'greenhouses' (Saxenian, 1994; DeLanda, 1991; Yudken and Black, 1991, 196; Campbell-Kelly and Aspray, 2004, 199; Melman, 1970, 101).

Now that the general theoretical mechanisms enabling informational GPT diffusion in the American case have been laid out, it is time to introduce some important theoretical corollaries. The first can be stated thusly: *As a mode of development shift matures the opportunity costs associated with continued military expenditure increase.* Such a proposition derives from the notion that as any certain defense technology evolves into a widely diffused commercial GPT, military expenditure will necessarily play a decreasingly important role in its evolution (Stowsky, 1992; Tirman, 1984, 221; DiFilippo, 1990, 98, 103). This is because global capital markets are much wider and deeper than government military expenditures, and in being so, the weight of profits and revenues in the commercial sector eventually swamp those devolving from defense contracting. Hence the pattern of advance exhibited in GPT development gradually transforms from defense-induced radical discontinuity to incremental and process-oriented technical change as defense-related GPTs feed into the commercial economy. GPT development sequences therefore, over time, begin to cycle much more rapidly in the commercial sector than in the defense sector, because longer high volume commercial production runs generate cost reducing process improvements at a faster and more efficient rate than small, short, specialized military production runs can (Stowsky, 1992, 140; Borrus and Zysman, 1992, 34; Vogel, 1992, 60). As this

occurs, firms increasingly come to realize that the costs imposed by cumbersome bureaucratic and regulatory defense procedures are no longer tolerable or necessary since firms can now internally finance process-oriented R&D projects by spreading costs across a much higher volume of sales (Stowsky, 1992, 116; Borrus and Zysman, 1992; DiFilippo, 1990).[150] As a consequence, DOD R&D funding becomes progressively shunned. Especially since many defense R&D projects, with their incessant focus on achieving battle hardened devices, are likely to swim against burgeoning commercial trends. Meanwhile, rising commercial volumes and sustained process and product improvements increasingly drive costs down and quality up in the commercial sphere (Gregory, 1993, 51; DeGrasse, 1984, 87). Commercial profits then skyrocket to levels unimaginable, and in fact prohibited, in the defense sector as commercial market feedback continues to accumulate. What were once revolutionary products now begin to be infinitesimally tailored to diverse commercial tastes and preferences. Eventually there develops a wide rift between technological trends in GPT commercial markets on the one hand, and their former progenitor defense markets on the other. Hence as a mode of development shift matures, military expenditure morphs from GPT parent to commercial sector drag (Vayrynen, 1992, 72; Vogel, 1992, 60; Ruttan, 2006, 5).

As will be discussed in the narrative chapters of the American case, the

[150] "Participation in global high-volume markets now gives private firms the capacity to amortize the development and manufacturing costs of technological inputs that were once thought too expensive and risky for any entity other than the Pentagon to support" (Stowsky, 1992, 139).

informational mode of development reached an initial stage of commercial maturity somewhere in the early 1970s; by this time computers and their related components and software had emerged from the military sector in commercially viable forms, and firms were persistently discovering new marketable applications for these infrastructural informational GPTs (Vayrynen, 1992, 72; Ruttan, 2006). Although the final coalescence of the informational mode of development in all of its glory would not occur for another twenty five years, marked by the diffusion of Internet technologies into the commercial and social milieu (Castells, 1996), the second important diffusion corollary applies from the early 1970s forward. It can be stated thusly: *In an international system characterized by open markets and rapid technological diffusion, nations not engaging in heavy military expenditures will not experience the accumulating opportunity costs associated with long-term large-scale military expenditure.*[151] *In so far as such nations have a suitable institutional structure for technological development, they will also have the ability to free-ride and adopt the GPTs produced in the militarily spending nation.*[152] *If the original GPT producing nation continues to sustain large-scale defense expenditures as commercial trajectories utilizing the once defense-related GPTs strengthen and multiply, the advantages conveyed upon free-riding nations will progressively mount.*

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[151] These costs include the aforementioned imprecise and expensive 'shotgun' like targeting of technical change, frictional market-mediated diffusion, increasing military drag, along with the soon to be discussed crowding out and preemption effects.

[152] Military alliances produce collective goods and the potential for free-riding (Olson and Zeckhauser, 1967, 27; Medema, 1993, 18).

This corollary of course foreshadows the 20th century Japanese / American Case comparison, and provides the overriding rationale for including post WWII Japan in the study. As discussed in chapter one, such a comparison holds the institutional variables in the dissertation's general theory relatively constant while letting military expenditure vary. And as will be discussed further in the Japanese Case, Japan took on the role of advantaged GPT free-rider with amazing gumption and panache, out-competing the United States in many important technological sectors during the 1970s and 1980s (Borrus and Zysman, 1992, 27; DeGrasse, 1984, 81-2; Vayrynen, 1992; Yudken and Black, 1991, 171). It will also become clear, however, that Japan played little to no role in the genesis of the infrastructural informational GPTs under consideration; their story is one relevant mainly to diffusion. This supports the idea that military expenditure was indispensable to initial informational GPT formation. Moreover, as military expenditures wound down rapidly in the United States after the fall of the Berlin Wall in 1989, it will be shown that the US experienced a renewed competitiveness, thus suggesting that the opportunity costs associated with long-term large-scale military expenditures are not permanent, and can wane as expenditure recedes (Vayrynen, 1992, 105). The dissertation will now turn to a theoretical discussion of the main financial opportunity costs associated with long-term large-scale military expenditure in the American Case.

THE FUNDING VARIABLES IN THE AMERICAN CASE:

Like 18th century Britain, the 20th century US funded its bout of long-term large-scale military expenditure via an evolving mix of tax revenue and public deficit finance. However, in the American case, the system of federal tax assessment and tax collection was bureaucratic and efficient from the start; which is not surprising given that the system was modeled quite deliberately on the late 18th century British system of taxation. Throughout the 19th century, revenue in America primarily devolved from various forms of indirect taxation, chiefly tariffs but also some excises. In the early 20th century a tax on corporate profits was imposed, and in 1913 the Sixteenth Amendment was passed which allowed for a personal income tax. Both forms of taxation have remained a part of the American assessment system ever since. In 1937, Federal Insurance Contribution Act (FICA) taxes, which include Social Security, Medicare, and other social insurance payroll taxes, were added to the system. The US federal tax system continues to be composed of these broad categories of taxation today (indirect taxation; corporate income taxes; personal income taxes; social insurance taxes) (Gordon, 1997; Kelly, 2000).[153]

Taxation in the US is important to this study's narrow purposes in a few different ways. Like in Britain, overall revenue levels provide the foundation for the entire funding system which makes the 'military expenditure impetus to mode of development shifts theory' operative; without efficient collection and

[153] Customs tax revenue and other forms of tax revenue combine to provide a very small percentage of overall tax revenue (less than 5%) in the US and thus will be left out of the discussion.

disbursement of revenues none of the causal mechanisms in the theory would obtain. Also similar to the British case, the economic potential for commercial diffusion of radically new infrastructural technologies is greatly conditioned by the relative regressiveness of the tax code; the more regressive the tax code, the larger will be the after-tax income of those classes with a higher propensity to invest (Gordon, 1997; Kelly, 2000). Finally, the degree to which defense contractors working on informational GPTs escape taxation is important in the same way it was in 18th century Britain; contractors receive federal expenditure, this expenditure propels technological development in various ways, and contractors are best off if they bear less of the taxation burden associated with heightened defense expenditure.

In regards to this latter point the American story is relatively straightforward; major defense contracting firms did effectively escape most forms of taxation during the temporal period under consideration (Weber, 2001, 15, 52; Kurth, 1973; Melman, 1970). Provisions allowing for rapid amortization of capital equipment used in defense contracting and depreciation write-offs at twice the commercial rate, along with deductions for the interest costs of loans (which were many times government subsidized anyway), kept the tax burden on defense contractors quite light (Beard, 1993, 37; Weber, 2001, 61-2; Peck and Scherer, 1962, 539; Scherer, 1964). Also, the Pentagon retained, and often asserted, the legal authority to order reimbursement of state and local taxes on profits to military contracting firms (Melman, 1970, 63). Additionally, because contractors receive

'progress payments'[154] rather than a lump sum sale, they have operated under a completely different set of tax laws than commercial firms. Basically, from 1940 to1984, the IRS allowed defense contractors to defer income tax until they completed their multi-year weapons contracts, while also not requiring contractors to declare progress payments. I.e., defense contractors reported incurred expenses as a loss without reporting progress payments as a gain; nor did they have to report profits until contracts were completed. The losses from incurred expenses, which were actually covered by progress payments, were carried forward as long as the contract was still considered open; the 'losses' were then used to defer, offset, or eliminate taxes on other income. In short, this 'completed contract' method of tax assessment enabled defense contractors to avoid paying taxes on their defense, and non-defense, related businesses. Although the completed-contract loophole was closed in the 1984 Tax Reform Act, the measure operated for nearly the entire span of the temporal interval reviewed in this study (Weber, 2001; Beard, 1993). The other mentioned provisions applied during the full temporal span, therefore, the assumption going forward will be that defense contractors largely escaped taxation during WWII and thereafter.

In order to get a broad sense of the overall tax burden and tax structure borne by the American public during the period under consideration, the narrative chapters of the American Case will include data indicating gross revenue and gross

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[154] The government reimburses 60-90% of a contractor's allowable costs on a monthly basis. Such payments provide a cheap torrent of funds promoting risky technological development in the defense sector (Weber, 2001, 60-61, 142; Fox, 1974, 54 Melman, 1970, 48-9).

revenue as a percentage of GDP. Gross revenue will also be broken down into its four main components – personal income taxes, corporate income taxes, social insurance taxes, and excise taxes. Analyzing the relative levels of these categories will convey the regressiveness of the tax regime in any particular period, thus indicating how taxation impacted the economic environment for investment and diffusion. Personal income taxes and corporate income taxes for obvious reasons line up on the progressive side of the ledger; while social insurance taxes and excise taxes line up on the regressive side (Gordon, 1997; Kelly, 2000, 178-190).[155]

Now onto public deficit finance. The basic premise guiding the analysis of public deficit finance in the American Case is that the central quality and tremendous size of the US public deficit finance system enabled massive expenditure on advanced weapons R&D and procurement without fostering economic or political collapse. During WWII and the Cold War, the rapidly escalating costs of advanced weapons projects clearly could not and would not have been funded sans effective public deficit finance; especially given the myriad of non-defense expenditure responsibilities and evolving social compacts inherent to the 20th century industrialized nation-state experience.

The general structure of the US public deficit finance system over the years 1940-1999 was and remains straightforward, and, owing to the previous British

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[155] Excises are regressive for the same reasons previously elucidated. Social insurance taxes in the US are regressive because tax is charged on everyone's first dollar of income, but contribution levels are capped, so dollars earned after a certain income level are no longer taxed (Gordon, 1997, 167).

case analysis, should not seem unfamiliar.[156] The US Treasury Department issues marketable public debt instruments and the interest rate paid out by the federal government to current holders varies inversely with the going market price of the security. Recall in the British Case that by the middle of the 18th century consols could be redeemed by the government at any time, and the entire debt could be refinanced at once if interest rates declined, but consols had no specific maturity dates. In the US public debt securities all have precise maturity dates; however, since the market for public debt in the United States is incredibly liquid, the US is able to issue new debt at regularly scheduled intervals in order to redeem old debt at its maturity date in a process known as rolling over. Rolling over allows the American system of public deficit finance to approximate the old British system where, in an aggregate sense, principals do not have to be repaid, and debt is consistently refinanced at current rates; although in the American case this refinancing takes place whether interest rates have increased or decreased. Again similar to Britain in the 18th century, interest rates on government bonds in the US set the baseline for the cost of credit in the country (because of their limited risk), with regularly scheduled auction sales of Treasury bonds, notes, and bills being one of the main links between the government and the economy (Malkin, 1987, 10-12; Steadman, 1993, 120; Parkin, 1995).

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[156] The US system of public deficit finance was consciously modeled on the British system of debt, with Alexander Hamilton acting as the main architect (Stabile and Cantor, 1991; Veseth, 1990; Gordon, 1997).

The US Treasury is known as the world's safest borrower; as suggested above, its securities are, for all intensive purposes, risk free. This is because the US pays interest in its own currency and also has the ability to issue more of its own currency at anytime (Malkin, 1987; Hormats, 1988; Sturm and Muller, 1999). The only real risk is that inflation may erode the value of a security over the term of its maturity. This is where the Federal Reserve comes in. The role the Federal Reserve plays in America's system of debt differs from that played by the BOE in the 18th century British system of debt in that the Federal Reserve does not oversee or manage the issuance of debt in the United States; the Treasury has internalized all such responsibilities. The Federal Reserve of course oversees and manages the nation's money supply, which impinges directly on inflation. The Fed governs the money supply by targeting interest rates for federal securities, mostly in the short-end, through open market purchases of government securities. The open bond market and its interaction with interest rates and the money supply acts as a check and regulator on the government's ability and propensity to issue dollars on one side and debt securities on the other; the former overseen by the Fed and the latter overseen by the Treasury (Malkin, 1987, 11; Stabile and Cantor, 1991, 98).

Grasping the above in a general way is important to the theoretical mechanisms in the American Case because the Fed periodically stumbles into rather unsound public deficit finance practices by stoking inflation through a reckless 'monetization' of debt; most notably this occurred during the Vietnam War. In the narrowest sense of the term, monetization of debt occurs whenever the

Fed buys public securities on the open market. More colloquially, the Fed can be considered to be monetizing debt if the Fed buys treasury securities at a faster rate than the Treasury is issuing them. The Fed would do this in order to maintain interest rates at an unnatural level in the face of increased public expenditure by mopping up any unwanted debt securities at a set price level. The best statistical indicator that this may be occurring is the percentage of US public debt outstanding held by the Federal Reserve; if this statistic increases rapidly during a period of heightened government deficits, reckless monetization of debt is taking place (Buchanan and Wagner, 1967; Malkin, 1987, 123).

The inevitable result of rapid debt monetization (in the colloquial sense) is runaway inflation. As in the 18th century, sustained inflationary spirals in the 20th century indicate unsound public deficit finance; i.e. the economy and its financial systems are overburdened by the level of government expenditure (Parkin, 1995; Cavanaugh, 1996, 41). As discussed in the 18th century cases, runaway inflation terribly erodes the potential for a military expenditure inspired mode of development shift. To begin with, the economic, political, and social destabilization resultant from rapidly rising price levels ultimately constrains the flow of funds being directed to defense contractors. Additionally, "The ability of the capital market to channel savings into a productive industrial capacity relies upon a stable financial climate within which the value of investments can be determined" (Steadman, 1993, 20; Buchanan and Wagner, 1967). Clearly then, any widespread diffusion of new capital intensive technology is unlikely to materialize

in an environment of rapid inflation and concomitantly rising interest rates.

Essentially, in the 20th century, central bank monetization of debt is one mechanism that can cause crowding out, by way of rising inflation leading to rising interest rates, both of which inhibit private investment. Military expenditure may also contribute to crowding out through deficit stimulation – as the Treasury increases its security issues, competition for capital is heightened, interest rates rise, and private capital is bled away from productive investment (Tirman, 1984, 2; Sturm and Muller, 1999; Cavanaugh, 1996; Hormats, 1988, 65; Heilbroner and Bernstein, 1989).[157] Crowding out then is another important opportunity cost associated with long-term large-scale military expenditure in the 20th century (as it was in the 18th century).

The literature debating the extent of crowding out during the Cold War is vast, varied, and complex. From this literature emerges a clear point that is quite relevant to our narrow purposes here: crowding out is highly unlikely to obtain in economies exhibiting sufficient slack (i.e. underemployed resources) (Cavanaugh, 1996, 38; Eisner and Pieper, 1988, 20; Majeski, 1992, 218; Parkin, 1995).[158] Thus, like in the British case, the 'military expenditure impetus to mode of development shifts theory' is going to be most operative in the American case when slack exists

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[157] Although it should be noted that widespread foreign participation in public debt markets can greatly limit this form of crowding out (Cavanaugh, 1996, 75; Malkin, 1987).

[158] In an environment characterized by unemployed resources, rising prices in any one sector draws increased investment in productive capacity thus halting inflation (Heilbroner and Bernstein, 1989, 109). An influential 1988 paper by Eisner and Piper demonstrates that from 1961-1984 deficits in the US were "correlated positively with increases in both consumption and investment. Deficits were crowding in investment, not crowding it out." This was because the economy over this period typically operated below potential (full-employment) GDP (Eisner and Pieper, 1988, 20-21).

in the underlying macro-economy. The best way to directly obtain a read on slack in the American case is through government statistics on capacity utilization, and this data will therefore appear in the ensuing narrative chapters. The level of slack in any particular period will also be imputed through an analysis of inflation and interest rates.

Interestingly, the US, like Britain, seems to have experienced gradually heightened crowding out effects as the temporal period under consideration progressed. In both positive cases, the macro-economy exhibited low inflation and interest rates as the central novel infrastructural technologies began to incubate. But, as military expenditure continued and the mode of development shift matured, we find decreasing slack, increasing inflation, and rising interest rates in both Britain and the US. Linking the long-term trends of increased inflation and interest rates, experienced by both 18th century Britain and the post WWII United States, with the military expenditure inspired processes that gave rise to novel modes of development in each case, while also noting the ability of Japan to free ride on the US's informational technological developments without having to bear the increased economic burdens imposed by crowding out, may be the best overall contribution this study can make to the crowding out literature.

THE MILITARY EXPENDITURE / PRODUCTIVITY DEBATE:

The military expenditure / productivity debate is actually a subset of the crowding out literature that narrows the focus from the financial economic level

down to the manufacturing level. The debate queries whether military expenditure directly inhibits capital investment in manufacturing and technical change thus reducing productivity growth. The productivity debate is relevant to this dissertation because of the definition employed for the overarching object of interest, a mode of development shift. A mode of development, as has been averred throughout, is defined primarily by alternative methods of deriving productivity gains from capitalist enterprise; i.e. agrarian methods, industrial methods, or informational methods. This dissertation asserts that military expenditure was a crucial factor enabling the two existing mode of development shifts by contributing in indispensable ways to the development of the technologies that opened up the potential for new productivity paradigms; hence, I am arguing that military expenditure has had positive, even transformative, effects on productivity over the long-term. However, there is a large existing literature which asserts that military expenditure has only detrimental effects upon productivity, at least in the short-run. This literature will now be engaged.

Immediately following WWII very few people questioned whether military expenditure had negative effects upon productivity. Conventional wisdom viewed the Depression as an outcome of insufficient aggregate demand. FDR's New Deal programs attempted to stimulate aggregate demand, but proved insufficient. WWII military expenditures on the other hand did the job. Subsequent Cold War military expenditures were accompanied by rapid rates of productivity growth; between 1945 and 1960 US productivity increased 3% or over annually. But rates of

productivity growth in the US began to ebb towards 2% in the 1960s. By the mid-1970s productivity in the US was growing at a 1% annual clip, accompanied now by moribund real GDP growth. Given the post-Vietnam political climate, this distressing deceleration in the American economy generated considerable controversy regarding the negative consequences excessive military expenditures may have upon productivity growth (Ruttan, 2006, 167; Malkin, 1987, 242; Tirman, 1984, 6-10; Dumas, 1991, 59; Alexander, 1991, 81).

One cannot help but be struck by the highly polemical nature of large slices of the literature analyzing military expenditure's relation to productivity. Especially given that productivity growth is an extremely tricky phenomenon; no one is quite sure what drives its vicissitudes. We know how to bluntly measure it (output divided by labor hours), and we know that three major factors go into it (capital, labor, and technology); but beyond that productivity remains somewhat of a mystery.[159] The 'military industrial complex' (MIC) polemicists of course believe that they have the mystery solved, at least during those moments when productivity rates are receding: "Industrial productivity, the foundation of every nation's economic growth, is eroded by the relentlessly predatory effects of the

[159] Economists today accept the one-third rule which states that "a one percent increase in capital per hour of labor, with no change in technology, brings a one third of one percent increase in output per hour of labor." Thus if output per hour of labor increases at a faster rate than one third of the increase in capital inputs per hour of work, the residuum can be attributed to technological change. From there, however, technical change remains an opaque box; there is no consensus as to which of many factors may drive it and when. There is also no way to determine what technologies account for the residuum in any given period, or the sort of mechanisms that might be conditioning their effect on productivity (Parkin, 1995, 213-217; Devarajan, 1993, 115-6; Alexander, 1991, 81; Rosenberg, 1998, 168).

military on the economy" (Tirman, 1984, 13; Melman, 1970; Dumas, 1995, 1991; DiFilippo, 1990, 1991; Yudken and Black, 1991, 163; DeGrasse, 1983, 1984).

The MIC polemicist invariably cites 'preemption' as the main theoretical mechanism causing military expenditure to negatively effect productivity and economic growth in the United States. Preemption occurs when defense programs seeking radical technological progress draw human and fixed capital away from R&D efforts aimed at producing regular incremental path dependent commercial technical change. There is little doubt that preemption is yet another opportunity cost associated with long-term large-scale military expenditure; nations not experiencing preemption effects are likely to out-compete nations experiencing preemption effects in high-tech commercial sectors where a prevailing trend favoring incremental path dependent technical change has been established (DeGrasse, 1983; Tirman, 1984; DiFilippo, 1990; Stowsky, 1992; Ruttan, 2006, 4). Hence, preemption opportunity costs will mount for a militarily spending nation as a mode of development shift matures. We will gauge preemption effects in the US during the Cold War by looking at the varying percentage of the aggregate American engineering corps deployed on defense-related projects at any one time.

But analyzing preemption in this way is a far cry from deeming preemption to be the primary causal mechanism driving the 1970s productivity slowdown. To begin with, the productivity slowdown was global in scope, but significant preemption effects obtained only in the US. In fact productivity declined most

spectacularly in Japan (where military expenditure approached zero), moving from an 8% clip in the late 1960s to a 3% clip just five years later (Parkin, 1995, 107). Secondly, studies that have attempted to link preemption with productivity invariably assume some sort of 1:1 or near 1:1 trade-off between defense R&D on the one hand and other forms of R&D on the other. One is constantly confronted with 'might have' type arguments in the productivity debate: "If government had not spent so much on high technology military products, the engineers doing military work might have developed commercial electronics products to compete more effectively with the Japanese" (DeGrasse, 1983, 53; DiFilippo, 1990, 6; Dumas, 1995). But there is simply no evidence indicating that precise trade-offs between defense R&D and other forms of R&D actually exist (Stowsky, 1992, 233; Tirman, 1984, xiii; Smith, 1985; Weber, 2001, 46).[160] Lacking such evidence, the MIC polemicist relies on contrasting a laundry list of figures indicating cross-national productivity growth rates against a laundry list of figures indicating cross-national defense expenditure levels. The causal link between the two inventories is

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[160] There are various econometric studies purporting to show that military R&D has had no discernable positive effects on industrial productivity in the US, while independently undertaken private sector R&D has (Lichtenberg, 1984, 1989; Grilliches, 1995 are representative; see David, et al, 2000 for others). These studies have been described as problematic because public R&D is assumed to be substituting for private R&D in a 1:1 ratio in the statistical analyses, even though the evidence for such a notion is scant. When viewed in another way, with public R&D and private R&D acting as complements rather than competing, public R&D may very well be enhancing the profitability of private sector R&D, rather than preempting it. And there is evidence that the relationship between public R&D and private R&D is in fact complementary rather than competing. For example, David, Hall, and Toole (2000) conducted an econometric reanalysis of previous studies that measured public R&D and private R&D as substitutes. They found that over two-thirds of these studies were more consistent with a complementary hypothesis rather than a substitution hypothesis. Their findings suggest that military expenditure has rarely preempted private R&D in the United States at the aggregate level, but has often complimented it; thus in so far as private R&D has stimulated productivity growth in the United States, so too has defense R&D, although at an indeterminate ratio (Ruttan, 2006, 169-171).

blindly asserted but rarely statistically substantiated, while the muddling effects conveyed by large outliers and potentially spurious variables are either glossed over or entirely disregarded (see DeGrasse, 1983, 1984; Tirman, 1984; DiFilippo, 1990, 1991; Bischak, 1991; Dumas, 1991, 1995; Melman, 1970; and Pascall and Lamson, 1991 for particularly egregious examples).

Most importantly, when preemption and productivity are directly compared over time, sans all the rhetoric and rhetorical devices, even the simplest of correlations do not obtain: In the 1950s productivity growth in the US was brisk (3-4%), and yet an estimated 40% to 50% of the nation's scientists and engineers were engaged in defense-related activities (Berkowitz, 1970). In the 1960s between 35% and 45% of all US scientists and engineers were working on defense-related projects while productivity growth ebbed to between 2% and 3% (Berkowitz, 1970; Fox, 1974, 33; 65-67). In the 1970s the proportion of scientists and engineers dedicated to defense projects fell to between 25% and 30%, and yet productivity growth continued to recede down to 1% (Fox, 1974, 33; 65-67; Dumas, 1984, 142). Then, in the 1980s defense expenditure mounted rapidly, particularly the advanced weapons R&D component which requires widespread participation of scientists and engineers. Upwards of 45% of all American engineers and scientists became involved in defense-related activities; strangely, productivity growth rates turned up slightly during the1980s (DeGrasse, 1984, 80; Alexander, 1991, 94; Malkin, 1987; Parkin, 1995). Indeed, an impartial observer would have to assume that preemption somehow promotes productivity.

This impartial observer, however, would never assert such a thing because an amazing variety of factors entirely unrelated to military spending can impact productivity. The following causal variables have been cited in the myriad studies seeking to account for the 1970s global productivity slowdown: oil shocks,[161] a pick up in the pace of human and fixed capital obsolescence,[162] inflation, tax burdens, deficits, debt monetization policies, currency fluctuations, increased financial speculation, corporate M&A activity, short-sighted corporate management practices, capital flight, outsourcing, the rise of the service industries, agricultural subsidies, population growth, deskilling of the labor force, long-term convergence theory, poor education, and even the blunt and perhaps improper methods of measuring productivity itself (Howitt, 1998; Malkin, 1987, 243-296; Vayrynen, 1992, 65-81; Gold, 1990, 75-81; Cavanaugh, 1996, 80-3; Alexander, 1991, 90; Yudken and Black, 1991, 164; DiFilippo, 1990, 50-75; Gregory, 1993, 64-65; Hormats, 1988, 14-15; Veseth, 1990, 141-147; Mosley, 1985, 74-5; Parkin, 1995). In short, "The literature on declining productivity is positively liturgical in its repetitiveness. Everyone has some laundry list of causes, and too many people have their own magic cure (for which read political hobbyhorse)" (Malkin, 1987, 296).

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[161] Since the major oil producers escaped the productivity slowdown, it seems safe to assume that the oil shocks were indeed a main culprit (Parkin, 1995, 107).

[162] Presently, consensus seems to be congealing around this particular causal factor. The idea is that information technologies counterintuitively interrupted productivity growth in commercial sectors initially, but ultimately caused productivity to surge. Few, if any economists continue to cite military expenditure as a primary causal or contributing factor in the global productivity slowdown (Helpman, 1998, 10; Helpman and Trajtenberg, 1998, 72-3; Howitt, 1998, 219-248; Lipsey et al, 1998, 23; Parkin, 1995; Doms, 2004; Fernand et al, 2007; Ruttan, 2006; Sichel, 1997). We will briefly return to this point at the end of the American Case narrative.

Given the above long, and probably non-exhaustive list, it is not surprising that even the most advanced and unbiased econometric models are confounded by the military expenditure / productivity relationship. A large volume in and of itself would be required in order to adequately review the better models, so here, a few lit review summaries will have to suffice: Gold (1990: 29-44) reports after reviewing the literature that various measures correlating military spending and economic change are usually insignificant, and that the correlation between military and civilian R&D spending over the long-term and their respective effects on productivity have been reported as both positive and negative and are also many times insignificant. Gold therefore asserts that "it has not been shown conclusively that military spending per se would undermine a nation's productivity to any significant degree" (Gould, 1991, 43). Vayrynen (1992: 66-69) reports "The empirical evidence that military expenditure is discouraging economic development is ambiguous and certainly not compelling." Alexander (1991: 93) states "To date there are no very satisfactory econometric models of either productivity changes or the economic effects of military spending."[163] Vernon Ruttan's (2006) recent

[163] An interesting econometric analysis run by Alexander (1991) found that rates of military expenditure and the ratio of military investment to manufacturing output did have some small significant negative correlations with productivity rates over the years 1951-82. Amusingly though, because real military spending fell at an annual average rate of 3.3% over the most intense period of the productivity slowdown, 1970-1982, as did the ratio of military investment to manufacturing output (at a 3.80% annual clip 1970-1982), it was found that declining military spending actually added to productivity growth during the productivity downturn: the declining military share of manufacturing output boosted productivity growth by .22% from 1970-1982, while declining aggregate military spending boosted productivity perhaps by .17% over the same period (Alexander, 1991, 101-2). How then could military spending have caused the productivity slowdown? Such a finding basically applies to any careful econometric analysis revealing a negative correlation between military expenditure and productivity, because during the crucial period of productivity slowdown military expenditures were in fact declining.

declaration is also most instructive: "We do not yet have, and perhaps cannot have, a body of rigorous econometric evidence against which to evaluate the economic impact of defense and defense-related R&D and procurement... careful narrative analysis of individual cases is at present a more effective method of capturing the effects... than econometric analysis" (Ruttan, 2006, 170). Vayrynen echoes Ruttan's position:

> "Statistical analyses help to define exact relationships between military capabilities and economic changes in specific temporal or spatial contexts. I am skeptical, however, of their ability to capture significant historical relationships between military allocations and socio-economic development. Statistical analyses may be able to define for example, short-term economic effects of military expenditures, but they are hardly able to tackle long-term structural consequences of military spending and weapons acquisitions... in the study of complex issues and relations it is prudent to believe in comparative case studies in which a relatively small number of units is intensively studied and compared" (Vayrynen, 1992, 25).

Paul David (2004) and J. Alexander (1991: 110) also maintain that carefully composed narrative remains the best way to capture the complex dynamic interactions between military expenditure and macro-economic variables such as productivity over the long-term (Ruttan, 2006; Vayrynen, 1992; Howitt, 1998, 248).

This author of course wholeheartedly agrees. Comparative historical narrative analysis may be the only method capable of capturing the key relations between military expenditure and productivity over the long-run.[164] What

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[164] "The relationship between (defense) R&D and economic growth may involve a much longer lag than time-series econometricians are used to dealing with"; perhaps up to 25 years. When the lag between cause and effect is this long, causal relationships are particularly difficult to statistically discern (Howitt, 1998).

repeatedly emerges from the comparative historical analysis here then is the following: If the temporal focus is shifted from the short-term to the long-term, and the technological focus is shifted from incremental commercial style process change to radical product innovation, it becomes apparent that the main effect large-scale military expenditure has on productivity is not negative, it is qualitative (as long as the other conjunctional causal conditions laid out in the dissertation's theory are fulfilled). In the particular case of the United States, 1940-1995, military expenditure, in diverting resources from the civilian economy to advanced weapons procurement, altered effective investment and demand, displacing it from regular incremental commercial technical change and directing it towards infrastructural informational GPT development; thus paving the way for the radically new technological trajectories which coalesced into the informational mode of development. Such preemption, along with the other opportunity cost factors previously cited, did at times effect American competitiveness negatively in the short-run; but in the long-run, the potential for future productivity growth was enhanced.

Interestingly, the current state of the literature is not entirely unsupportive of such notions; in fact just the opposite. For after experiencing two decades of slow productivity growth, US productivity surged in the mid 1990s and beyond.[165] The literature is nearly unanimous in its agreement that this productivity boom was in large measure a result of the macro-coalescence of the infrastructural

[165] The rate of productivity growth in the US declined from 3.5% 1948-1973, to 1.5% 1974-1995. It rose to 2.6% between 1996 and 2000; and to 4% between 2000 and 2004 (Ruttan, 2006, 167).

informational technological sectors specified in this study (Litan and Rivlin, 2001, 19-22; Ruttan, 2006, 110, 128, 166; Greenspan, 2000; Oliner and Sichel, 2002; Doms, 2004; Fernand et al, 2007). Given the temporal correlation between the information technologies productivity boom and the end of the Cold War, the time is ripe for a well constructed comparative historical analysis seeking to establish some important general causal mechanisms regarding large-scale military expenditure and its effect on productivity, technological diffusion, and modes of development over the long-term. Taken together, all of the multiple conjunctional causal variables, scope conditions, corollaries, and caveats in the 'military expenditure impetus to mode of development shifts theory', along with their complex interactions, combine to make the emergence of a defense expenditure driven mode of development shift a rare occurrence indeed. But when it does crystallize, it is a process of enormous transformative power; as the narrative and comparative historical data of the American Case will now demonstrate.

CHAPTER 10: AN OVERVIEW and WORLD WAR II

Before the American Case narrative commences, allow me to provide a road map outlining the path forward. The following narrative is broken down into a series of chapters, with each corresponding to a particular defense expenditure era. Each chapter begins with a rundown of defense expenditure aggregates. Relevant revenue and public deficit finance statistics are then discussed and an overall sense of the economic environment for technological development and diffusion is conveyed. Next, the key events that took place in the technological sectors of interest (semiconductors, computers, and computer networking) are detailed while the ways in which defense expenditure impacted upon these events is highlighted.

The first defense expenditure era is WWII (1940-1945). During WWII military expenditure in the US increased by 50 fold, rising to 37% of GDP. Numerous novel technologies arose as a consequence of the many vast and varied WWII related R&D efforts. Two take center stage: specialized high speed electronic calculating devices, and semiconductor radar. The next defense expenditure era is the Postwar Era (1946-1949). Here, defense expenditure declined precipitously, falling by 90% between 1945 and 1948, to just 3.4% of GDP. Taxes were slashed and the economic environment became ripe for technological diffusion. Many new technologies did diffuse, although incipient 'general purpose electronic digital computers' did not, owing to the unreliability and high cost of the one-of-a-kind warehouse sized machines. In the semiconductor sector, the transistor was invented during this period; the invention's many connections with

military expenditure are detailed in this chapter.

The subsequent chapter is marked by the Korean War (1950-1953). Military expenditure again skyrocketed, reaching 14% of GDP in 1953. Importantly, much of this expenditure was directed toward advanced weapons R&D and production intended at securing strategic advantage in the nuclear arms race with the Soviets. In the semiconductor sector, defense expenditure propelled crucial enhancements to transistor production. In the computer sector, IBM made its first forays into computer manufacturing on the back of lucrative Korean War era defense contracts. Also, the Semi Automatic Ground Environment (SAGE) project was initiated, immediately yielding important new computing inventions, such as magnetic core random access memory.

Next we enter the Cold War defense expenditure era. Owing to the differing expenditure regimes presided over by the Eisenhower administration on the one hand and the Kennedy / Johnson administrations on the other, along with the dense technological narrative intrinsic to this lengthy era, this stretch of the Cold War is divided into two chapters; the first spans 1954 to 1959, the second spans 1960 to 1964. In the first, defense spending continued to trend upwards, and also became increasingly aimed at advanced weapons R&D and procurement. With Eisenhower, an avowed balanced budget man at the reigns, this period can be characterized as propitious for defense-induced technological development, although not great for technological diffusion. And indeed, this was certainly an era of vast technological development in both the semiconductor and computer

sectors. In the semiconductor sector the DOD pushed the transistor industry away from low frequency germanium transistors, and towards high frequency silicon transistors. Meanwhile, commercial firms for the most part remained reticent to integrate transistors into their manufacturing processes and products at this time. In the computer sector defense expenditure drove numerous improvements and inventions in regards to architecture, graphic interfaces, memory, processing, disk storage, and software. Also, IBM's participation in large defense projects such as SAGE and STRETCH allowed it to emerge from the 1950s with 70% of the mainframe manufacturing market. During the subsequent 1960-1964 Cold War defense expenditure era, military spending continued to trend upwards, and its advanced weapons orientation was maintained. Kennedy, however, was the nation's first unabashedly Keynesian president. He therefore let deficits rise. Taxes were slashed, interest rates were kept artificially low, and the economy responded. Kennedy thus presided over an era that was ripe for both technological development and technological diffusion. Interestingly, however, with military expenditure remaining at elevated levels, this period is marked more by technological development in our sectors of interest, than it is by commercial diffusion. In the semiconductor sector, the integrated circuit (IC) was invented in 1960; over the next four years over 90% of all ICs went to military uses. The military also consumed an overwhelming majority of transistorized mainframe computers produced during this era. And for the first time, computer networking materialized as an independent research sector. Specifically, the Defense

Advanced Research Projects Agency (DARPA)[166] initiated Project MAC, an effort aimed at creating 'time-sharing' terminals linked to a single mainframe computer.

The Vietnam escalation marks the next defense expenditure era, 1965-1970. Counterintuitively, spending on advanced weapons R&D and production broadly declined in this period as resources were reallocated from major weapons systems to manpower and ordnance. Meanwhile, the economic environment for technological diffusion was halcyon, characterized by a relatively regressive tax structure, low inflation, and low interest rates. Given declining advanced weapons expenditures and a ripe economic environment for technological diffusion, 'the military expenditure impetus to mode of development shifts theory' would predict a heightened pace of diffusion in the semiconductor and computer sectors, and this is precisely what occurred. Transistors finally diffused widely into commercial capital goods and appliances, and ICs were increasingly applied to consumer and industrial uses. In the computer sector, IBM marshaled its many defense-related architectural innovations to come up with the revolutionizing System / 360, which was expressly intended for commercial and civilian use. IBM quickly sold more System / 360 mainframes than all of the computers it had manufactured up to that point combined. The System / 360 also inspired the rise of a corporate software products industry; an industry to which programmers previously involved in

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[166] The official moniker for DARPA has vacillated between ARPA and DARPA for over four decades. Some management regimes prefer the D for defense, others do not. Nonetheless, the agency has always been a division of the DOD, which provides its funding and chooses its leadership. For simplicity sake the D will be maintained throughout this study.

advanced weapons efforts quickly gravitated to. Many of the companies that came to dominate this new industry were started by former employees of defense contractors. DARPA expenditures on computer networking projects, on the other hand, continued to rise throughout this era, thus driving important new developments. The UNIX networking operating system was born, and the first ever decentralized packet-switched wide area computer network, the ARPANET, was invented and deployed.

The next chapter covers the Détente defense expenditure era (1971-1977). During the Détente era military expenditure was drastically reduced; although DARPA was able to shield its networking projects from the cuts by funneling expenditure away from 'computing projects' and towards 'computer networking projects.' The economic environment for diffusion in the US, in the meantime, took a turn for the worse. The Fed had been extensively monetizing debt amid increasing capacity utilization since the mid-1960s and the eventual consequence was a 'great inflation'; the CPI hit 11% in 1974 and remained elevated thereafter. Although commercial diffusion of previously defense-related technologies did continue to occur in the US semiconductor and computer sectors, upstart foreign semiconductor and computer manufacturing firms began to erode dominant US market share in international markets. Nevertheless, the key diffusion event in this period occurred in Palo Alto, when a number of DARPA computing project refugees left their university posts to join Xerox PARC after their funding had dried up. This led to the advent of the first desktop sized personal computer, the Alto,

which featured a windows based graphic user interface accessible through a mouse. Meanwhile, in the still well funded computer networking sector, defense-induced development proceeded apace. DARPA oversaw the creation of the first TCP/IP Internet – a globally scoped network for defense-related C3 (command, controls, and communication) capable of flexibly 'scaling-in' an infinite number of new networks. Also, DARPA researcher Robert Metcalfe invented Ethernet local area networking at this time.

The final leg of the Cold War (1978-1989) composes the next defense expenditure era. During this period all forms of military expenditure rocketed. With public debt soaring, inflation still brisk, interest rates well over 10%, capacity utilization averaging well over 80%, and defense expenditures ramping upwards, the final Cold War era provides the classic textbook case for crowding out. And as would be expected, US firms experienced declining market share in the now global semiconductor and computer sectors. To make matters worse, new and expensive DOD semiconductor and computer projects were initiated which swam against the tide of extant commercial trends, thus heaping preemption opportunity costs upon the already suffering US semiconductor and computing industries. DARPA efforts in the computer networking sector, on the other hand, continued to blaze new commercial trajectories. 'Networked workstation' powerhouse, Sun Microsystems, which was for all intensive purposes a DARPA project spin-off, led the capital goods industry towards an inter-networked horizontally integrated future. Emerging informational production chains were also powered by Ethernet

networking technologies provided by Metcalfe's 3Com. The explosive growth exhibited by these two American companies during this era points to the inexorable pull of the rapidly fusing informational mode of development.

The final chapter in the American Case reviews the post Cold War decade (1990-1999). Over these years all forms of defense expenditure waned and concomitant crowding out effects receded. The informational mode of development infrastructure fused and the globe entered a period of heightened informational 'take-off.' With defense expenditure declining, American firms experienced a renewed competitiveness in the semiconductor and computer sectors. There was also a sudden and rapid diffusion of Internet technologies during this era, and American firms quickly came to dominate burgeoning Internet industries. The narrative comes to a close with productivity in the US taking a sustained turned upwards, thus indicating the coalescence of the informational mode of development.[167]

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[167] **STATISTICAL DATA SOURCES** – Throughout the following chapters of the American Case statistical sources are as follows unless otherwise indicated: All 'Real' statistics have been converted into year 2000 dollars using the GDP Implicit Chain Weighted Deflator, as reported in Bureau of Economic Analysis (BEA), "Current Dollar and Real GDP", *National Economic Accounts*, 2007; GDP statistics also come from this source. All Aggregate Military expenditure statistics come from the US Office and Management Budget (OMB), "Federal Government – Outlays and Debt, 1940-2003", *Budget of the US Government Historical Tables*, Fiscal Year 2004; Non-Defense Expenditure totals and aggregate Federal Debt statistics also come from this same source. Procurement and RDT&E defense expenditure statistics covering the years 1953-1961 come from Scherer, 1964, 57. Procurement and RDT&E defense expenditure statistics covering the years 1962-1999 come from OMB, "Outlays by Function and Subfunction: 1962-2012", *Budget of the US Government Historical Tables*, Fiscal Year 2008. NASA expenditure statistics covering the years 1958-1961 come from Scherer, 1964, 57. NASA expenditure statistics covering the years 1962-1999 come from OMB, "Outlays by Agency: 1962-2012", *Budget of the US Government Historical Tables*, Fiscal Year 2008. All DARPA and IPTO expenditure statistics as reported in Norberg and O'Neill, 1996, 22-24. All Aggregate Revenue, Personal Income Tax Revenue, Corporate Income Tax Revenue, Social Insurance Tax Revenue, and Excise Tax Revenue statistics

WORLD WAR II – 1940-1945:

The American information technologies revolution germinated in the tempest of WWII. By any measure, the United States ran an 'awesome garrison economy' throughout the war (Higgs, 1990, xvii). Between 1940 and 1945 total military expenditure in the United States increased approximately 50 fold, reaching a high of $82.97 billion in 1945, which was an astounding 37% of GDP. From 1940 to 1945 the US spent an aggregate $262.5 billion on the war; which equates to over $2.18 trillion in 2000 dollars. During the war the government paid for approximately 65% of total investment in plant and equipment, and by war's end owned 40% of the nation's capital assets; these assets were of course operated by private market-based contractors, which included all of the nation's leading corporations of the day (Weber, 2001, 61).

Besides the enormous total mobilization effort, what marked WWII as historically unique was the critical role played by R&D. Prior to the war the nation as a whole spent $300-$400 million per annum on scientific research, one-fifth of

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come from OMB, "Receipts By Source: 1934-2003", *Budget of the US Government Historical Tables*, Fiscal Year 2008. Percentage of Public Debt Held by the Federal Reserve statistics come from OMB, "Federal Debt at the End of the Year: 1940-2012", *Budget of the US Government Historical Tables*, Fiscal Year 2008. All M1-M3 data as reported in OMB, "Money Stock and Debt Measures, 1959-1999", *Budget of the United States Government: Economic Report of the President*, 2000. All Bond Yields and Interest Rates as reported in OMB, "Bond Yields and Interest Rates, 1929-1999", *Budget of the United States Government: Economic Report of the President*, 2000. CPI statistics as reported in US Census Bureau, "Consumer and Gross Domestic Price Indexes", *Statistical Abstract: Historical Statistics*, 2007. Capacity Utilization (Manufacturing) statistics as reported in OMB, "Capacity Utilization Rates, 1950-1999", *Budget of the United States Government: Economic Report of the President*, 2000. Private Fixed Investment and Computers and Peripheral Equipment Investment statistics come from OMB, "Private Gross Fixed Investment by Type, 1959-1999", *Budget of the United States Government: Economic Report of the President*, 2000. Statistics on the Percentage of US Debt Foreign Held come from OMB, "Foreign Holdings of Federal Debt", *Analytical Perspectives, Budget of the US Government*, Fiscal Year 2001.

which was provided by government. During the war, total R&D shot up to $800 million annually, 75% of which was funded by the government; in fact, government expenditures on R&D multiplied by 10, while private R&D expenditures declined by 50% (Purcell, 1972, 164).

In order to fund R&D programs and total mobilization efforts, the US used an interesting mix of heavy taxation and debt financing. A few months after Pearl Harbor income taxes were widely extended and deepened, for the first time becoming a mass tax; income tax withholding was also born (Gordon, 1997, 142; Kelly 2000, 2). As a result personal income tax revenue rose over 20 fold between 1940 and 1945, reaching a high of $19.7 billion in 1944. Corporate tax revenue also rose astoundingly but less, increasing over 13 fold, reaching a high of $16 billion in 1945.[168] Social insurance tax revenue on the other hand rose 92%, reaching a high of $3.47 billion in 1944; while excise revenue tripled, reaching a high of $6.27 billion in 1945. Needless to say, taxation in America became entirely more progressive and burdensome during WWII.

Nonetheless, even these intensified revenue aggregates failed to meet the majority of the war's expense, paying for approximately 45% of the total (Stabile and Cantor, 1991, 92). The government ran an average $29.7 billion deficit per annum between 1940 and 1945, which amounted to 15% of GDP over this period. As a result, gross federal debt rose over five fold during course of the war reaching

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[168] Corporate tax revenue aggregates were mitigated by the generous tax provisions lent to contractors. For more on these provisions see Beaumont, 1977, 131; Peck and Scherer, 1962, 164; Purcell, 1972, 162.

a total of $260.1 billion in 1945, which equates to $2.08 trillion in 2000 dollars. In 1946 gross national debt reached an astonishing 122% of national GDP, a figure which has not yet been approached in subsequent American history (the gross national debt was less than half this percentage of GDP in the year 2000). To be certain, America could not have managed the war effort, nor ever recovered from it, sans sound public deficit finance.

With such heavy debt expenditure in play, one would expect massive inflation, but as is well documented and understood, price controls, consumption curbs, and forced income savings muted the inflationary effect. Not to mention that the nation entered the war with plenty of economic slack as a result of the Great Depression hangover (Stabile and Cantor, 1991, 94-101; Beaumont, 1977, 131).[169] Amazingly enough, the average rate of growth in the CPI from 1940 to 1945 was only 4.46%. In effect, the forced savings, curbs, and limits imposed during this era amounted to a conscious policy of 'crowding out' – the government preempted private investment and consumption so that it could spend with relative abandon (Fishback, 1993, 6; Cavanaugh, 1996, 26). As we will now see, such crowding out, in an economic environment characterized by slack, was undoubtedly positive for the long-term technological development of the national economy, especially in regards to nascent electronic information technologies (Flamm, 1988, 2; Vayrynen, 1992, 71; Ruttan, 2006).

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[169] In 1939 unemployment was running at 17.2% (Tirman, 1984, 7).

COMPUTER DEVELOPMENT DURING WWII:

Before we embark upon a discussion of computer development during WWII, the term computer, as it will be employed throughout this study, must be defined. Prior to WWII, 'computers' were people who manned mechanical calculating devices (these devices used analog gears, wheels, and switches to perform specialized calculating tasks). Such machines differ substantially from the 'general purpose stored program electronic digital computers' that emerged from the cauldron of WWII, and which compose one of the major objects of interest for this leg of the dissertation.

The concept of the computer as we know it today was born n the fecund mind of Alain Turing, a British mathematician, in 1936, as an imaginary device. In a visionary paper, originally written to settle some abstract mathematical questions, Turing showed "that any computation can be described in terms of a machine shifting among a finite number of states in response to a sequence of symbols read and written one at a time on a potentially infinite tape" (Mahoney, 2002, 93). Turing argued that such a 'Turing Machine' could conceivably mimic any other known computational or data oriented device, whether it be a type writer or an abacus. In effect, Turing had described a general purpose computer. Making the machine perform a task was simply a matter of breaking the job down into a series of simple machine-readable instructions. Every instruction would contain an 'address' describing the location of the next instruction thus facilitating continual branching of instructions, which enabled the general purpose nature of the device.

Turing believed, and went a long way towards demonstrating, that with such an imaginary device, an algorithm (a series of mathematical instructions) could be developed to solve any information related problem (Akera, 2002, 85; Ceruzzi, 1998).

In following years, John Von Neumann, a superb American mathematician who worked on various wartime R&D efforts and subsequently became a powerful voice in the American scientific establishment, pursued Turing's work to its logical conclusion. Von Neumann drew the architectural blueprint for a material general purpose computer; a blueprint which for the most part is still followed today. Von Neumann described a machine with four main components: 1) a processor where calculations are performed on data and where processing instructions can be infinitely modified; 2) a memory unit accessible by the processor storing data and instructions with the ability to feed and retrieve data and instructions to and from the processor in any desired order with no temporal disparity; 3) input devices which allow new data and instructions to be loaded into memory; and 4) output devices which reported finished computations. Thus war born the 'Von Neumann architecture', as it became known (Cerruzi, 1998, 20-24; Mahoney, 2002, 92; Flamm, 1988, 49; Hughes, 1998, 85-86).

There are two more components to the definition of a modern day 'general purpose stored program electronic digital computer' that must be elucidated, and these of course devolve from the electronic and digital aspects of the moniker. An electronic computer refers to the method of computation utilized in the processing

unit. A mechanical calculating device employs gears and wheels and the like to grind out mathematical operations, while an electronic device uses voltaic current to perform operations. For obvious reasons, electronic processing should be expected to perform calculations far faster than grinding wheels and gears, but prior to WWII this was not the case. Mechanical calculating was more amenable to computation in the early 20th century because wheels and gears could be set to represent any value along an analog continuum. A current on the other hand is more difficult to tailor in this way, especially given mid 20th century electronic technologies such as vacuum tubes. At that time currents in tubes could be turned on or off fairly rapidly, but setting them to a particular value was challenging if not impossible. Thus entered the notion of digital binary methods of computing. In 1936 "Claude Shannon showed how relay and switching circuits could be expressed by equations using Boolean algebra. In these equations, true and false correspond to the opened and closed states of a circuit. The binary connectives, that is, 'And' and 'Or', are modeled by different kinds of (on/off) switches." Shannon continued to work out his binary information theories at Bell Labs (the research laboratory and prime contracting R&D division attached to AT&T) during WWII, demonstrating how 'and / or gates' could become universal building blocks with which to build complex calculating machines (DeLanda, 1991, 146; 213; Williams, 2002, 18).

The enormous computational and processing needs spurred by WWII propelled the general purpose stored program electronic digital computer, as just

described, from the realm of the imaginary closer to material reality. The four main defense needs that drove computer development during WWII (and thereafter as well) were cryptanalysis, real-time guidance and fire control, strategic operational analysis, and nuclear modeling (Flamm, 1988, 36; Beaumont, 1977, 130; Cortada, 2002b, 35). From these threads sprung a variety of specialized semi-electronic / semi-mechanical advanced calculating devices.[170] The key machines that blazed the path toward a general purpose stored program electronic digital computer will now be highlighted.

At the height of WWII, Alain Turing built the first semi-electronic / semi-mechanical digital calculating machine, known as Colossus. Colossus was designed to automate the decoding of German military ciphers; a task that would have been impossible with even the most expensive pre-war calculating devices. Colossus was a relatively small and specialized machine. It was not a stored program computer, although it was limitedly programmable through wires and mechanical type contraptions. British Colossus was crucial to the Allies' victorious Atlantic war efforts (Flamm, 1988, 35-9; Ruttan, 2006, 93; Evans, 1995, 99; DeLanda, 1991, 129).

On the other side of the pond, Vannevar Bush, head of the newly minted US Office of Scientific Research and Development (OSRD), also realized that traditional mechanical calculating device were far too slow for timely code breaking. He thus directed the military brass to fund any and all programs

[170] The machines built during the war lacked sufficient storage ability and programmable flexibility to be considered general-purpose stored program computers (Flamm, 1988, 62).

attempting to develop faster information processing devices (Flamm, 1988, 36). The American military drew the likes of IBM, Bell Laboratories, National Cash Register (NCR), Remington Rand (RR), and Kodak into the effort, developing several semi-mechanical / semi-electronic devices capable of rapidly performing specialized analytical lexical encryption functions (DeLanda, 1991, 213; Flamm, 1988, 41).[171]

By 1944 the epicenter for computer research had clearly moved to the increasingly synergistic US defense department – defense contractor system. This in no small part was a result of the Manhattan Project, which involved the 'intensive use' of semi-electronic digital calculating machines (DeLanda, 1991, 147). The most advanced completed electromechanical calculating device operating in the US in early 1944 was the Mark I, alternatively termed the Automatic Sequence Controlled Calculator (ASCC). Interestingly, IBM had begun developing the ASCC just prior to the outbreak of WWII, but when the US entered the war the Navy took over management of the project, greatly expanded it, and moved the main R&D work to Harvard, where Professor Howard Aiken became the project manager. Because of the nonmilitary beginnings of the Mark I "the electromechanical components and machinery used were conservative. And, though constructed on a vastly larger scale, were little advanced over standard practice in commercial business equipment" (Flamm, 1988, 252). As a result, the

[171] In 1940 the six major office equipment companies, including IBM, Burroughs, Remington Rand and NCR, received only 76 patents; but well over 100 and sometimes 200 during each of the following war years (Cortada, 2002b, 36).

Mark I could only perform a couple of arithmetic operations per second. Nonetheless, Mark I helped 'pave the way for technical development of the US computer industry" (Flamm, 1988, 41, 58-9; Ruttan, 2006, 92; Ceruzzi, 1998, 82).

No machine, however, furthered computer development more in this period than the Electrical Numerical Integrator and Computer (ENIAC), the first fully electronic general purpose advanced calculating machine. Rather than performing a handful of operations per second, the ENIAC could perform over 5000 operations per second (Williams, 2002, 22). Plus the machine could be utilized for a number of different applications, such as cryptanalysis, ballistics computation, or simulation; prior machines were specialized to perform one or the other. The ENIAC project was initiated in late 1942 at the University of Pennsylvania's Moore Engineering School, and was overseen by J. Presper Eckert and John W. Mauchly, both of whom would soon become incredibly influential pioneers in the emerging field of computing. The ENIAC was developed in order to simulate the ignition of the hydrogen bomb, and in 1944 this simulation became the first program run on the ENIAC. The ENIAC occupied 1800 square feet, contained 18,000 vacuum tubes, and consumed 174 kilowatts of power (enough to power a small town for a day). The system cost $800,000 to build; approximately $7 million in 2000 dollars. The traditional calculating machine companies, such as IBM, NCR, and RR, played little to no role in the effort as they had advised the defense establishment against gambling on Eckert and Mauchly's radically new all-electronic general-purpose approach (Flamm, 1988, 252). Although ENIAC is

"often called the first modern electronic digital computer" it should be noted that ENIAC was not a stored program computer as described in the Von Neumann architecture, it had no program memory (Flamm, 1988, 47). Indeed setting up the ENIAC to perform a calculation took days and required 'plugging and unplugging a maze of cables and setting arrays of switches.' The process was tantamount to rebuilding the machine for each new problem (Ceruzzi, 1998, 21; Hughes, 1998, 55). To be certain, this kind of 'programming'[172] highlighted the need for an efficient and flexible memory mechanism that could store instructions and data while the processor operated on both. This would soon become the focus of postwar R&D efforts. For although ENIAC had 'no obvious commercial applications', its successful use in the hydrogen bomb simulation generated exploding defense agency demand for the machine, thus providing extreme and urgent impetus for further development of the general purpose electronic digital computer (Ruttan, 2006, 93; Akera, 2002, 62-5).

FROM RADAR TO SEMICONDUCTORS:

A parallel research effort during WWII was aimed at radar development, and although no one at the time could have possibly foreseen how radar technologies might one day move computers from warehouse size behemoths to desktop appliances, this is precisely what transpired over the course of the next four decades. Radar research during WWII provided purer semiconductor material and

[172] "Applying the modern term, 'to program', to a computer probably originated with the ENIAC team at the Moore School" (Ceruzzi, 1998, 20).

key insight into semiconductor functions (Riordan and Hoddeson, 1997, 5). Radar detection and ranging relies on short-wave radio transmissions and receptions.[173] Generating and detecting short waves was quite difficult in 1940, but with the onset of war, the need became vital. Hundreds of engineers and scientists began working on the problem in the US and Britain (Riordan and Hoddeson, 1997, 89). Through this research, it was found that semiconductor elements, such as silicon and germanium, exhibited properties which allowed them to be superior detectors of short waves (Riordan and Hoddeson, 1997, 90). This discovery led to intensified efforts on both sides of the Atlantic aimed at understanding why this was the case.[174] Two institutions led the US effort, Bell Laboratories, and the newly minted MIT Radiation Labs, both of which received previously unseen levels of government funding during the war (Misa, 1985, 257).[175] At these two locales, armies of researchers, many who would soon participate in the invention and subsequent development of the transistor, such as William Shockley and Walter Brattain amongst a host of others, cut their teeth on semiconductor, silicon,

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[173] Radar works best with wavelengths less than a meter; AM radio, in vogue at the time, typically utilizes 300 meter wavelengths (Riordan and Hoddeson, 1997, 89).

[174] For an accessible layman's description of semiconductor materials and why they provide an ideal medium for high frequency amplification see Riordan and Hoddeson, 1997, 60-70.

[175] During the war military research consumed approximately 3/4 of Bell's technical manpower – over 700 leading scientists and engineers at Bell were working on defense projects, which soon came to account for 90% of Bell Labs' budget (Riordan and Hoddeson, 1997, 104; Misa, 1985, 257). "MIT was the largest single recipient of wartime research contracts; it's $56 million in contracts with the OSRD ran about 20% of the nearly quarter billion in wartime research conducted by educational institutions and was a significant fraction of the $1 billion going to industrial firms" (Flamm, 1988, 55).

and solid-state research (Riordan and Hoddeson, 1997, 97-114; Braun and Macdonald, 1982, 27).[176]

Importantly, "Wartime urgency encouraged a remarkably open sharing of information among the expanding networks of scientists and engineers working on crystal detectors" thus moving semiconductor technology far beyond what would have or could have been achieved absent wartime exigencies (Riordan and Hoddeson, 1997, 103). As early as 1942, the manufacturing arm of AT&T, Western Electric (WE), was granted 'carte blanch' to manufacture large volumes of silicon wafers for air and seaborne radar systems (Riordan and Hoddeson, 1997, 103);[177] while Bell Labs was directed to spread production specifics to Raytheon, GE, Motorola and other various vacuum tube producers in order to widen the radar production base. By 1943 wavelength transmission and detection had been driven down to the previously unthinkable 1 cm range as knowledge of semiconductor properties and manufacturing processes blossomed (Riordan and Hoddeson, 1997, 100-110; Braun and Macdonald, 1982).

Throughout the war, the next generation of semiconductor based radar devices was on the drawing boards just as the last one rolled off the production lines. Semiconductor progress, driven by wartime pressures and carte blanch

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[176] Walter Brattain, later a member of Shockley's Bell Labs team which invented the transistor, was part of the WWII research team that discovered that it was certain types and levels of impurities in silicon that modulated semiconductor conductivity. William Shockley meanwhile was being drawn ever deeper into defense projects, frequently meeting with top military officials at the Pentagon to discuss future technological breakthroughs desired by the top military brass (Riordan and Hoddeson, 1997, 97; 104-7).

[177] Over half of the radar systems used by US forces during WWII were produced by WE, which manufactured in excess of 10,000 a month (Riordan and Hoddeson, 1997, 103)

funding, proceeded at a rate that simply 'stunned' the soon-to-be leaders of the nascent US electronics industry and the emerging defense industrial complex (Riordan and Hoddeson, 1997, 114). By the end of the war it had become abundantly clear that vacuum tubes were the main impediment to better, smaller, more rugged, and progressively mobile military weapons and communications systems. Given the leaps and bounds that were occurring in semiconductor devices, solid-state research seemed the avenue most likely to yield a route around the increasingly worrisome vacuum tube bottleneck during the postwar era (Riordan and Hoddeson, 1997; Buderi, 1996).

CHAPTER 11: THE POST WORLD WAR II PERIOD – 1946-1949

World War II was followed by a tenuous peace. In 1947 the Truman Doctrine was declared; in 1948 Soviet Forces occupied East Germany and Churchill decried the 'Iron Curtain' being drawn across Europe; in 1949 the Communists achieved victory in China, NATO was established, and the USSR exploded their first nuclear device (Higgs, 1990, xviii). Nevertheless, in the US military expenditure rapidly declined from its demobilization peak, thereby aiding a rapid diffusion of war born capital and technologies into the American economy. It was truly the heyday of 'spin-off.'[178] As will be shown, however, the technologies that compose our objects of interest in this period, namely computers and semiconductors, did not diffuse commercially; although attempts were made. For neither the technologies nor the civilian commercial market were prepared for the radical new world these devices portended.

Aggregate military expenditure declined by 48% in 1946 and 70% in 1947 reaching a nadir of $9.1 billion in 1948, some 90% below the 1945 peak. During the WWII years military expenditure had averaged 21.6% of GDP, during these postwar years, 8.19%. The tax burden was rapidly reduced, with real total revenue declining 26% in 1946 and another 12% in 1947. Revenue did however remain permanently on a much higher plateau after the war, some 261% higher in 1949

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[178] A 1948 report to the US Senate Special Committee on Small Business stated "There is only the narrowest of gaps between scientific knowledge developed in wartime and the application of that knowledge to peacetime production. Wartime scientific developments which have no peacetime uses are few and far between." It has been estimated that 77% of the technological improvements that resulted from WWII efforts found commercial applications (Purcell, 1972, 172).

than in 1940. Personal income tax revenue declined an average 9% per annum in real terms over these post war years, while real corporate tax revenue declined an average 11.5% per annum in real terms. Real social insurance tax revenue fell an average 4% per annum. Real excise tax revenue, on the other hand, increased some 20% per annum on average in this period, as the US edged back towards the more regressive tax structure that had been in place prior to the war. This move back towards a regressive tax structure and a liberal five year tax depreciation write-off for investment in new plant and equipment combined to make the tax structure relatively amenable to diffusion of war born capital and technologies (Mosley, 1985, 171). Auctioning off of government owned plant and equipment at fire-sale prices also contributed to a generally positive diffusion atmosphere. Investment and consumption rose while unemployment levels remained stable, thus surprising many economists who had expected a return to the prewar economic malaise (Boulding, 1973, 237; Malkin, 1987, 137). In terms of public deficit finance, revenue and expenditure were brought back into balance over this period and the national debt was reduced by 25% in real terms, aided by a reasonably orderly rise in inflation to an average 7.4% per annum as wartime curbs and controls were removed.

COMPUTER DEVELOPMENT – 1946-1949:

With the economic environment primed for diffusion of wartime technologies, one might expect general purpose electronic digital calculating

devices to begin their diffusion into the commercial marketplace, but this was hardly likely for the highly specialized, incredibly expensive, warehouse sized, one of a kind machines. "At the war's end it was far from obvious that the newly developed electronic computers were going to have much practical impact on business." According to prevailing wisdom large electronic computers would never have broad appeal (Flamm, 1988, 46; 205). But the machines' appeal to the defense sector was already established and growing. Interestingly, key players in the military repeatedly attempted to convince established businesses and investment bankers to invest in computer manufacturing. They repeatedly failed. Even the large business machine companies, many of which had participated widely in the nation's WWII computer development efforts, such as IBM and NCR, refused to launch commercial computer divisions (Flamm, 1988, 43; 61-4; DeLanda, 1991, 213; Norberg, 2002, 174). "Computer development was a project with little obvious commercial payoff, an enormous cost, and a solid consensus of scientific opinion that it was likely to fail." Plus, a private business could have easily seized on any successes to build similar systems (Flamm, 1988, 253). Undoubtedly, just as chapter nine suggested would be the case, the private market was insufficient to initially sustain computer R&D sans a strong, continuing, and near patriarchal commitment from the military (Flamm, 1988, 68; Norberg, 2002, 174).

Perhaps the best example of the patriarchal tact US defense agencies were required to take in order to develop a base of computer contractors is the case of

Engineering Research Associates (ERA). During the rapid postwar demobilization, the cryptology unit of the Navy, known as the Naval Communications Supplemental Activity Agency (NCSA), succeeded in maintaining its team of computer researchers, led by Howard Engstrom and William Norris. After failing to interest existing commercial companies in computer contracting for the military, the NCSA attempted to spin-off a 'commercial' firm, ERA, to be overseen by Engstrom and Norris and manned by other defense agency researchers.[179] The idea was that the company would be funded privately, would be for profit, but for all intensive purposes would remain 'captive to the Navy from which it had sprung' (Ceruzzi, 1998, 26; 37). In 1946 the NCSA set out to organize financial backing for the firm. Notably, 17 private firms were approached in order to secure investment startup capital for the company, and all 17 declined. "The only private financier ended up being an individual with prominent political and Navy connections" (Flamm, 1988, 44). Having secured funding, much of it federal, ERA was incorporated and began serving the US national security apparatus (Ceruzzi, 1998, 38).

ERA's outstanding contribution to computing in this era was its development of magnetic drum memory. Magnetic drum memory technology was the first rudimentary form of reliable 'random access' memory (RAM). The major bottleneck facing general purpose computer development at the time was the lack of a stored program memory. Powerful electronic digital computer processors

[179] All 51 members of ERA's founding engineering group came from the military's leading cryptanalysis divisions (Flamm, 1988, 44).

needed to be able to access any particular program or data point stored in memory with little to no time disparity (thus the term random) in order to fulfill their high-speed potential. The Navy and the NSA pushed ERA to develop the magnetic drum as a mechanism to overcome this bottleneck, which it did to some extent – by 1949 ERA had patented a rather large oil drum shaped rotating mechanism capable of storing up to 2 megabits of information. Processors were able to access data stored anywhere on this drum at a speed somewhere between 8 and 64 milliseconds, depending upon how far the drum needed to rotate. Utilizing this new memory storage mechanism, ERA built its most famed general purpose computer, the Atlas, for the Navy between 1947 and 1950. The Atlas was the second general purpose stored program electronic digital computer to go into regular use in the United States; the EDVAC was the first (Norberg, 2002, 165-169; Ceruzzi, 1998, 38; Flamm, 1988, 18; 45).

The EDVAC effort spawned the other key computer R&D and production company that arose during this period; the Eckert Mauchly Computer Corporation (EMCC), headed by Eckert and Mauchly, the developers of the aforementioned ENIAC. By 1946 Eckert and Mauchly's ENIAC was in great demand as numerous military agencies sought to utilize its enormous computational power and relative flexibility. Hence, the US defense complex desired another ENIAC; in fact, defense agencies desired a better, more flexible, and more general purpose ENIAC. Such demand led Eckert and Mauchly to team up with Herman Goldstein and John Von Neumann to develop the next great leap in computer technology, the

Electronic Discreet Variable Automatic Computer (EDVAC) (Flamm, 1988, 252). The effort was funded by the US Army Ballistic Research Laboratory. The EDVAC was the first computer consciously designed to conform to the Von Neumann architecture; it used analog acoustic mercury delay lines for its RAM mechanism, a technique which later proved less reliable than ERA's drum technology. Nonetheless, "improvement of computer technology owed a great deal to the EDVAC. It's widely circulated design was used in many other computers, and lectures by the Moore school staff were critically important in getting other computer groups started" (Flamm, 1988, 49-50; Ceruzzi, 1989, 20-22, 110; Akera, 2002, 65-66).[180]

In 1947 Eckert and Mauchly, along with a host of faculty and students who had been working on the EDVAC, left the Moore School to form EMCC, incorporated in December 1948.[181] The EMCC team began developing the Universal Automatic Computer, otherwise known as the famed UNIVAC. The UNIVAC was the first general purpose computer designed particularly for business uses, such as payroll and accounting. But after some initial preliminary interest on the part of major corporations, such as GE, commercial corporations became disenchanted with the complex contraption. Unsurprisingly, most of EMCC's first contracts came from defense contractors and defense agencies, such as Northrop

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[180] One computer group which merits mention as this juncture is Howard Aiken's Office of Naval Research funded group at Harvard, which continued the Mark series into the 1950s. Aiken trained many of the computer engineers who later became influential movers in the field (Flamm, 1988, 60)

[181] In 1947, the Moore School's research director, Irwin Travis, also left the EDVAC project in order to establish a computer division at Burroughs. Travis drew participants from large defense projects of the day, and Burroughs began to serve niche military markets (Flamm, 1988, 50; 116).

Aircraft Company which was at the time developing the Air Force's Snark guided missile. To the Air Force's dismay, EMCC's development effort for Northrop ran over budget by 180%. Not only was there little commercial demand for EMCC's wares, but Eckert and Mauchly were finding out that building a UNIVAC was considerably more costly and difficult than they had expected. "Finally in 1950, in desperate financial straits, Eckert and Mauchly sold out to Remington Rand (RR)." Noted typewriter manufacturer and WWII defense contractor, RR,[182] forced Eckert and Mauchly to concentrate solely on the natural market for computers at this time, the defense market, and in so doing, the UNIVAC division of RR was able to become profitable and attain market leadership in the early 1950s (as will be touched on in the next chapter) (Flamm, 1988, 51; Ceruzzi, 1998, 15-16; 25-30).

Watching these developments from the sidelines was Thomas Watson Sr., the founder and President of the mechanical accounting machine juggernaut IBM. A number of IBM engineers had returned from the war with ample knowledge of cutting edge electronic computing devices and semiconductors. These engineers, such as Ralph L. Palmer, whom had worked intensively on code-breaking during the war, were constantly clamoring about new-fangled electronic digital computers and their massive multi-purpose potential (Flamm, 1988, 33).[183] Although Watson saw no current commercial applications for the device, he could not fail to notice the expanding defense-related market for the machines. In 1949 Watson hesitantly

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[182] During WWII Remington Rand produced more M1911A1 pistols than any other manufacturer.
[183] Ralph L. Palmer "steered IBM's transition to electronic technology" (Flamm, 1988, 40).

entered into an agreement with ERA to build a magnetic drum computer for the military. Although the project was canceled, IBM gained valuable technical knowledge from the effort, thus piquing Watson's interest. It was becoming apparent that military demand for such machines was going to be sustained and large-scale; plus, few of the current computer companies could compete with IBM's levels of capital expenditure should IBM decide to enter the sector. Just then, on the horizon appeared a catalyzing event, an event that would propel IBM into the world of computer R&D and production – the communists had invaded in Korea, the US was going to remobilize for war. "It was the Korean War that led to a decision by IBM to test the market for computers" (Ruttan, 2006, 94). In other words, Watson Sr. refused to move his juggernaut decisively until the Korean War forced the government to eliminate all risk and guarantee IBM a profitable market, as will be discussed further in the next chapter (Flamm, 1988, 40-45, 64, 205; Norberg, 2002, 170)).

By the closing year of this chapter, 1949, the US was clearly at the forefront of incipient computing technology (Flamm, 1988, 49). Computer historian Kenneth Flamm (1988: 148) points to two main reasons why the US left Britain, the other site of computer development during WWII, in the dust during the postwar era; both reasons accord with the 'military expenditure impetus to mode of development shifts theory': 1) Defense expenditures were not "of the same overwhelming magnitude" in Britain as in the US. 2) Defense firms in Britain were largely non-competitive with each other; they were not truly market-based (Evans,

1995, 100).

To be certain, the US defense sector propelled computer technology forward in the years immediately following WWII. But computers remained imperfect devices at best. Vacuum tube based logic circuits consumed power voraciously, generated extreme heat, and tubes needed to be replaced often, sometimes daily. Memory apparatus remained bulky with unsatisfactory capacity and did not truly conform to the Von Neumann notion of random access (access with no temporal discrepancy). Input / output devices, such as tapes and punch-cards many times slowed processing to a crawl. Had technical development stalled here, it is highly unlikely that computers would have ever found their way into the commercial business world (Flamm, 1988, Ceruzzi, 1998). Fortunately, revolutionary breakthroughs in a seemingly unrelated sphere of technology emanated from Bell Labs during the years 1946-1949. We now turn back to the semiconductor sector.

TRANSISTOR DEVELOPMENT – 1946-1949:

Few events in the history of the Information Technologies Revolution compare in momentousness to the invention of the transistor. In layman terms, the transistor is a semiconductor device that permits the flow of an electric current; it can be designed to amplify the flow, switch the flow, or turn a flow on and off. It performs the same operations as large vacuum tubes once did, and then some, but today transistors are microscopic and can operate at high frequencies while

consuming minuscule amounts of power. In short, the transistor has become the nerve cell for the information age (Riordan and Hoddeson, 1997, 7; Misa, 1985, 256; Flamm, 1988, 15).

Perhaps it is not so surprising that such a momentous invention spewed forth from Bell Labs in this period. In the stirring words of Riordan and Hoddeson (1997: 280):

> "Nothing on the scientific landscape at the time compared with Bell Labs. It combined intellectual power equal to that of the nation's best science departments with technical resources and manpower that none of them could come close to matching. When these tremendous resources became focused on developing practical products based on war time advances in semiconductor technology, something big had to happen. And something did."

The events leading to the invention of the transistor have been recounted many times.[184] Some prominent scholars and commentators have highlighted the fact that the invention occurred without military funding in a private sector commercial laboratory, and thus asserted that the invention had little, if anything, to do with military expenditure (Misa, 1985; DeGrasse, 1983; Tirman, 1984; DiFilippo, 1990; Stowsky, 1992). Such an argument borders on the myopic. The following brief description of the event will emphasize the ways that long-term large-scale military expenditure, and its vicissitudes, impinged upon the invention.

Bell Labs emerged from WWII as, what certainly can be considered, a quasi-military laboratory. During the war over 75% of Bell's engineering manpower had worked on defense projects, and defense projects accounted for over

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[184] See Riordan and Hoddeson's 1997 *Crystal Fire* for the widely acclaimed definitive account.

90% of Bell's budget. Bell's president, Mervin Kelly, directed Bell's extensive microwave radar R&D efforts from 1940 to 1945 (Riordan and Hoddeson, 1997, 108). Although Bell was still heavily engaged in military research in the postwar period it was also once again very much a commercial laboratory for AT&T (Peck and Scherer, 1962). In other words, Bell stood at the junction of private sector embeddedness and defense agency autonomy in the postwar period.

After the war, Kelly quickly realized that enormous improvements in communications technology could result from the wartime insights gained into solid state semiconductors. Namely, Kelly believed that war research had brought Bell Labs to the cusp of developing a miniature high frequency electronic amplifier. Clearly the advent of such a device would have implications for Bell's communications systems; by the late 1940s it was apparent that vacuum tubes, with their poor speed, unwieldy size, and heat generating capacities, would one day pose a constraint on electric switching and amplification in increasingly dense telephone networks. But such a device would also unquestionably have profound and more immediate repercussions for national defense (Ruttan, 2006, 99; Riordan and Hoddeson, 1997, 109, 162; Misa, 1985, 256).

Kelly used the demobilization opportunity to handpick and recruit leading WWII semiconductor radar engineers, many of which accepted his invitation to join Bell Labs' new 'solid state research team.' Installed at the head of the group was William Shockley, a prominent radar researcher who in the postwar period did double duty as a consultant for the Joint Research and Development Board, "a

select committee named by Vannevar Bush to advise the top military brass on promising research directions" (Riordan and Hoddeson, 1997, 127-8). Mervin Kelly, however, shrewdly and very deliberately isolated his new promising solid state research team from any funding that could be directly linked to military expenditure. Bell Labs could not afford to give the US military an opening that might lead to patent control, free licensing, or national security classification strictures on such a potentially revolutionary device (Braun and Macdonald, 1982, 70; Riordan and Hoddeson, 1997, 162). Nonetheless, there can be no doubt that Shockley and his researchers had gained key insights into the physics of semiconductors during their WWII radar work, and that these insights ultimately proved indispensable to the invention of the first transistor.[185] Also, it is certain that both Kelly and Shockley were hyperaware of the newly minted Defense Department's intense yearning for a miniature electronic amplification device (Riordan and Hoddeson, 1997, 112, 116, 162; Flamm, 1988, 16).[186]

The first solid-state amplifier was born on December 16, 1947. It was a crude device containing a slab of germanium,[187] a thin plastic wedge, and a tiny strip of gold foil. It was delicate and not yet applicable to any real world situation.

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[185] Over the course of the war researchers had become extremely knowledgeable about the purification of silicon and germanium 'as well as with the methods of doping these elements to obtain controllable and reproducible electrical characteristics' (Riordan and Hoddeson, 1997, 124).

[186] In fact, a research team entirely funded by the Army Signal Corps was only a few months behind Shockley's team in semiconductor research on the eve of the Bell team's discovery (Riordan and Hoddeson, 1997, 162).

[187] Owing to its unique voltaic properties, germanium proved to be the superior material (as compared with silicon) for producing early laboratory point-contact transistors. Later, germanium's fragility, rarity, price, and inconsistent frequency response at high temperatures would pose a bottleneck to further development in transistor application and manufacture (Riordan and Hoddeson, 1997, 134).

Nevertheless Mervin Kelly decided to demonstrate the newly dubbed 'point-contact transistor' to the public in June of 1948. Tellingly, Kelly first opted to demonstrate the device privately to the military a week before the official public unveiling; "We felt we had the obligation to inform the Defense Department because we knew that it had military implications" commented Walter Brattain. The DOD green-lighted the public event for it was quite anxious to get a wide body of researchers working on the contraption. The transistor was introduced to the public on June 30, and although there was some fanfare, few if any realized the event's future significance; The *NYT*, in fact, buried the story on page 46 of its July 1st issue (Riordan and Hoddeson, 1997, 1; 6; 137; 162-5).

Thus when taking a broad view, it becomes clear that the invention of the transistor accords quite well with the 'military expenditure impetus to mode of development shifts theory.' The requisite knowledge and human capital was formed in the crucible of WWII. The postwar demobilization released this capital into Bell Labs, a marketplace contractor standing at the junction of embeddedness and autonomy. And as we will now see, the military then took the lead role in shaping and providing a market for this nascent general purpose technology.

Not much time needs to be spent establishing this last point, for researchers far and wide agree that "the development phase of the point-contact transistor was to a large extent guided and funded by the US military and in particular by the Army Signal Corps" (Misa, 1985, 254; Tirman, 1984; DiFilippo, 1990; Vayrynen, 1992, 75; Riordan and Hoddeson, 1997, 141; Stowsky, 1992, 117-120; Ruttan,

2006, 101). Following the press conference, Western Electric set up a production line turning out experimental transistors, each of which proved to be weak, fragile, and problematic. These transistors were sold almost exclusively, at top dollar, to defense agencies for further R&D. The military also persuaded Bell Labs to sign licensing agreements with GE, Motorola, RCA, Raytheon, and Westinghouse in the hopes that these companies too would begin manufacturing experimental transistors, which they soon did. Importantly, in late 1948 the Army Signal Corps contracted with Bell Labs to develop the first transistorized logic gate. This effort resulted in the "first published research on transistor applications to digital computers," a prospect which Bell Labs had not previously considered (Misa, 1985, 264-5; Riordan and Hoddeson, 1997, 158-169, 226; Stowsky, 1992, 118; Flamm, 1988, 116). Each of these occurrences prefigures the close interplay between defense departments and defense contractors that would mold the embryonic semiconductor industry during the following decade, a subject we will return to as we turn to study military expenditure and informational GPT development during the Korean War.

CHAPTER 12: THE KOREAN WAR – 1950-1953

In early 1950 the Truman administration was reviewing an internally circulated Nation Security Council memorandum known as NSC 68. NSC 68 called for a massive peacetime military buildup designed at containing the Soviet threat. In June of that year North Korean forces poured over the 38th parallel; surmounting tension had finally turned to armed combat. As a result, NSC 68 was publicized and instituted as both American policy and dogma. The long Cold War mobilization had begun, and few would be so bold as to even hint at a potential demobilization for nearly two decades (DeGrasse, 1983, 2-3; Tirman, 1984, 5).

Military expenditure skyrocketed, rising 71% in 1951 and another 96% in 1952, approaching 14% of GDP in 1953. Interestingly, most of this expenditure was not spent on the Korean War. Political economists have estimated that only between 17% and 20% of military expenditure during the Korean War was directly related to the war. The rest was aimed at advanced weapons R&D and procurement intended at securing strategic advantage in the nuclear arms race with the Soviets (Huntington, 1969, 12). For example, Ward and Davis show that strategic military expenditure, that is, expenditure on advanced weapons procurement and R&D, rose by three and a half fold between 1950 and 1952 (Ward and Davis, 1992, 85). Braun and Macdonald (1982: 69) highlight the electronics centered nature of the new weapons expenditures: the government share of end-use electronic consumption rose from 24% in 1950 to 57.7% in 1953, while the value of the electronics industry itself more than doubled to $5.7 billion. The military

would continue to consume a majority share of the end-use electronics market for the rest of the decade. As discussed above, and as will be shown below, it is precisely this type of massive fear driven defense expenditure, aimed at surmounting vast technical hurdles, that propels the 'military expenditure impetus to mode of development shifts theory.'

Truman, an avowed balanced budget man, opted to raise taxes in order to pay for these substantial new expenditures (Kelly, 2000, 40). Real total annual average revenue was some 25% higher in this period than the last. Personal income tax annual average revenue was 21% higher in real terms. Real annual average corporate tax revenue was 41% higher in this period. Social insurance tax annual average revenue rose 45% in real terms as compared with the post WWII period; and real average annual excise tax revenue rose a smaller 6%. The tax structure thus became more progressive, with excises and social insurance taxes combining for less of a percentage of total overall revenue, and corporate and personal income taxes combining to account for more of overall tax revenue. On the deficit side of the equation, Truman and later Eisenhower managed to run slight surpluses in 1950, 1951, and 1953; hence real gross federal debt fell by 5.6% during the Korean War. With higher tax rates and some price and consumption controls in place, the economic environment was not ideal for technical diffusion. But with defense contractors receiving generous tax amortization provisions, along with subsidies for expanded production (Mosley, 1985, 13), one can hardly imagine a more sanguine environment for defense expenditure induced technological development.

THE SEMICONDUCTOR SECTOR – 1950-1953:

There is broad consensus that 'at the very least, military expenditure accelerated transistor development' during the Korean War. In this way, the transistor was rapidly sent down the learning curve, moving from experimental object to potentially commercially viable product as military electronics and missile guidance mechanisms became increasingly 'transistorized' (Braun and Macdonald, 1982, 8; Ruttan, 2006, 15). The Korean War released a torrent of R&D funds into the nascent transistor industry. For example, the share of all transistor research performed at Bell Labs but funded by the DOD shifted from under 10% in 1950, to 20% in 1952, and then to 50% in 1953, a level sustained through 1955 (Misa, 1985, 273; Ruttan, 2006, 101). During the Korean War, when the transistor was unreliable and difficult to manufacture, the military consumed by far the vast majority of the infant industry's output; approximately 90%, exhibiting little concern regarding price (DeGrasse, 1984, 90; Riordan and Hoddeson, 1997, 195; Braun and Macdonald, 1982, 70).

The military, however, was quite concerned over the quality, reliability, and availability of transistors in this period. The military took four major steps to increase each of these vectors during the Korean War: 1) It drove the industry away from fragile and unreliable point-contact transistors and towards superior, albeit more expensive and more difficult to manufacture, 'junction transistors.' 2) The DOD oversaw the widespread dissemination of cutting-edge transistor research and knowledge, many times to the chagrin of Bell Labs' parent company AT&T. 3)

The DOD funded R&D efforts which successfully yielded more reliable forms of mass manufacture for transistors and the circuit boards which contained them. And 4) The military created manufacturing overcapacity by underwriting the construction of transistor production facilities for several firms. Each of these occurrences will now be briefly surveyed.

By 1950 it was becoming painfully clear that point-contact transistors, with their hand soldered contacts and wires, were experiencing vexing problems that would likely prove impossible to overcome. The military was disappointed with the poor and variable frequency response exhibited by point-contact transistors, along with their erratic reliability. Indeed, "people beyond AT&T were beginning to suspect that all the original enthusiasm over the transistor had been premature" (Riordan and Hoddeson, 1997, 181). Fortunately, William Shockley at the time was engaged in a heroic effort to create the first 'junction transistor.' A junction transistor eliminates the wires and contacts of a point-contact transistor, substituting them for a three layer sandwich of differently 'doped' semiconductor material (Stowsky, 1992, 119).[188] In mid-1950, utilizing breakthrough techniques in 'crystal growing' and 'double doping', Shockley successfully formulated the first germanium based junction transistor (Riordan and Hoddeson, 1997, 174-185).[189]

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[188] Doping refers to a method of introducing impurities into a semiconductor substrate in order to alter its electronic properties. See Riordan and Hoddeson's *Crystal Fire* for more.

[189] Crystal growing refers to a method of generating pure semiconductor material, while double doping provides a more precise method of controlling the level of impurities introduced into the pure semiconductor substrate. See Riordan and Hoddeson's *Crystal Fire* for more on both.

Again, none of the research was funded by defense agencies, although again, all of the same missives applied to the development of the point-contact transistor hold here as well: each of the breakthroughs occurred at the quasi civilian / quasi military research laboratory Bell Labs; the major innovations were achieved by former radar pioneers utilizing methods and techniques rooted in WWII R&D; Kelly purposely detached Shockley's work from military funds; and Shockley still sat on various high-level military panels where he was made aware of emergent military needs (Riordan and Hoddeson, 1997, 175-189; Misa, 1985, 269-72). In fact, in late 1950 Shockley was sent to Korea to analyze the military's technological requirements in the field. In Korea, officers demonstrated to Shockley how point-contact transistors were too fragile to be effectively utilized in mortar shell proximity fuses, which allowed mortar shells to explode at determinable moments rather than upon impact. Shockley intrigued the officers with his description of the new junction transistor; it was potentially smaller, more rugged, and would operate at higher frequencies than the currently utilized point-contact transistor.[190] Upon returning stateside, Shockley convinced Kelly to immediately increase Bell's efforts to generate methods of mass producing junction transistors, for which there was no existing non-defense markets. Satisfied with Shockley's already pending patent application, Kelly now allowed military funding to guide the development effort. By mid 1951 Bell had developed a rugged pea sized junction transistor and a method of manufacturing it as well. The junction

[190] Higher frequencies meant better long range communication between the mortar and the detonator.

transistor could operate at frequencies measured in millions of hertz rather than the thousands level at which point-contact transistors operated. It was also more efficient, reliable, and consumed far less power than point-contact transistors. Junction transistors were perfect for mortar proximity fuses; they would soon prove indispensable to all manner of military electronic equipment (Riordan and Hoddeson, 1997, 186-194).[191]

On September 25, 1951 Shockley's patent for the junction transistor was issued. With Bell's licensing rights now secured, the DOD wanted Bell to spread knowledge of the device throughout the defense contracting industry. Defense agencies thus began adding stipulations to Bell's and Western Electric's lucrative defense contracts requiring them to do so. To the chagrin of AT&T, Bell was required to hold a major symposium in late 1951 where information on the junction transistor was disseminated to Bell's major competitors. In 1952 the military services presided over a conference held at Western Electric that 'resulted in two fat volumes that became the canon of transistor technology.' An internal Bell memo at the time noted that the information provided at this conference "enabled all licensees to get into the military contracting business quickly and soundly." Western Electric subsequently began licensing its junction transistor manufacturing techniques to other defense contractors for the modest sum of $25,000 (Misa, 1985, 266-268; Delanda 1991, 150; Riordan and Hoddeson, 1997, 190).

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[191] After 1952 William Shockley increasingly fell into the Pentagon's orbit; in March of 1954 Shockley left Bell Labs to become the Pentagon's Deputy Director of the Weapons Systems Evaluation Group (Riordan and Hoddeson, 1997, 190; 227-9).

Now concern turned towards developing mass manufacturing techniques which could effectively incorporate junction transistors into the circuit boards that provided the internal skeleton for electronic weaponry of the day. In 1950 the only way to manufacture these boards was by hand, which posed a tremendous bottleneck to reliability, miniaturization, and increased complexity. A standard automatic manufacturing technique was needed for transistorized circuit boards. Here the Army Signal Core played a paramount role. The Signal Corps seized on a method developed during WWII by the Centralab Division of the Globe-Union Company in Milwaukee. At that time, Centralab had been producing extremely simple resistor-capacitor circuits for the military. Centralab found that they could mass produce these simple resistor-capacitor circuits by etching their pattern into a ceramic substrate and then dipping the ceramic card into a bath of conductive copper. The Signal Corps realized that this simple method, if properly refined, might be used for mass producing more complex transistorized electronic circuit boards. Drawing on the torrent of R&D funds released by the Korean War, the Signal Corps established the Auto-Sembly program, which soon yielded successful results.[192] By 1952 'printed' circuit boards incorporating junction transistors were being reliably mass produced through refined methods of silk screen imprinting and automatic soldering. Transistorized printed circuit boards immediately began to be extensively utilized in advanced weaponry, and later in the decade, would allow for the advent of the transistor radio (Ceruzzi, 1998, 80;

[192] Jack S. Kilby, later an inventor of the integrated circuit, was an engineer involved in this project.

Stowsky, 1992, 118; Flamm, 1988, 17; Ruttan, 2006, 101; Riordan and Hoddeson, 1997, 257).

The next major bottleneck the military sought to surmount in the semiconductor industry revolved around supply. By 1952 transistors were exhibiting a fourfold reduction in size as compared with 1950 transistors, an eightfold reduction in power requirements as compared with 1950 transistors, and transistors now had an expected lifetime of 70,000 plus hours. But production volume was not keeping pace with increasing demand, which was still almost entirely defense-related (Misa, 1985, 264-5; Riordan and Hoddeson, 1997, 206).[193] Moreover, the DOD desired surge capacity – the ability to produce well beyond current demand in case of world war. Thus the Army, and later the other services as well, began to underwrite the construction of new transistor manufacturing facilities for major defense contractors (Misa, 1985, 272-3). Huge new plants were built for Western Electric, GE, RCA, Motorola, and Raytheon, amongst others; and funds were distributed to each of these companies in order to increase engineering development and training at the new plants (Ruttan, 2006, 101; Misa, 1985, 275).[194] In return for guaranteed government purchases at premium prices, each company that benefited from militarily subsidized transistor production facilities agreed to build and maintain production capacity 10-12 times greater than needed to supply the government's existing demand. Besides creating surge capability, such

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[193] A small portion of low-end transistors were finding their way into the hearing aid market (Misa, 1985).

[194] In 1951 there were four companies producing transistors in the US; in 1952 there were 8; in 1953 there were 15 (Braun and Macdonald, 1982, 71).

enormous overcapacity provided an undeniable incentive for transistor manufacturers to curry and cull new commercial markets (Stowsky, 1992, 118; Braun and Macdonald, 1982). In the words of Riordan and Hoddeson (1997: 204), "Suddenly a new industry had been born."

THE COMPUTER SECTOR – 1950-1953:

As stated, the DOD began sponsoring R&D aimed at transistorizing computers as early as 1949. By 1950 the military was directly funding computer R&D at roughly $15 million to $20 million per year (Flamm, 1988, 78-9). During the Korean War, Bell Labs built several special purpose semi-transistorized computers for guided missile systems such as Nike and Titan, as did a few of the other transistor producing companies (Ceruzzi, 1998, 65; Flamm, 1988, 17). Nevertheless, owing to the experimental nature of the machines and the transistors that went into them, many of the military's new computers remained largely non-transistorized during the Korean War. This is not to say that the NSC 68 mobilization did not have extreme effects on computer development; it most certainly did. Another order of magnitude gain in arithmetical operation speed was attained, magnetic memory improved by leaps and bounds, and new computing technology was increasingly applied to command and control applications such as aircraft and missile guidance (Flamm, 1988, 8, 65; Ceruzzi, 1998; Hughes, 1998).[195]

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[195] Meanwhile, commercial businesses remained 'baffled' by computers (Norberg, 2002, 175).

There is one major project that can be considered paradigmatic for defense expenditure induced technical change in the computer sector during the Korean War, and that is the SAGE project. SAGE – the Semi Automatic Ground Environment – proposed to cover the nation in a radar net capable of tracking and intercepting multiple Soviet bombers should the USSR launch a nuclear attack. SAGE was the first project that viewed the computer as an interactive device designed for real-time informational communication rather than as a mere computational tool (Hughes, 1998, 4; Ceruzzi, 1998, 51; Campbell-Kelly, 2003, 36-9; Ruttan, 2006):

> "The task envisioned for SAGE was to detect alien aircraft, select appropriate interceptor aircraft, and determine antiaircraft missile trajectories. Critical to the SAGE system would be two pieces of equipment that in 1950 still had to be designed, built, and tested: 1) a high-speed electronic digital processing machine that would be located at each radar site to perform real-time processing of radar signals and send the data over telephone lines to the command and control center, and 2) a central computer at the command and control center that would accept and process the data from the distributed radar sites (Ruttan, 2006, 96).

In 1951 the Air Force chose MIT as the systems integrator for SAGE.[196] The Air Force funded the construction of an entirely new laboratory, just off Route 128 near MIT, where the bulk of the R&D for the high priority project would take place. The laboratory, dubbed Lincoln Labs, has been an important epicenter for advanced computer related research ever since. The military funded Lincoln Labs and its SAGE project to the tune of $20 million annually during the Korean War

[196] Due to the highly experimental nature of the project, the Air Force decided that a university laboratory should be given prime status" (Hughes, 1998, 15).

(Hughes, 1998, 27-30; 41; Flamm, 1988, 56).[197] Much of this early expenditure went towards developing what would become the first real-time interactive computer – a machine originally built for the Navy, known as Whirlwind.[198] Overseen by Jay Forrester, the initial project design called for a high speed electronic digital computer with a partially transistorized processor, interactive cathode ray tube graphical displays, and an improved and as of yet undefined memory apparatus capable of supporting real-time information processing (Hughes, 1998, 27-8; Ruttan 2006, 94; Flamm, 1988, 53-55).

Jay Forrester immediately identified the critical bottleneck for the project as being the real-time capable random access memory. The other components of the computer would have to be cutting edge, but they were still within the boundaries of what had presently been achieved. In fact, Forester had already built a version of the Whirlwind with a processor some ten times faster than any other computer in development at the time that also featured cathode ray tube displays. He now concentrated his impressive talents on the memory bottleneck (Hughes, 1998, 33; Campbell-Kelly, 2003, 36; Flamm, 1988, 56-7).

Extant memory devices, such as magnetic drums and acoustic mercury delay lines immediately proved lacking; they were either too slow or too unreliable (Ceruzzi, 1998, 41; Hughes, 1998, 33). The major challenge in developing a real-

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[197] SAGE was easily one of the largest and costliest military systems projects of the 1950s. Estimates for the entire decade long effort range between $4 billion and $12 billion; $8 billion is probably a reasonable ballpark estimate (Flamm, 1988, 88).

[198] The Whirlwind's origins traces back to 1944 when the Navy funded the MIT Servomechanisms Laboratory to develop a computer capable of simulating an airplane's reactions to atmospheric conditions (Hughes, 1998, 31).

time RAM was finding a material that could consistently indicate an on off state and switch between states rapidly. Forrester began exhaustively searching for a material that could be magnetized or demagnetized by electrical pulses. He soon settled on deltamax, a composite invented by the Germans during WWII to make analog control devices for tank turrets. Shaped into small doughnuts, deltamax rings provided lightning fast magnetization and demagnetization and could reliably indicate a 1 or 0. In 1952 Forrester confidently predicted that a 'three-dimensional array matrix flux magnetic-core memory' would fulfill the real-time needs of Whirlwind. Forrester's flux magnetic core provided the first truly random access memory as described in the Von Neumann architecture; access to any bit of a core plane was as rapid as any other.[199] "The experimentation, testing, development, and manufacture of the memory cost more than $1 million (over just a few months). If the development had taken place under commercial circumstances rather than with the lavish funding of the Air Force, completion might have been delayed for months, even years" (Hughes, 1998, 36-37; Cerruzi, 1998, 49-51; Flamm, 1988, 57-58).

By mid-1952 Forrester's team had completed a prototype of the SAGE Whirlwind real-time computer. One of its important new and unique features was an 'interactive' graphical display. Using a 'light pen', users could interact with the data being displayed on the screen by highlighting it, closing it, or calling up new

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[199] Key to Forrester's design was a circuit developed by Ken Olsen (a graduate student of Forrester's) which reduced the amount of current needed to operate in the array (Ceruzzi, 1998, 50). Olsen will reemerge later in the dissertation as an important figure in the world of commercial business computing.

data from memory; the first graphic user interface (GUI) had been born. With the prototype complete, the Air Force decided to test the system. To the top military brass gathered at MIT's Lincoln Labs that day, the light pen must have seemed like a magic wand. And sure enough, like magic, a radar engineer located just off Route 128 in Boston was able to successfully use real-time feedback to guide interceptor aircraft toward a moving 'enemy' squadron over Cape Cod. SAGE was ready to enter the production phase (Hughes, 1998, 45-6, 257-8; Flamm, 1988, 24; Campbell-Kelly, 2003, 370).

In the spring of 1952 MIT opened a project design competition for private contractors seeking to manufacture standardized computers based on the Whirlwind prototype.[200] "Initial plans called for the manufacture of about 50 computers, an unusual commitment at a time when producers of such large digital computers usually built one of a kind in a model shop instead of engaging in serial production" (Hughes, 1998, 48-50). IBM, Remington Rand, Bell Laboratories, RCA, and Raytheon were among the top firms up for consideration. Bell and RCA were forced to withdraw as their prior defense project commitments had already expanded beyond their current capacity. Raytheon was thought to lack the requisite engineering talent. This left Remington Rand as the obvious choice (Ruttan, 2006, 96; Hughes, 1998, 38-40).

As aforementioned, Remington Rand (RR) had acquired EMCC in early 1950. Later that year RR's UNIVAC division began building the Standards

[200] "Traditionally, MIT, though willing to engage in research and limited development, avoided competing with the corporate world in the realm of manufacture" (Hughes, 1998, 48).

Eastern Automatic Computer (SEAC) for the Air Force. SEAC was used for Project SCOOP, which organized the production and shipping of war materials and men across the Atlantic to NATO bases (Flamm, 1988, 70). SEAC was notable as the first computer to utilize rudimentary magnetic disk drives and one of the first which employed some solid state components in its logic circuits (germanium diodes in this case). By 1952 RR UNIVAC had built a handful of computers actively utilized in Korean War era defense endeavors, and the company had turned profitable (Flamm, 1988, 71-4; Ceruzzi, 27-31).[201] Early that year RR also acquired ERA which had likewise fallen into financial difficulties. By late 1952 RR had managed to turn ERA profitable by intensively focusing on the scientific end of the Korean War defense market (while UNIVAC focused on the data processing / organizational defense-related segment) (Ruttan, 2006, 94; Ceruzzi, 1998).

In a shocking move however, MIT spurned RR and awarded what was surely then the most lucrative computer production contract in the history of the United States to IBM, which had just recently entered the digital electronic computer market with its first and only offering, the 701 Defense Calculator, in early 1952 (Flamm, 1988, 64).[202] IBM's lack of experience in producing general

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[201] In November of 1952, the UNIVAC 5 destined for AEC's Lawrence Livermore Labs was used to predict Eisenhower's victory over Adlai Stevenson live on TV. Many historians note this as the moment that computers became a collectively recognized phenomenon. For a short time thereafter UNIVAC served as a synonym for computer (Ceruzzi, 1998, 31-2).

[202] The lead engineers on the 701 effort were Ralph Palmer and Steven Dunwell, both of whom had worked on designing and implementing advanced electronic cryptanalysis machinery for the Navy during WWII. Dunwell went onto to direct the important IBM Stretch project funded by the NSA in the late 1950s (Flamm, 1988, 63).

purpose stored program electronic digital computers certainly counted against it. But as early as 1951, Thomas Watson Sr. was directing 30-35% of IBM's large earnings pool to computer R&D while at the same time garnering DOD R&D funds which matched IBM's internally financed R&D expenditures. In total IBM's R&D expenditures dwarfed RR's. And MIT knew it. They also found out that the 701's processor was four times faster than UNIVAC's best offering, owing to IBM's enhanced logic gates. In the end, the superiority of IBM's I/O devices, along with its large and largely untapped capital facilities, put IBM over the top.[203] In 1953, just as the Korean War settled to a tension plagued standstill, MIT awarded IBM a multi-year production contract to build 56 Whirlwind type real-time computers priced at an estimated $30 million each.[204] As we will see in the next chapter, this contract award would soon propel IBM to the apex of the computer market (Flamm, 1988, 83-89, 94, 107; Ceruzzi, 1998, 35; Hughes 1998, 48-50).

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[203] Much to the chagrin of RR, Thomas Watson was able to lure the designer of RR's SEAC magnetic disk storage arrays, Jacob Rabinow, to IBM just as MIT was surveying IBM and RR's respective engineering units and I/O capabilities. Also Von Neumann began consulting for IBM in 1951 (Flamm, 1988, 53; 71).

[204] In the end, this estimate would prove far too low.

CHAPTER 13: THE COLD WAR YEARS – 1954-1959

The NSC 68 / Korean War buildup had been massive and little in the way of real demobilization followed. The Cold War continued to boil in this period, with tensions seething in Korea, Egypt seizing the Suez Canal, and Castro coming to power, to name just a few momentous events. These incidents seemingly paled in comparison to the morning of October 5, 1957, when Americans woke up to news that a Soviet satellite, Sputnik, had passed over their heads as they slept. The media response and public outcry bordered on hysteria. The USSR would soon have ICBM capability and the missiles could be arriving on America's doorstep any day (Gavaghan, 1998; Riordan and Hoddeson, 1997, 252).

Overall military expenditure began to decline from its high levels in 1954 and 1955, falling 7% and then 13% in nominal terms, but stabilized at 9.7% of GDP in 1956, and then began climbing again, rising at a 5% per annum average clip from 1957 through 1959. The DOD began keeping more detailed records of expenditure from the end of the Korean War, now breaking expenditure down into 5 major categories: Personnel; Operations and Maintenance; Construction; Procurement; and RDT&E.[205] This is quite useful for our purposes in that Personnel, O&M, and Construction spending can be considered as having little to do with 'the military expenditure impetus to mode of development shifts theory' and therefore discounted. Procurement of course does impinge directly upon the causal mechanisms of the theory, although the category as reported is rather broad

[205] Research, Development, Test and Evaluation.

and includes traditional infantry weaponry such as rifles, when in fact what we're truly interested in here is advanced weapons procurement only. RDT&E expenditures can serve as a good proxy for advanced weapons expenditures, although it is necessarily reported at levels much lower than total advanced weapons spending, in that it excludes production aggregates (Scherer, 1964; Mintz, 1992; Boise, 1994). That being said, the figures reveal that procurement as a percentage of total military expenditure stayed between 30% and 32% from 1954-1959 after having reached 32% in the final year of the Korean War. RDT&E, on the other hand, rose an average 5.2% per annum from 1954 through 1959 (swelling over 30% 1957-1959), reaching 6% of overall total military expenditure whereas it had been only 4% in the final year of the Korean War. We can also begin including NASA expenditures in this period, which were for all intensive purposes entirely defense-related. NASA expenditures in 1958, the year of its inception, totaled $89 million, and rose 63% to $145 million the following year.

Thus the mix of spending at this more detailed level indicates that advanced weapons outlays rose briskly over the period 1954-1959, with the largest increases occurring from 1957 through 1959. The qualitative data bares this out as well, with the US initiating a crash program to develop an ICBM in 1957 that achieved success early in 1959, and Eisenhower's 'new look' security policies concentrating squarely on strategic defenses rather than on infantry and ordnance (Domke, 1992, 42; Baumgartner, 1970, 174; Purcell, 1972, 11; Weidenbaum, 1973, 258). Moreover, this period exhibits a clear shift towards increased military expenditure

in the electronics sector. The electronics industry's share of prime contracts moved up from 17% of total prime contracts during the Korean War to nearly 30% between 1958 and 1960 (Peck and Scherer, 1962, 122). In the mid-late 1950s the government funded approximately 60% of R&D expenses in the electrical equipment and electronics industries in the US, reaching perhaps as high as 85% in 1959 (Vayrynen, 1992, 71; Peck and Scherer, 1962, 25; Flamm, 1988, 16). As military expenditure flowed in, the electronics and communications sectors increased their engineering ranks by 57% and 39% respectively. Expenditure on computer R&D and production likewise mounted between 1954 and 1959 (Peck and Scherer, 1962, 162-175; Flamm, 1988, 72).

With aggregate military expenditures stabilizing at a high level (around 10% of GDP), and non-defense expenditures also stabilizing (around 7% of GDP), Eisenhower (an avowed balanced budget man) was able to achieve a slight average annual surplus from 1954 to 1959 on the back of total revenue that rose an average of 2.4% per annum in nominal terms (.17% when controlling for inflation). As a result, the gross federal debt was reduced in this period, falling by 5% in real terms. The tax structure became somewhat more regressive, with personal income tax revenue rising slightly (3.7% on average per annum), corporate tax income declining slightly (2.8% on average per annum), social insurance tax revenue rising more (9.6% on average per annum), and excise tax revenue also rising slightly (1.9% on average per annum). Such changes probably had little effect on the economic environment for technological diffusion, which was surely more effected

by moribund real GDP growth (which rose on average only by 1% between 1956 and 1958), and the Fed's tight monetary policy (the federal funds rate rose from 1.78% in 1949 to 3.6% in 1959 even though inflation averaged a quiescent 1.45% per annum over these year).

The environment for defense expenditure induced technical change however remained robust. Contractors were flush with cash for investment in new R&D facilities, and 'the competition for defense contracts was such as to induce contractors to make investments in order to secure contracts, while rapid write-offs for tax purposes provided an incentive to keep physical facilities modern' (Peck and Scherer, 1962, 168-169). Nowhere was this clearer than in the booming defense electronics sector, where the 7 largest military electronics contracting firms (including Raytheon, Motorola, Texas Instruments, and ITT) spent a hefty 8.2% of sales on capital plant and investment from 1956 to 1959. Such growth made these companies "darlings of the stock market" (Peck and Scherer, 1962, 167).

THE SEMICONDUCTOR SECTOR – 1954-1959:

By 1955 transistors had been around for a little over half a decade. How were the leading non-defense related corporations in the US integrating this vital new technology into their products? Surprisingly, they weren't. Transistors were still perceived as an 'expensive laboratory curiosity' with mainly specialized

military applications (Riordan and Hoddeson, 1997, 7; Misa, 1985, 274).[206] So what we see here is early transistor diffusion conforming to the theoretical predictions averred in the theoretical chapter of the American Case. The mainstream commercial market was still not sustaining progress in transistor development, and with military expenditure remaining high, transistors were not diffusing widely (Stowsky, 1992, 229; Braun and Macdonald, 1978, 69). Indeed, this was even the case for AT&T, the parent company of the transistor's progenitor, Bell Labs. AT&T transistorized American telephone networks at a remarkably slow pace.[207] Transistors were not deployed on a large-scale in the American telecommunications system until the middle 1960s (Misa, 1985, 274; Braun and MacDonald, 1982, 95).

Of course, one entirely new commercial market did materialize for transistors in the middle 1950s – the market for transistor radios. In obvious ways the emergence of this application also conforms to the 'military expenditure to mode of development shifts theory.' Immediately following the Korean War, military demand for transistors momentarily faltered, and visibility regarding future military demand declined as well. Texas Instruments, a successful 1951 entrant into the semiconductor sector, and a key Korean War defense contractor, was feeling the pinch particularly keenly as two of its major transistor contracts were

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[206] "The transistor was so radically different from the (vacuum tube) in the way it worked, in the way it could be manufactured and sold, and in its apparent potential, that it could not be comfortably accommodated within the existing electronics industry without changes that the industry was then unwilling or unable to make" (Braun and Macdonald, 1982, 63).

[207] Bell was only willing to gradually add new transistorized equipment to its telephone network as old equipment was retired; and the transistors that were eventually utilized ended up being quite low-end (Helpman and Trajtenberg, 1998, 115-116; Braun and MacDonald, 1982, 95).

cancelled in early 1954. The president of TI, Pat Haggerty, hatched a bold plan to develop a consumer 'transistor radio' before the 1954 Christmas season. The world's first transistor radio, priced at $49.95,[208] was on the market by October 1954. The radio used low-end germanium transistors, and the profit margins paled in comparison to those TI garnered for its high-end transistors in the defense sector. So with defense demand perking back up in 1956, TI abandoned the transistor radio market. We will return to the transistor radio narrative during our analysis of the Japanese case, for a small Japanese startup company named Sony filled the vacuum left by TI. What is important to understand now is that 1) TI started the market as a result of canceled military contracts. 2) TI abandoned the market because returns were poor on the low-end transistors that went into transistor radios. And 3) Military demand was still where the important action was in the semiconductor sector over the years 1954-1959 (Riordan and Hoddeson, 1997, 213-22; Misa, 1985, 274-5).

This third point deserves some elaboration. As late as 1960, 48% of all semiconductor output (this aggregate includes a broad range of products spanning from cheap diodes to high-end transistors) was still being consumed by the military; only about 10% of semiconductor output went into radios. The widespread application of higher-end transistors to televisions, automobiles, and appliances did not even begin to occur until the mid-1960s (Braun and Macdonald, 1982, 68; 80). In the meantime, military expenditure shaped the semiconductor

[208] Approximately $275 in 2000 dollars.

sector into a form well suited for commercial market competition. For example, in its zeal to create an effective industrial base for transistor production, the Army helped to expand industrial capacity for transistor production to 15 million units per year in 1955, even though only 3.6 million transistors were consumed in the US that year (Misa, 1985, 276). In 1956, 1958, and 1959 the DOD spent $15 million, $13.9 million, and $16.2 million respectively on semiconductor R&D (while the entire market for transistor radios was somewhere south of $10 million per annum at this time) (DiFilippo, 1990, 97; Misa, 1985, 272; 281-2). Moreover, military contracts had the effect of creating firms that specialized in transistor production for sale on the open market; whereas the traditional model established by the major radio and television vacuum tube manufacturers of the day had been tube production for internal use only.[209] In this way, an independent, specialized, flexible, competitive, and dynamic sector for transistor production grew up in the US (Braun and Macdonald, 1982, 72; Stowsky, 1992, 122). Most importantly, the DOD drove this flexible and specialized dynamic sector towards the manufacture of ever better performing transistors, especially in regards to frequency.

The significance of the military's drive for higher frequency response in semiconductor devices cannot be overstated. Frequency response is of course the

[209] In fact, 69% of military demand was supplied by smaller firms that specialized in high-end transistor production; far greater than small firm share of the non-military semiconductor market (Braun and Macdonald, 1982, 72).

main way to measure microprocessor capability today,[210] but in the 1950s there was little if any need in the commercial world for high frequency transistors. In fact, AT&T resisted any and all moves towards high frequency transistor production, fearing that commercial efficiency was being compromised by the military's focus on high-end high frequency devices at the expense of cheaper simpler technology (Smith, 1985, 35). But the military persisted; the military required high frequency responding transistors for all of its advanced weapons needs, especially those relating to computer driven ICBM guidance and detection, where frequency determined capability and range (Riordan and Hoddeson, 1997, 224; Peck and Scherer, 1962, 234-244). The military moved the transistor industry toward the manufacture of high frequency response semiconductors in two main ways during this period: 1) It compelled the industry to adopt the 'diffusion' method of doping semiconductor crystals; 2) It channeled the market away from germanium based transistors and towards silicon transistors.

In 1953 and 1954, Bell Labs was intensively studying a new and potentially powerful method of precisely introducing impurities into semiconductors, known as the diffusion technique.[211] Although expensive, the diffusion technique held forth the promise of higher frequency responding transistors. The subsequent drama followed the same script previously described: early in the process, the main R&D efforts were isolated from defense funding, even though the military was the

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[210] Frequency determines the switching speed of logic gates and thus determines byte/second throughput in a microprocessor (Riordan and Hoddeson, 1997, 202; Flamm, 1988, 33).
[211] The diffusion technique exposes a solid semiconductor substrate to an atmosphere of vaporized doping agents, which diffuse into the substrate (Misa, 1985, 272; 281-2; Stowsky, 1992, 119).

only existing market for high frequency transistors. In late 1954 an engineering research team at Bell Labs achieved the first 'diffused-base' germanium transistor, which was capable of amplifying signals up to 170 megacycles, ten times higher than the best transistors of the day. After the patent license was applied for, Bell Labs allowed Army funding for diffused-base transistor R&D to exceed its in-house support. From there the Army Signal Corps played a key role in both improving the technique and in pushing the technique from development to manufacture (Riordan and Hoddeson, 1997, 220; Misa, 1985, 272-282).

But now a new problem emerged. The military environments where high frequency diffused-base transistors were deployed tended to be hot, like a missile. Plus higher frequency devices in and of themselves generate more heat. But germanium, which had since 1949 been the main semiconductor material used in transistor production, performed inconsistently at temperatures above 70° C. Furthermore, germanium, at high frequency speeds, leaked electrons, thus confusing on/off switches. Again, such quandaries, at this time, mattered only to the military. But in the late 1950s transistor industry, only the military mattered. From the highest levels in the DOD the word came down that a silicon semiconductor industry would have to be created (silicon was known to perform better at higher temperatures and frequency). Although silicon is a more abundantly occurring natural resource than germanium, in the 1950s making a

silicon transistor was both difficult and expensive.[212] Responding to the military's publicized desire for diffused-base silicon transistors, TI began a crash program of its own in 1954. A top TI engineer at the time later remarked "my main aim at TI was to make grown-junction silicon single-crystal and small-signal transistors that would meet military environmental conditions" (Riordan and Hoddeson, 1997, 208). In April of 1954 TI achieved the first 'grown-junction silicon transistor.' TI immediately began producing them for the military, and even though these silicon transistors cost five times more than the best germanium transistors of the day, the military consumed each and every one produced. By 1955 WE was also producing silicon junction transistors, and other semiconductor companies were ramping up to do so in order to meet the seemingly limitless demand coming out of the defense industrial complex. As a result, diffused-base silicon transistors were sent rapidly down the learning curve. By 1960 they were exponentially more powerful than germanium transistors, and almost as cheap (Riordan and Hoddeson, 1997, 209-224; Braun and Macdonald, 1982, 55; 62).

In 1953 there were 60 different types of transistors being manufactured. By 1956 that number had exploded to 275. Integrating all these varied types into an advanced weapon system was proving difficult. In any case, the defense sector now really only wanted one kind of transistor – diffused-base silicon. In 1957 the DOD set up a program (The Military Semiconductor Program) to expedite and

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[212] "In the early 1950s, the seeming intransigence of silicon led many researchers to despair that they would ever be able to manufacture transistors from this ubiquitous, tantalizing element" (Riordan and Hoddeson, 1997, 208).

standardize transistors procured for the military. Increasingly, from that point on, the military only bought diffused-base silicon transistors; and where the DOD went, the semiconductor industry followed (Misa, 1985, 281-2; Stowsky, 1992, 120). It is hard to imagine that the DOD could have fathomed the impact the revolution they were sponsoring in the semiconductor sector would ultimately have. When the diffusion technique was combined with advancing silicon refining methods the semiconductor industry became capable of manufacturing ever smaller, ever more powerful, and ever more rugged transistors, at ever cheaper prices (Riordan and Hoddeson, 1997, 231; Stowsky, 1992, 119). One need only listen to the hum of the cooling fan in their computer as they check the specs on their microprocessor to understand the importance today. Were it not for the advent of the diffused-base silicon transistor, the informational mode of development, where transistors operate in every imaginable environment, from your hot car engine to your warm in-motion pocket, would not have emerged. And had the military not required diffused-base silicon transistors in the 1950s, what organizational entity would have?

COMPUTER DEVELOPMENTS – 1954-1959:

As the nation entered the mid 1950s the general purpose stored program electronic digital computer, as laid out in the Von Neumann architecture, had also been around for a little over half a decade, and here too the defense market remained the main market. In fact, by 1955, only 250 computers had been sold,

with the overwhelming majority going to defense agencies or defense contractors (Helpman and Trajtenberg, 1998, 114; Flamm, 1988, 12-13). Computers in the middle 1950s often used a combination of solid-state logic and vacuum tube amplification. As the current Cold War period under analysis progressed, the level of transistorization in defense-related computers increased (DeLanda, 1991, 149). Here we will now pick up the story of SAGE, for SAGE remains paradigmatic of defense expenditure induced computer development in this period; it also allows us to trace the development of IBM, which rose to a command position in the computer manufacturing market during the late 1950s.[213]

In 1954, IBM did not appear to be poised for dominance of the computer sector. After all, UNIVAC had become a synonym for computer. Meanwhile, IBM computers were still utilizing vacuum tube based processors and magnetic drum memory; architectures that were quickly becoming dated. However, with the SAGE contract to build 56 cutting edge computers filling IBM's coffers with $500 million over a four year period (approximately $2.5 billion in 2000 dollars), IBM was about to transform into an IT leviathan (Flamm, 1988, 87-90; Hughes, 1998, 51-2; Campbell-Kelly, 2003, 38).

All SAGE efforts at IBM revolved around creating a reproducible Whirlwind clone which became known as the AN/FSQ-7. IBM achieved and acquired a number of crucial technical breakthroughs during this multi-year effort

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[213] In the 1950s IBM earned 40% of its revenues from business with the Pentagon (Malkin, 1987, 135-6). In the words of Thomas Watson Jr., "The Cold War helped make IBM the King of the computer business" (Campbell-Kelly, 2003, 38).

which propelled it to the forefront of computer development. It became the first company capable of mass manufacturing and architecturally integrating ferrite core RAM (Ceruzzi, 1998, 51-3; Hughes, 1998, 51).[214] It developed the capacity to mass produce transistorized circuit boards. IBM pushed the envelope in regards to real-time interactive computing. SAGE led IBM to innovate the hydrodynamic slider head – the mechanism still used in most magnetic disk storage systems today; IBM's superior disk storage systems then became a key element accounting for IBM's market dominance in the 1960s (Flamm, 1988, 87-89; Ceruzzi, 1998, 70; Ruttan, 2006, 96). IBM also developed early lead capabilities in interactive computer display graphics and in writing the program codes necessary to making them perform. "In addition, development of an unprecedentedly large software program to provide the operating system for the AN/FSQ-7 also became a milestone in the history of programming" (Hughes, 1998, 40).[215] Perhaps the most

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[214] One AN/FSQ-7 required over 140,000 cores. The yield of good core production at IBM went from 25% to 95% during the SAGE project (Ceruzzi, 1998, 51-3). "IBM's ability to produce inexpensive and dependable core memory systems figured importantly in the competitiveness of the commercial computer systems it delivered in the late 1950s and 1960s" (Flamm, 1988, 88). Jay Forrester commented that it took about 7 years before the non-IBM industry would accept core memory as a solution to a major missing link in computer technology. The military forced IBM to incorporate it immediately (Hughes, 1998, 40).

[215] SAGE kicked off intensive development in the software arena. In 1954 J.H. Laning and N. Zierler completed a software program for Whirlwind which was the first modern compiler – it translated shorthand human and algebraic syntax language commands into executable binary code (Ceruzzi, 1998, 86). As the AN/FSQ-7's software systems rapidly grew in complexity, IBM was forced to subcontract out many of the software tasks. However, there was no organization capable of performing the tasks. The Air Force sponsored think-tank, RAND, stepped up and spun off the first ever software company, Systems Development Company (SDC), to work exclusively on SAGE. SDC was provided with an initial $20 million contract, their total revenue garnered from the SAGE project eventually approached $1 billion. By 1959, over 800 people were working on the software for SAGE, which was over half of the nation's programming manpower. SDC remained the premier software company well into the 1960s (Campbell-Kelly, 2003, 3, 38-40, 308-9; Hughes, 1998, 55-58). Further software developments also revolve around IBM and its participation in defense and aerospace projects during this period. In 1955 a number of IBM 701 defense calculator

important consequence of SAGE for IBM was the training of an army of engineers in every important cutting edge computer hardware and software tool of the day (Hughes, 1998, 51; Flamm, 1988, 24, 90; Campbell-Kelly, 2003, 38; Ceruzzi, 1998, 51-3; Ruttan, 2006, 96; Barnes, 2002, 139).

Moreover, IBM was not the only company to technically benefit from SAGE. More than 100 other industrial contractors contributed to the project. AT&T produced the data transmission links for the continental spanning SAGE system, the first of their kind. From this effort sprung the first modem (Abbate, 2002, 122; Hughes, 1998, 58; Flamm, 1988, 120). Burroughs built peripheral 'data and acquisition and reduction computers' for the SAGE system. These were smaller and less centrally important than the AN/FSQ-7, but were also more transistorized (Flamm, 1988, 88-90).[216] RCA, Bendix, GE, and SDC also contributed in crucial cutting edge ways to SAGE, gaining valuable knowledge and developing new techniques that enabled each to emerge later as movers in the data processing field.[217]

The first SAGE defense sector went operational in June 1958, and new ones

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users from the aerospace industry organized SHARE, which developed and spread IBM compatible software programs for a variety of operations. From this group sprung the first formalized computer software languages such as FORTRAN. Also notable in this period was the DOD's underwriting of the COBOL computer language, which the DOD then required on all of its defense-related machines. In the 1970s 90% of all application programs had been written in either FORTRAN or COBOL (Ceruzzi, 1998, 88-93; Campbell-Kelly, 2003, 34-40; Flamm, 1988, 26; Campbell-Kelly and Aspray, 2004, 173). The SAGE project also led to important developments in operating systems; early operating systems were often written in ALGOL, a language developed by the DOD for the SAGE project (Ceruzzi, 1998, 98-100).

[216] Burroughs SAGE computer was probably the first fully transistorized computer to go into mass production (Flamm, 1988, 90).

[217] See Hughes, 1998; Flamm 1988; and Ceruzzi, 1998 for more on the roles played by RCA, Bendix, and GE. See footnote 215 above for more on SDC.

were added every two months. By 1962, when the system was finally fully deployed, the total cost had exceeded $8 billion (Campbell-Kelly, 2003, 40). When it came together SAGE looked like this: The coastal U. S. was divided into 21 SAGE sectors, each with a combat center equipped with multiple AN/FSQ-8 computers. Over telephone lines, 'data acquisition and reduction computers' sent information concerning the location and velocity of aircraft to the combat center's computers. The combat center computers generated an overall view of the threats and potential responses, producing information to assign and direct defensive aircraft and missiles. The system was capable of tracking a total of 200 enemy aircraft and 200 defensive aircraft and missiles (Hughes, 1998, 54). SAGE was essentially the first digital data communication system, the first wide area computer network, and the first real-time information processing system. The SAGE system was also one of the first fault tolerant computer systems (Flamm, 1988, 89; Ruttan, 2006, 96; Hughes, 1998).

By the time SAGE became fully operational it was already superfluous; ICBMs were now the main threat, and SAGE tracked bombers (Hughes, 1998, 215). And that is the irony of the 'military expenditure impetus to mode of development shifts theory.' Defense expenditure need not be reasonable or in this case even practical in order to produce the relevant causal effects. It just needs to effectively develop a toolbox of novel GPTs from which firms can pick and choose as they rationalize their business models in subsequent years. Crucial to this process of course is diffusion via human capital, for this is how firms come to be

aware of the new technologies, and come to understand how they can integrate the new GPTs into their business routines. SAGE was unbelievably effective in terms of both fixed capital development and human capital diffusion. In regards to fixed capital developmental, the innovations made in connection with SAGE include magnetic core RAM, interactive graphical interfaces, computer to computer data networking, modems, real-time computing, processor transistorization, effective disk based storage devices, and software systems building, to name a few (Ruttan, 2006, 98; Hughes, 1998; Ceruzzi, 1998). Perhaps when looked at in isolation, one can imagine a slower timeline by which each of these innovations would have eventually materialized. But absent the military expenditure impetus, it is hard to imagine a mechanism through which each of these innovations would have emerged in the rapid and temporally coordinated nature spurred by SAGE (Ruttan, 2006; Hughes, 1998, 36-7). Remember, it is not only the appearance of radically new GPTs that marks a mode of development shift; it is also the coordinated nature of their development and diffusion (Castells, 1996, 1998; Cortada, 2002; Helpman and Trajtenberg, 1998).

In regards to human capital diffusion, 'SAGE was perhaps the most effective technology transfer agent in the history of the nation' (Hughes, 1998, 65-70; Campbell-Kelly, 2003, 40). "The SAGE project became a center of learning for computer engineers, scientists, and technicians." As will be shown in subsequent chapters, many of the engineers and software developers who later became key figures in the Information Technologies Revolution cut their teeth on

the SAGE project. The SAGE learning legacy can be characterized as 'profound' (Hughes, 1998, 118). As SAGE funding wound down after 1962, a slow but inexorable exodus from SAGE contractors, such as IBM and SDC, circulated throughout the US computing industry. This exodus not only molded the computer sector into the shapes and forms we know today, it also, essentially, fashioned the software labor market out of thin air. In palpable ways then, SAGE enabled the nation to vault to a head start in computer and software development.[218] When combined with the countless other expensive defense-related projects undertaken in the United States in the mid to late 1950s, the technological gap the United States opened in computer and software development vis-à-vis its international trading competitors became insurmountable, and would stay that way for nearly two decades (Campbell-Kelly, 2003, 30-40, 69; Hughes, 1998, 67; Flamm, 1988).

Before we move onto a discussion of the 1960s, one other 1950s national security computer development program warrants mention. Not necessarily because it had more profound effects than the numerous defense computer development programs that have not been mentioned; but because this project also involved IBM. As aforesaid, IBM emerged as a near monopolist in the computer

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[218] Before SAGE there were perhaps one thousand competent programmers in the nation; SAGE contractor, SDC, trained thousands upon thousands more (see note 215 above as well). In 1960 there were 3500 SDC employees, and 4000 ex SDC programmers already in the field; by 1964 SDC employed 4300 employees while 6000 past employees were 'feeding the industry.' "SDC embraced its role as a university for programmers and its policy was to not match higher salary offers with raises... The chances were reasonably high that on a large data processing job in the 1970s you would find at least one person who had worked with the SAGE system" (Campbell-Kelly, 2003, 40-41).

sector in the 1960s.[219] Thus any discussion of the 1960s computer industry necessarily revolves around IBM. And one cannot possibly understand the defense-related nature of the many innovations that spewed forth from IBM in the 1960s without having some knowledge of Project STRETCH.

In 1956 the NSA and the Atomic Energy Center (AEC) teamed up to fund the development of a powerful computer that would exponentially push the state of the art in both the character driven cryptanalysis field and the mathematical nuclear modeling field. IBM proposed a highly flexible fully transistorized computer that won the design competition and development contract. The computer became known as STRETCH. Building STRETCH stretched IBM's resources to the limit, and the project stretched well beyond the budget caps IBM had originally agreed to, by over $9 million. Rather than haggle a new contract, IBM "arranged to have free use or ownership of all patents produced by the project, which it would then be free to use in its commercial products" (Flamm, 1988, 91). This was a wise course of action. Component, manufacturing, and programming technologies either pioneered or developed at IBM for the STRETCH project include: high-speed port memories, advanced diffused-based silicon transistor processors, standardized printed circuit card assembly (known as standard modular systems), automated design and manufacture of SMS cards, automated component insertion, and automated wire wrapping machinery to interconnect SMS cards. The eight bit chunk of data known as the byte was pioneered at IBM during the STRETCH

[219] IBM market share hovered around 70% from the early '60s onward (Ceruzzi, 1989, 110; Flamm, 1988).

project (the term byte was coined by IBM engineer Werner Buchholz). Manipulation of data in words of fixed or variable length built up from bytes was achieved, a simple system for handling an extended set of alphabetic characters was created, and the basic logic circuit still used in high performance computers today was invented for STRETCH. STRETCH fomented significant innovations in 'processor pipelining' and 'construction look ahead.' Also, common interface standards for peripherals and new advances in high-speed magnetic tape storage were introduced.[220] Each of these many technologies eventually found their way into IBM's subsequent generations of transistorized computers, thus helping IBM to achieve and then maintain near monopoly status in the 1960s mainframe sector (Flamm, 1988, 91-3; Ceruzzi, 1998, 151-2; Ruttan, 2006 MacKenzie, 1996, 114)

By 1960 computers were no longer being called UNIVACs.[221] Under the increasingly influential tutelage of IBM, the industry had entered the 'mainframe era'; wherein 'high priests of computing' oversaw room-sized computers with transistorized circuit-board processors hanging on cabinet bound frames while air conditioning and magnetic tape I/O peripherals buzzed loudly in the background (Ceruzzi, 1998, 79; Flamm 1988). In the next chapter we will see how military expenditure combined with market dynamics to generate the technologies that

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[220] The lead engineer on Project Stretch was Steven Dunwell who had worked on cryptanalysis machines during WWII. Other WWII computer pioneers on the team included Max Femmer, David Crawford, and Phillip Fox (Flamm, 1988, 63). STRETCH stayed in operation for 14 years and was the backbone of the most powerful computer system in the world, operated by the NSA (Ruttan, 2006, 104; Flamm, 1988, 92).

[221] RR, previously IBM's main competitor, merged with noted defense contractor Sperry Corporation in 1955. Sperry refused to commit the levels of R&D necessary to maintaining competitiveness with IBM in the late 1950s, and its computer division declined rather precipitously (Flamm, 1988, 108).

would ultimately result in the decline of the mainframe era and the rise of 'direct access computing.'[222]

[222] It should be noted that in the mid-1950s, beneath the big computer contractors (IBM, Remington Rand, Burroughs, Bendix, RCA, and Raytheon), there percolated a dynamic market driven by military expenditure. Amongst the smaller producers, the 1950s computer sector exhibited a pattern: "Fluid movement of talented engineers from one aerospace patron to another and into startups that often survived only long enough to be acquired by a larger firm." For almost all of these small producers, such as Computer Research Company and Logistics Research Corporation, the military was the first and generally the best customer. It should also be mentioned that in the early 1950's a small California firm named Hewlett-Packard made its first foray into the computer business when it contracted with Northrop Aircraft to design a differential analyzer used for missile guidance (Flamm, 1988, 6, 78-9; Cerruzi, 1998, 41).

CHAPTER 14: THE COLD WAR YEARS – 1960-1964

The Cold War continued unabated into the 1960s. For example, the Berlin Wall was erected in 1961 while 1962 brought the Cuban Missile Crisis. The winning Kennedy platform included higher defense spending aimed at creating 'flexible response' to Soviet threats. Space increasingly became the main theatre for the arms race, with numerous crash programs initiated to develop missile defense capabilities (which for the most part failed), and MIRV capabilities (which for the most part succeeded). And of course, in May of 1961, in direct response to the Soviet's evident lead in space based technologies and weapons, Kennedy issued a challenge to the nation to put a man on the moon by the end of the decade (Purcell, 1972, 11; Domke, 1992, 42; Nincic, 1982, 14-5).

Total real military expenditure rose 2% in 1961, over 4% in 1962, and another 1% in both 1963 and 1964; reaching $247.4 billion in real terms ($54.8 billion nominally).[223] At the level of procurement, real expenditure increased only an average .4% per annum between 1960 and 1964. Nevertheless, RDT&E expenditures suggest a rapid pace in accumulation for spending related to advanced weapons development in this period. Real RDT&E rose 62% in 1960, another 29% in 1961, stabilized at a high level of $29 billion (around $7.5 billion in nominal terms) in 1962 and 1963, and rose another 8.5% in 1964. NASA expenditure growth, which mirrors RDT&E in its effects on advanced weapons development

[223] With real GDP rising a robust 5.4% per annum average between 1962 and 1964, total military expenditure as a percentage of GDP declined from 9.14% at the beginning of this period to 8.25% in 1964, which is still quite high historically speaking.

(Ruttan, 2006), was simply 'off the charts' in this period. Real NASA expenditures rose 172% in 1960 (before Kennedy's 1961 challenge to the nation), and continued to rise, averaging a 100% per annum gain between 1960 and 1964. NASA spending reached $18.8 billion in real terms ($4.2 billion nominal) in 1964, which was almost 9 fold its 1960 level. Such spending had profound effects on the nation's R&D manpower, along with its electronic and computing sectors. Estimates of the national engineering corps engaged in defense related activities in this period range between 40% and 50%. In 1961 the military purchased 21% of all electrical equipment and supplies produced in the nation, and the DOD funded between 50% and 60% of the R&D undertaken in the electronics and communications sectors in the early 1960s (Weidenbaum, 1966, 106; Bolton, 1966, 94; Reich, 1973, 94; Nelson, 1966, 147). In regards to computing specifically, Kennedy's moon-challenge "transformed the US space program into a complex of research and production centers with unlimited budgets and insatiable appetites for computing power" (Ceruzzi, 1998, 110).

With non-defense expenditure also increasing in this period (non-defense expenditure rose an average 6.8% per annum in real terms 1960-1964), various proposed schemes for heightened growth took center stage. Kennedy, an avowed Keynesian, opted to cut taxes and maintain spending in order to achieve 'full employment GDP', believing that ensuing deficits would be curtailed by rising GDP (Malkin, 1987, 32; Kelly, 2000, 77). In the short-term, he was proven correct, as total revenue continued to rise on the back of strong real GDP growth in this

period. Real GDP grew an average 4.2% per annum 1960-1964, and real total revenue grew 5.7% per annum. In 1963 Kennedy passed a major tax bill that significantly reduced income taxes on the top earnings bracket (from 92% to 70%), and reduced corporate taxes significantly as well. Still, aggregate personal income tax revenue rose an average 4.5% per annum in real terms from 1960 to 1964, and real corporate tax revenue increased an average 5.4% per annum. Real social insurance tax revenue also rose, at a robust 12.2% per annum average rate in this period, and real excise tax revenue declined modestly by 1.2% per annum on average. All in all, the numbers and Kennedy's 1963 tax bill suggest that the tax structure became more regressive as this period progressed.

As alluded to above, this was an era of increasing deficits, and the deficit rose from nil in 1960, to average $23.6 billion in real terms ($5.1 billion nominally) in the four years following. As a result gross federal debt increased 3% in real terms to $1.43 trillion, 10% nominally to $316 billion, over this period. Interestingly, the percentage of public debt held by the Fed rose swiftly between 1960 and 1964, accumulating from 11% to 14%. And although inflation remained rather quiescent (1.27% per annum average on the CPI), slack did begin to disappear from the economy, with manufacturing capacity utilization moving from 77% in 1961 to 86% in 1964.

Taken together, these figures indicate that the economic environment for both defense expenditure induced technical development and technological diffusion was pitch perfect from 1960-1964. And as will be shown, both did occur

in the semiconductor and computer sectors; we also now add the computer networking sector to the mix. Assuredly though, with expenditure on advanced weapons R&D and procurement remaining robust, 1960 to 1964 was more a period of development in our sectors of interest, than it was a period of diffusion. This accords well with the 'military expenditure impetus to mode of development shifts theory' in that it points to defense expenditure as the key factor conditioning the pace of informational GPT commercial diffusion. It should also be noted that the tightening economic slack resultant from the halcyon economic environment combined with heightening military expenditure amid a friendly Fed should have been viewed as worrisome, although it was not. The story of the economic consequences will be taken up later, for now, we return to our narrative regarding defense-induced technological development and diffusion in the semiconductor sector.

THE SEMICONDUCTOR SECTOR – 1960-1964:

By the early 1960s, defense expenditures had established a fair level of maturity in the transistor industry. The market for transistors passed the $1 billion revenue mark in 1961 and sales were nearly doubling each year. In 1963 47% of this growing market was still finding its way into military systems, although from there the military share began to decline (Braun and Macdonald, 1982, 80). Interestingly, just as lower-end transistors were gradually diffusing commercially (more widely than just in the relatively small radio segment that is), the military

was underwriting a new momentous technological transformation in the semiconductor sector. The early 1960s marks the rise of the Integrated Circuit (IC) (Riordan and Hoddeson, 1997, 7).

Previous to the advent of the IC, electronics were powered by circuit boards containing discrete transistors, resistors, capacitors, diodes, inductors, and wire. As circuits with transistors became more complex, connecting thousands of discrete components proved to be a massive bottleneck (Riordan and Hoddeson, 1997, 25; Ceruzzi, 1998, 179). The idea of replacing circuit boards with some kind of miniaturized automatically wired circuit unit requiring fewer discrete components and connecting leads, termed at the time a 'monolithic circuit', had been discussed in military circles since at least 1952; and a number of programs were initiated which attempted to bring the monolithic circuit into fruition (Riordan and Hoddeson, 1997, 255). Once again, the final breakthroughs that achieved the 'integrated circuit' were not funded by the military and occurred in private company laboratories. Again, this has led certain theorists to claim that military expenditure played no role in the invention of the IC. Moreover, these theorists have described the three major defense funded programs aimed at creating 'monolithic circuits' as unsuccessful and wasteful (DeGrasse, 1984, 90; DiFilippo, 1990, 97; Stowsky, 1992, 121; Tirman, 1984). Once more, such supposition borders on the myopic. Let's therefore trace the advent of the IC, starting with an analysis of the three major defense funded monolithic circuit efforts, and moving

on from there with an eye toward highlighting the many defense-related impetuses that figured in the process.

The first military program aimed at miniaturizing transistorized circuits was funded by the Navy and known as Tinkertoy. Initiated in 1952, the program had expended nearly $5 million by 1953 attempting to print, and then connect ceramic wafers in a method analogous to a child's tinker-toy. Some tinker-toy type circuits did begin to appear in guided weapons systems, but the circuits proved unreliable and costly to manufacture. Perhaps the greatest contribution this early effort made to the eventual advent of the IC was that it got the inventor of the first rudimentary IC, Jack Kilby, working on the project at Centralab, which was the lead corporate defense contractor on Tinkertoy (Braun and Macdonald, 1982, 93).

The Army revived the effort to miniaturize transistorized circuits in 1957 with its 'Micromodule' program. This time the metaphor was the Lego – an attempt was made to miniaturize and standardize different circuit components which could then be snapped together like Legos, stacked together like poker chips, and encapsulated in modules. Between 1957 and 1960 the Army spent approximately $26 million on Micromodule. Major contract work was performed at RCA, along with TI where Jack Kilby had recently relocated; Kilby for a short time worked on Micromodule as well (DeLanda, 1991, 151; Braun and Macdonald, 1982, 93; DeGrasse, 1984, 90-1).

Although Micromodule did not produce 'earth shattering' breakthroughs, it absolutely did have successful results. As we will see in the next section, the

highest selling computer system of the mid to late 1960s, the IBM System / 360, utilized the modular approach to miniaturizing transistorized circuits. Indeed, the modular approach to miniaturization achieved during Micromodule can be viewed as an intermediary step between circuit boards and ICs (Braun and Macdonald, 1982, 96-97; Ceruzzi, 1998, 190). Another and perhaps even more important development to come out of the Army's Micromodule program was the advent of photolithographic / photo-resist techniques of etching wiring patterns onto semiconductors. In 1957 the Diamond Ordnance Fuze Laboratory (DFL), a military laboratory receiving Micromodule funds, announced the construction of a 'diffused-base p-n-p germanium transistor integrally incorporated in a printed circuit plate' through the use of photolithography.[224] This method of creating circuit connections via 'masking' and 'etching' through photo-resist techniques would ultimately prove key to the invention of mass producible ICs (US Army Materiel Command Historical Office, 2003; Braun and Macdonald, 1982, 94).[225]

By far the most audacious military effort aimed at miniaturizing transistorized circuits came from the Air Force, which funded the Molecular Electronics program, initiated in 1959. This multi-million dollar project sought to manipulate silicon crystals at the molecular level in order to create electronic properties that could function as resistors, capacitors, and diodes. Although the

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[224] The term 'microelectronics' was also coined at Diamond Fuze Laboratories at this time (Braun and Macdonald, 1982, 94).

[225] Perkins-Elmer, a noted and long-time defense electronics contractor, developed "the critical optics assembly needed to produce the photomasks" utilized in photolithographic etching during Micromodule (Ceruzzi, 1998, 359).

idea never really got off the ground, two things warrant mention here. First, during the Molecular Electronics effort Sandia National Laboratories pioneered the use of clean rooms.[226] There is not an IC foundry in the world today that does not use clean rooms. Secondly, the Air Force was way ahead of their time with the 'molecular' notion. In the late 20th century researchers again became interested in using molecular properties to mimic transistor switching mechanisms, and intense efforts continue along these lines today (Ceruzzi, 1998, 181; Riordan and Hoddeson, 1997, 255; DeLanda, 1991, 155, Shinal, 2007).

Meanwhile, in 1959, the two researchers who would ultimately invent the IC and the technique needed to mass produce it, Jack Kilby and Robert Noyce, toiled away on internally funded efforts to miniaturize transistorized circuits, at TI and Fairchild respectively. Both efforts were consciously isolated from military funding for the same reasons previously described, but both researchers were keenly aware of the military's intense demand for such a device:

"The firms that developed the concept purposefully avoided military funding for their research so that the basic technology was privately owned, though motivation for developing the device was the announced intention of the armed forces to provide a substantial market for devices with the appropriate characteristics" (Flamm, 1988, 17; Ceruzzi, 1998, 180; Braun and Macdonald, 1982, 95).

In fact, "Jack Kilby's own account of his invention confirms that Texas Instruments had solely military applications in mind when research into the new devices began" (Stowsky, 1992, 121). Working on the knowledge he had gained at Centralab, and at TI's Micromodule division, Kilby brainstormed a new way of

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[226] Such rooms were washed by a constant flow of ultra-filtered air flowing from the ceiling to the floor.

approaching the monolithic circuit. He reasoned that if all of the discrete components in a circuit could be made out of semiconductor material then an entire circuit could be fashioned from one slice of semiconductor material.[227] In mid 1959, after intense effort, Kilby achieved a simple circuit fashioned from, and on, one small wafer of silicon. However, the components on the chip still had to be wired by hand using a microscope in a process that was too cumbersome and expensive for commercial development (Riordan and Hoddeson, 1997, 256-261; Ceruzzi, 1998, 182-184; Flamm, 1988, 17; Ruttan, 2006).

Enter Robert Noyce at Fairchild Semiconductor; it should be noted that both the man and the firm were steeped in previous defense expenditures.[228] In January of 1959 Noyce began working on creating a monolithic circuit using new silicon processing technologies being improved at Fairchild at the time. The key difference between Kilby's and Noyce's IC technique was that Noyce used

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[227] Kilby argued "Whatever increase costs there were for the individual components would be more than offset by not having to set up separate production, packaging, and wiring processes for each" (Ceruzzi, 1998, 183; Riordan and Hoddeson, 1997, 259).

[228] The story of Noyce and Fairchild Semiconductor begins with William Shockley – the radar pioneer, developer of the transistor, and then Pentagon employee. After a multi-year stint at the Pentagon, Shockley returned to the private sector in 1956 when he started Santa Clara Valley's very first semiconductor firm, Shockley Semiconductor. Shockley located the firm near Stanford in order to draw from Stanford's well of engineering talent, which itself had drawn nourishment for decades from defense-related funding. Shockley was able to peel Robert Noyce away from Philco, a major defense contractor. At Philco, Noyce had been leading development efforts regarding Philco's then cutting edge high frequency transistors, which were entirely consumed by defense agencies and defense contractors. At Shockley Semiconductor Noyce quickly tired of Shockley's increasingly erratic management style. Noyce, along with other members of the 'traitorous eight', set out to start their own Santa Clara Valley based semiconductor firm in 1957. Fairchild Semiconductor was capitalized and incorporated in late 1957 by Fairchild Aviation Camera and Instrument, a New York defense contractor which had provided gunnery cameras to the military since WWII and was now getting involved in missile and satellite systems. Almost every Silicon Valley semiconductor firm, still today, can in some way, many times in a very direct way, trace their genesis back to Fairchild Semiconductor (Riordan and Hoddeson, 1997, 235-240, 250-252; Ceruzzi, 1998, 198; Braun and Macdonald, 1982, 125-126; Saxenian, 1994).

diffused-base 'mesa' transistors as his starting point.[229] Later that year, Fairchild engineer Jean Hoerni employed the new photolithographic techniques recently designed at DFL during Micromodule to improve the mesa technique, thus creating the 'planar process.' Notably, Hoenri's process was only appropriate for silicon transistors,[230] which in all likelihood would not have existed were it not for the middle 1950s DOD push. Noyce combined knowledge of mesa transistors, the planar process, and photolithographic techniques to produce not only an 'Integrated Circuit' made from and upon a single wafer of silicon, but also a reproducible method of mass manufacture for the device. Fairchild was mass producing ICs in clean rooms by 1961 (Riordan and Hoddeson, 1997, 262-5; Braun and Macdonald, 1982, 75, 87-89; Delanda, 1991, 152; Ceruzzi, 1998, 186; Ruttan, 2006, 100).

Thus it becomes clear that the inventors of the IC benefited in numerous ways from 'know-how spilling over' from defense-related efforts and research programs (Borrus and Zysman, 1992, 215). To suggest anything less is either misguided or polemically guided disingenuousness. The military faced with space related bottlenecks keenly required a monolithic circuit device and initiated numerous program efforts that cast a wide net, trained numerous engineers, achieved an intermediate-step towards miniaturized circuits, and pioneered important photolithographic and clean room techniques. Clearly the military itself

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[229] The mesa technique, developed at Bell labs in the late 1950s, involved transistor formation in a flat topped profusion on a small wafer of silicon. Such advanced transistors were highly popular with the military and were thus being produced by some of the larger military contractors working on the space program in the late 1950s such as Fairchild, Motorola, WE, and TI (Riordan and Hoddeson, 1997, 262).

[230] See Braun and Macdonald, 1982, 75 for more on the complex planar process.

was not the key repository for the technical knowledge that led to the IC; this of course resided in private firms which were guided by military demand and made use of military R&D funds as they saw fit. All in all, the narrative regarding the invention of the IC accords quite well with the 'military expenditure impetus to mode of development shifts theory.'

What is indisputable is that after the invention of the IC the military was "virtually the only market" for integrated circuits (Braun and Macdonald, 1982, 97). "As happened in the case of the transistor, the first integrated circuits were too expensive to compete directly in the marketplace and had to depend on military contracts to survive" (DeLanda, 1991, 152). Fairchild was first to market in March of 1961 selling ICs to NASA for $120 a piece. By that summer Fairchild was manufacturing hundreds per week and unit price had dropped to under $100. In 1962, defense-related agencies purchased 100% of all of the ICs manufactured by Fairchild, and now TI and Motorola as well, at $50.00 per unit. In 1963 defense-related agencies purchased 94% of the $4 million worth of ICs produced; with each unit now selling for $31.60 as more producers entered the sector. In 1964 85% of the market went to defense-related users, unit price $18.50. And in 1965 72% of the now $40 million dollar IC market was purchased by defense-related agencies, for $8.33 a pop (Braun and Macdonald, 1982, 98; Stowsky, 1992, 122; DeLanda, 1991, 15). Again, defense contracts helped create 'a flexible and highly independent production network' for ICs and caused there to be widespread

dissemination of basic technical knowledge among competing companies.[231] Additionally, the first applications of ICs to computer logic circuits all occurred under defense auspices (Riordan and Hoddeson, 1997, 272-275; Stowsky, 1992, 121; Vayrynen, 1992, 76).[232] We now turn to discuss the computer sector, where at the non-experimental level the transistorized mainframe still ruled the day.

THE COMPUTER SECTOR – 1960-1964:

Much like in the market for transistors, military expenditure had established a fair level of maturity in the computer sector by the early 1960s (Campbell-Kelly, 2003, 41). As a result, the rate of computer usage grew considerably in the early 1960s, especially among non-defense governmental agencies; 'there can be little doubt that much of this growth resulted from the availability of trained computer professionals – many from the military establishments' (Norberg, 2002, 174). Still, with military expenditure at high levels in this period, most trained computer professionals remained in the defense-related sector, from which key computing innovations continued to emanate. For example, defense-related agencies and firms consumed the overwhelming proportion of computer systems with core based memory and transistorized processors in the early 1960s; the defense sector provided the main market for disk based storage systems which improved markedly during this period; defense demand guided the storage market toward important

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[231] The DOD strongly preferred second-sourcing in IC contracting – "co-contractors often shared patent rights, drawings, photomasks, and manufacturing know-how" (Stowsky, 1992, 122).
[232] ICs would not appear in commercial computers until 1965 (Flamm, 1988, 18; Braun and Macdonald, 1982, 100; Ceruzzi, 1998, 188).

developments in database management; RAND invented the first digital drawing tablet computer with DOD funding in 1962; and the DOD initiated the first ever research into Artificial Intelligence (AI) computing in the early 1960s (Flamm, 1988, 21-24; Ceruzzi, 1998, 48-9, 66, 165). Indeed, on the back of increased defense-related demand the number of computers installed in the US rose by factor of five, from 4,400 to 21,600, between 1960 and 1965 (Campbell-Kelly, 2003, 89; Braun and Macdonald, 1982, 79).[233]

In this period IBM solidified its role as the mainframe monolith, garnering 65%-70% of all computer manufacturing revenues. The most successful IBM machines of the day, such as the 7090 series, drew technology directly from IBM's many DOD funded R&D programs (such as SAGE and STRETCH), and were chiefly sold to defense-related organizations (Ceruzzi, 1998, 75-6; 147; Flamm, 1988, 80). IBM also emerged in this period as the nation's premier software developer; another result of its extensive military efforts. In fact, IBM's first major commercial software project, the Semi-Automatic Business Environment for Research (SABRE), which allowed American Airlines customers to book reservations in near real-time by telephone, was a direct spin-off of SAGE systems software (Ruttan, 2006, 107-108; Flamm, 1988, 89-95; Nebecker, 2002, 149; Campbell-Kelly, 2003, 45).[234]

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[233] Defense and government users still accounted for 100% of the computer market in 1962 (Stowsky, 1992, 122)

[234] SABRE, operational in 1964, was an important precursor to CICS, which IBM developed in 1967. CICS is a real-time information system that is still widely used throughout the banking,

Beneath IBM in the early 1960s mainframe sector stood the 'Seven Dwarves': Sperry Rand (with 12% market-share); Control Data (5 %); Honeywell (4%); Burroughs (3.5%), GE (3.5%); RCA (3%); and NCR (3%). Although each has an interesting narrative regarding its genesis and progression, here we will just note that each of these firms' computer divisions were heavily rooted in defense-related procurement prior and subsequent to the early 1960s (Ruttan, 2006, 105; Flamm, 1988, 102; Ceruzzi, 1998).[235]

THE IPTO AND COMPUTER NETWORKING – 1960-1964:

'Computer networking' first materialized as an independent research quarter in the early 1960s. NASA was the first agency to push SAGE networking technology forward, extensively utilizing mega-expensive interactive networked computing for its early 1960s vehicle launches. Still, real-time computer networks remained plagued by problems and bottlenecks (Campbell-Kelly, 2003, 42; Ceruzzi, 1998, 117). Such issues took center stage in 1962 when President Kennedy discovered during the Cuban Missile Crisis "that the US military did not

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financial and utilities industries today; it remains a 'crucial part of the world's information infrastructure' and owes a great debt to SAGE (Campbell-Kelly, 2003, 149, 152).

[235] Sperry Rand's defense roots have been previously discussed by way of RR. In 1957 Sperry Rand's leading computer engineers left to form the Control Data Corporation (CDC); these engineers were original members of the ERA team. In the late 1950s CDC came to focus on producing high-speed computers for defense agencies (Ceruzzi, 1998, 126). In 1955 Honeywell acquired Raytheon which had been producing computers for the military since the late 1940s (Flamm, 1988, 113; Ceruzzi, 1998, 116). Burroughs was successful mainly because it had always focused on the military market (Flamm, 1988, 117; Ceruzzi, 1998, 67). GE "began producing military computers in the late 1940s" and continued these activities through the 1950s and 1960s (Flamm, 1988, 124). RCA performed research on analog computers during WWII and continued to work on various defense-related projects through the early 1960s (Flamm, 1988, 124). NCR purchased Computer Research Corporation (CRC) in 1953. "CRC (an ERA spin-off) developed small computers under government contract for use in military applications" (Flamm, 1988, 118).

have an effective worldwide communications system for command and control… The Cuban Missile Crisis was responsible for increasing the military's interest in computer networks" (Abbate, 1999, 134). After the crisis, the DOD consciously set out to develop computer networking technologies that would one day enable 'command, control, and communications' (C3) at the intercontinental level (Hughes, 1998, 257; Abbate, 1999, 234).

The core of the DOD computer networking program was transferred to a newly minted division of the Defense Advanced Research Projects Agency (DARPA). DARPA had been created, in 1958, for just this sort of far-sighted effort, and given the size of the project, it made sense to create an entirely new office devoted to it.[236] So began DARPA's Information Processing Techniques Office (IPTO), in 1962. The IPTO quickly came to have a budget that 'exceeded that of all other sources of US public research funding for computing combined' (Campbell-Kelly and Aspray, 2004, 191; Abbate, 1999, 36).[237] Joseph Licklider was installed at the helm of the IPTO.[238] Licklider immediately used IPTO funds to establish 'computer science' research centers at numerous universities including MIT, Stanford, Carnegie Melon, the University of Utah, UCLA, and UC Berkeley.

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[236] DARPA's budget was approximately $400 million in 1960 (Peck and Scherer, 1962, 74).

[237] In order to receive IPTO funding a project had to offer a more than 10% improvement in the state of the art, be over two years ahead of commercial sector achievements, be likely to cost a million dollars or more for development, and have obvious important implications for military C3 operations (Hughes, 1998, 269).

[238] Through military work, Licklider had developed a powerful vision of interactive computing; Licklider had been a SAGE project leader at Lincoln Labs. Licklider's approach to computers is laid out in his seminal paper "Man-Computer Symbiosis" published in 1960. "In this essay, he calls for a partnership – a very close coupling – between humans and electronic computers that would facilitate thinking, decision-making, and the control of complex situations" (Hughes, 1998, 261; Abbate, 1999, 43).

Alumni from MIT, Lincoln Labs, and the SAGE project fanned out to accept computer professorships at these universities. Importantly, Licklider conceived of military contracts as "components from which coherent and systematic research and development programs that transcend individual universities could be fashioned." He believed that at a certain level of abstraction, "what the military needs is what the businessman needs is what the scientist needs" (Licklider quoted in Hughes, 1998, 265). Such a philosophy was instituted at the IPTO during its formative phase under Licklider, 1962-1965 (Hughes, 1998, 264; Abbate, 1999).

The first major difficulty Licklider sought to tackle via the use of computer networking was the batch processing bottleneck. In the 1960s solving a problem on a computer was a laborious and slow task. A researcher first formulated a problem, and then worked closely with a programmer to create a set of programs to operate on the problem. After these programs had been written, they were submitted to the operator of a centrally housed mainframe and placed in a queue. Eventually the programs would be run, information obtained, and printouts made. If a user's programs turned out to have errors, which they often did, the user would have to rewrite them, punch another set of cards, and then submit the cards again. This process was repeated until all the bugs were sweated from the program. For obvious reasons, this was an inefficient formula for the complex multi-programmed real-time data processing necessary for effective C3 networks (Ruttan, 2006, 115-117; Abbate, 1999, 24; Hughes, 1998, 261-262).

Licklider sought to remedy this situation by developing a technology that would allow many users to interact and communicate with one mainframe in real-time all at the same time. He termed this process 'time-sharing.' He proposed a mainframe with multiple attached terminals from which users could access any set of data or programs housed in the mainframe's memory. The mainframe would lend computational cycles to each user as necessary, with the wait between cycles being so short that 'users would have the impression of continuous interaction with machine' (Abbate, 1999, 24; Ruttan, 2006, 115-117; Ceruzzi, 1998, 154-155; Hughes, 1998, 265-266).

In order to bring this vision of computing to fruition, Licklider initiated Project MAC (which stood for multiple-access computer or machine-aided cognition depending on who you ask) at MIT. The project received an initial sum of $3 million. By late 1963, a system, based around a GE mainframe capable of serving 30 researchers at a time, had been developed (Hughes, 1998, 266-7; Campbell-Kelly and Aspray, 2004, 191; Ceruzzi, 1998, 155-6; Flamm, 1988, 26).[239]

Around the same time, Paul Baran, a brilliant theorist working at the Air Force funded think-tank RAND, was also pondering the communications conundrum illuminated by the Cuban Missile Crisis. Baran became concerned that a few well placed Soviet missile strikes could entirely wipe out the American

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[239] A program that allowed multiple users to collaborate on and edit text documents proved most popular on this initial Project Mac system. This program can be considered the first 'word processor' (Campbell-Kelly and Aspray, 2004, 191).

military's highly centralized communication networks. In 1962 Baran applied for and received a RAND grant to design a decentralized and flexible communications system capable of withstanding nuclear attack. In 1964 Baran proposed a visionary system composed of numerous, densely interconnected, well distributed 'nodes' located in hardened silos far away from population centers. Each node would have the capacity to break messages into standardized digital packets, send the packets, and to recombine the digital packets once they had been received at the designated locale. The nodes would also be designed to communicate with the digital packets in order to find the best possible route to take along the decentralized densely interconnected node network. In other words, if some nodes were taken out, the existing nodes could work with the packets to find the best alternative paths to their final destination.[240] With many nodes, and many links attached to each node, redundancy would insure survivability. Baran argued that recent developments in real-time computing would enable localized semi-intelligent communication between the nodes and the digital packets. He also reasoned that since the packets were in digital rather than analog format, messages could be composed in any communicational medium – whether text, voice, or video. What Baran had proposed was the first packet-switched digital communications network; he had conceived the Internet in rudimentary form (Abbate, 1999, 9-19; Hughes, 1998, 272-3).

Baran's study was completed in 1964, and that August RAND officially

[240] Such a scheme would not be feasible using analog communication, thus the use of digital packets.

recommended that the Air Force proceed with R&D on a 'distributed adaptive message-block network.' Before work got started, the Air Force circulated Baran's ideas within the defense industrial complex. The proposal was roundly met with skepticism. Digital transmission of messages across a wide network of distributed nodes seemed inefficient at best, impossible at worst. Many engineers argued that the decentralized system would prove prohibitively expensive to 'ruggedize', entirely missing Baran's point that hardening was largely unnecessary as the system was rugged by dint of its redundancy. AT&T weighed in on the project calling it impractical and unlikely to succeed. One AT&T engineer remarked to Baran "First, it can't possibly work, and if it did, damned if we are going to allow the creation of a competitor to ourselves" (quoted in Hughes, 1998, 274). In the end, the Air Force, now embroiled in a bureaucratic tussle with the Defense Communications Agency regarding which agency would have jurisdiction over the proposed network, opted to scuttle the project. Soon however, Baran's proposal would be resurrected by the visionary Licklider and his accomplished IPTO confidantes (Abbate, 1999, 17-20; Ruttan, 2006, 115-117).

We'll of course return to describe the IPTO's first forays into packet-switched computer networking in the next chapter. But before we move on, the story of the Licklider led IPTO (Licklider left the agency in 1965) is incomplete without a mention of Douglas Engelbart. Engelbart, formerly a young radar pioneer during WWII, was working at the Stanford Research Institute in 1962 when he came across a paper that laid out Licklider's man / computer symbiosis

philosophies. The philosophies therein were remarkably similar to Engelbart's.[241] Engelbart applied for and received a large IPTO research grant in 1963. Over the next five years Engelbart used IPTO financing to develop the first computer to human interface that included a mouse, windows, hyper-textual linking of documents, and multimedia capabilities. In 1968 at a DARPA sponsored computer conference Engelbart demonstrated the system to a small number of DARPA researchers. Engelbart sat before a motion picture screen with a keyboard in front of him and a mouse next to it. "The changing information displayed on the large screen, activated by his motions of the mouse, began to animate under Doug's control... Engelbart was the very image of a test pilot that doesn't fly over geographical territory but through information space" (Delanda, 1991, 220-221). DARPA had not only glimpsed the future, it had begun to re-write it (Flamm, 1988, 24; Ceruzzi, 1998, 260; Campbell-Kelly and Aspray, 2004, 237).

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[241] "Thanks to his radar experience during the war, Engelbart realized that the computer display had become the surface contact between computers and machines... Now the screen had to be transformed into a tool allowing users not only to display data, but to control the machine" (DeLanda, 1991, 220).

CHAPTER 15: THE VIETNAM ESCALATION – 1965-1970

On August 2, 1964 North Vietnam attacked the USS Maddox in the Gulf of Tonkin. On August 7th Congress passed a joint resolution, the Southeast Asia Resolution, later known as the Gulf of Tonkin Resolution, which allowed for a rapid escalation of American involvement in Vietnam. Whatever the tangible reasons for US involvement in Vietnam, and many differing theories have been proffered, this project is narrowly concerned with the effects the Vietnam escalation had on military expenditure and how military expenditure in turn affected informational GPT development and diffusion. Expenditure on the conflict jumped in 1965 when ground troops were introduced on a large-scale, and dropped after 1970 as the US slowly disengaged (Mayer, 1992, 30; Kelly, 2000, 106). Nevertheless, the effects of Vietnam spending were not what one might expect. Counterintuitively, expenditure on advanced weapons R&D and production declined amidst a sustained resource reallocation 'from major weapons systems to expenditure on ordnance and manpower' (Rosen, 1973, 18; Fox, 1974).

Of course, at the comprehensive level military expenditure rose. After falling 9% in 1965, real military expenditure increased an average 14% per annum between 1966 and 1970. As a percentage of GDP, however, real military expenditure declined, averaging 8% in this period as compared with 9% in the prior, and 10% during the Korean War. At the level of procurement real expenditure fell 24% in 1965, but moved up from there, averaging a 3.9% growth rate between 1965 and 1970. Surprisingly, procurement as a percentage of total

military expenditure declined in this hot war period as compared with the former cold war period, falling from 28.4% to 26.2%. As we come to RDT&E spending, the fact of falling expenditures on advanced weapons development during the Vietnam War becomes clear: real RDT&E expenditures fell 13% in 1965 and continued to fall, albeit at a slower pace, posting an average 3% per annum decline between 1966 and 1970. As a percentage of total military expenditure RDT&E also decreased, moving from 12.8% of total military expenditure in 1964 to 8.8% of the total in 1970. DARPA expenditure figures similarly indicate falling defense spending on advanced weapons R&D in this period – the DARPA budget was trimmed slightly starting in 1965, and then slashed between 1967 and 1969, falling from $290 million to $210 million, a decrease of nearly 30% (although as we will see below, IPTO spending continued to rise) (Norberg and O'Neil, 1996, 22). Real NASA expenditures also decreased in this period, falling an average 4.2% per annum between 1965 and 1970; the bulk of this decline occurred after 1966, with real per annum NASA expenditure falling 14.6% on average from 1967 through 1970. Moreover, the percentage share of military contracts dedicated to advanced missile and space expenditures fell from 19% of the total value in 1964, to 15% in 1965, and then to 10% in 1966 (Weidenbaum, 1973, 256).[242] Indeed, Galloway (1973: 282) estimates the share of extraordinary Vietnam expenditures expressly related to advanced weapons development and procurement at a meager .67%. Additionally, in 1963 the DOD

[242] The share going to 'conventional armaments' increased from 6% in 1965 to 15% in 1968.

began recording procurement expenditures at a more detailed level of categorization, and these figures too reveal falling defense expenditures in our technological sectors of interest, with the most rapid declines occurring between 1967 and 1970; defense expenditure on 'electrical and electronic equipment' fell from $620 million in 1967 to $350 million in 1970, a decline of 44%. Defense expenditure on 'communications equipment' fell from $390 million in 1967 to $190 million in 1970, a decline of over 50% (Boies, 1994, 149-150).

The qualitative data regarding the economic environment for advanced weapons defense contractors accords with this statistical data quite well. Profits and stock valuations for the major advanced weapons contractors compressed between 1965 and 1970. Four years into the war, many missile and aerospace contractors were experiencing financial decay, and the government had to bail out Lockheed Corporation in order to keep it from collapsing (Rosen, 1973, 17-18; Fox, 1974, 44). As a consequence, during the late 1960s, a 'number of leading defense contractors began to seek out business in the private sector', with 17 of the top 25 prime advanced weapons defense contractors reducing their dependence on defense contracting revenue (Fox, 1974, 47). After 1965, layoffs of engineers and technicians from defense contractors 'reached into the tens of thousands', with the defense electronics firms around Route 128 in MA and Santa Clara Valley in Northern CA being hit particularly hard (Bolton, 1966, 93-8; Hughes, 1998, 185). Additionally, in 1966 approximately 40% of the nation's engineering manpower

was working on defense-related efforts, down from around 50% just three years earlier (Berkowitz, 1970, 1).

In regards to the federal budget, overall military expenditure is what mattered, and in this period, as discussed, it increased. Non-defense expenditure also increased, averaging a 6.9% per annum growth rate in real terms between 1965 and 1970. Real total revenue also rose in this period (by an average 5.8%), but not as much as it needed to in order to avoid deficits, which averaged $26.2 billion per annum in real terms ($6.42 billion nominally), or 4% of total expenditure. Real personal income tax revenue rose by 7.7% per annum on average; real corporate tax revenue actually declined an average 6.9% per annum; real social insurance tax revenue rose by 8.7% per annum on average; and real excise tax revenue declined slightly at a 1.2% per annum average rate. Thus the tax structure became slightly more regressive in this period after also becoming more regressive in the last period. Although gross federal debt rose by 21% to $381 billion in nominal terms between 1965 and 1970, it fell by 3.1% in real terms; a consequence of building inflation. In 1965 the CPI rose a modest 1.6%; by 1970 it was rising at a 5.7% per annum clip. The percentage of public debt held by the Federal Reserve also accumulated rapidly in this period, moving from a 15% share of total public debt in 1965, to a 20% share of total public debt in 1970, which marked a new record for this statistic. The Fed was clearly monetizing debt with abandon; M1 rose an average 5% per annum between 1965 and 1970, whereas it only had risen 2.8% per annum in the prior period. Capacity utilization also mounted in this period, hitting

a blistering 91.1% in 1966 and averaging 87% per annum between 1965 and 1970; up from an 81.6% average in the prior period. In other words, slack in the economy was briskly taken up during the Vietnam War while the Fed remained overly friendly.

However, the debilitating economic consequences inevitably brought on by such policies would not be felt until the early 1970's. Thus, in this period, with real GDP rising an average 4% per annum, the tax structure remaining relatively regressive, and the Fed monetizing debt, the Vietnam War era provided a halcyon environment for rapid technological diffusion; which was a good and important thing given the ongoing cuts in advanced weapons related defense expenditure. The 'military expenditure impetus to mode of development shifts theory' would therefore predict a rapid rate of commercial diffusion for defense-related GPTs in our sectors of interest between 1965 and 1970, and this is indeed what occurred, as will now be shown.

THE SEMICONDUCTOR SECTOR – 1965-1970:

As compared with the revolutionary changes that took place in the semiconductor sector in the early 1960s, developments in the semiconductor sector from 1965 to 1970 seem serene. After 1965, overcapacity for transistor manufacture increased; a consequence of waning advanced weapons expenditures no doubt. With transistor prices falling, the commercial capital goods producing sectors in America picked up their pace of transistor adoption; high-end transistors

now rapidly diffused into various aspects of automobile, television, and appliance production (Riordan and Hoddeson, 1997, 7; Braun and Macdonald, 1982, 68; 80-83; Helpman and Trajtenberg, 1998, 115).

Surprisingly, ICs also began to diffuse widely into the commercial sphere after1965, even though ICs had only been in existence for less than half a decade. Between 1964 and 1965, the share of the IC market going to military uses decreased from 85% to 74%. The following year, the share of the IC market going to military uses decreased to 53%. From there the military consumed ever less of the IC market, with its share declining to 47% in 1967, to 38% in 1969, and then to under 30% thereafter. On the commercial side of the ledger, the value of ICs used in consumer products increased by a factor of 17 between 1965 and 1969, rising from just under $1million in 1965 to $16.9 million in 1969. Over the same years, the value of ICs applied to industrial uses increased by a factor of 8, rising from $8.6 million to $67.8 million. This swift commercial diffusion was no doubt aided by an astounding 92% decline in price per IC unit; again an effect of overcapacity resulting from intense, and then waning, advanced weapons expenditures (DeGrasse, 1983, 108; Braun and Macdonald, 1982, 68, 98).

Recall that such widespread diffusion was not witnessed in the transistor industry 5 to 10 years after the advent of the transistor. One cannot fail to notice that a major difference between that period, 1954-1959, and this period, 1965-1970, was that in the prior era, expenditure on advanced weapons R&D and production was rising briskly, and in this period it was falling somewhat precipitously. Given

that high-end transistor diffusion also picked up pace in this period, declining advanced weapons expenditures seems a likely culprit accounting for the notable disparity in diffusion rates for transistors in the mid-late 1950s on the one hand, and ICs in the mid-late 1960s on the other.

THE COMPUTER SECTOR – 1965-1970:

The computer sector was anything but serene between 1965 and 1970. It is in this period too that computers began broadly diffusing into the commercial marketplace, but they did so with a boom![243] After 1965, "with many real-time command and control systems already in place, the DOD dramatically reduced spending on such systems… this left systems integrators with the problem of turning swords into ploughshares." As the DOD exited the market, mainframes and real-time systems rapidly declined in price, as did the expert services commercial companies required in order to integrate computer systems into their business routines. A few of the major prime defense contractor systems integrators of the 1950s and early 1960s (such as TRW) successfully migrated to the emerging software and computing industry after 1965, where they squarely focused on commercial business applications such as inventory control, sales analysis, cost analysis, payroll, trust accounting, and computer simulation. A handful of specialized computer and software manufacturers previously providing components for defense systems also successfully pushed outwards into the commercial market;

[243] From 1966 to 1968 the stock prices of computer and software companies soared, in what came to be termed the 'go-go' era of investing (Ceruzzi, 1998, 158-159).

in some sense because they had no choice – 'maintaining an idle engineering team was incredibly expensive, but letting good innovative engineers go had a disastrous effect on morale' (Campbell-Kelly, 2003, 49-52; 71-72; Norberg, 2002, 175).[244]

IBM proved most successful at 'turning swords into ploughshares' during this period. The introduction of the IBM System / 360 mainframe line of computers in 1965 is paradigmatic of IBM's shifting focus from defense markets to commercial markets during the Vietnam era. By 1965 IBM had been developing newer and better 'generations' of computer lines for nearly 15 years. With every new generation, users (who were of course for the most part working on defense-related projects) had complained to IBM about the labor required to transition to the new generation, primarily because software programs written for one machine were usually not usable on the next generation machines. IBM sought to remedy this situation by introducing the System / 360: a broad line of compatible computers spanning a large range of performances capable of running software applications written for other machines (Flamm, 1988, 97).

Clearly the IBM System / 360 mainframe line was aimed at the civilian market, as indicated by its wide range of performance specs.[245] New users could start on a small less powerful machine and then move up in the line as their needs and knowledge grew; whereas the military typically utilized only the highest

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[244] Recall that the British case also exhibited commercial diffusion driven by declining prices amid foregone capital investment (in that case fixed rather than human) during defense expenditure draw-downs.

[245] When first introduced the System / 360 line had a 25:1 performance range (Flamm, 1988, 97-99).

performing machines. Although the System / 360 was aimed at the commercial user, the advanced architectural features that powered the line drew heavily upon technologies developed at IBM during prior defense projects, especially Project STRETCH. Each of the many innovations listed in the section devoted to STRETCH in the chapter covering the 1954-1959 interval appeared in the System / 360, making 360 mainframes both unique and incredibly cutting edge. This "basic architecture served as the anchor for IBM's product line into the 1990s" (Ceruzzi, 1998, 145). Additionally, System / 360 processors were built using circuit modules rather than printed circuit boards; as previously described, circuit modules were pioneered during the Army's Micromodule Program.[246] It should also be noted that the lead design engineers for the System / 360, such as Gene Amdahl and Fred Brooks, were former WWII computer and radar pioneers who came to IBM in the postwar era, and had worked on defense-related projects like SAGE and STRECTCH throughout the 1950s and early 1960s (Ceruzzi, 1998, 145-153, 190; Flamm, 1988, 91-97; Campbell-Kelly and Aspray, 2004, 178).

System / 360 mainframes sold exceedingly well; sales numbers quickly surpassed the cumulative number of mainframes IBM had previously installed in the US. Between 1965 and 1970 IBM's yearly revenue increased by 150% to $7.5 billion. Also, in this period IBM pushed into foreign markets as it searched for

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[246] Another important innovation for the 360 line involved microprogramming a read only memory (ROM) built into the processor. This ROM activated the compatibility aspects of the line. This technique had its initial roots in a Bell Labs computer produced for the Nike missile program in the early 1950s, but went through a number of non-military developments before appearing in the System 360 (Ceruzzi, 1998, 148).

widening commercial revenues.[247] By 1967, however it began to appear that IBM may have pushed too hard, for "the success of the 360 threatened the company's existence almost as much as a failure might have" (Ceruzzi, 1998, 144-146). IBM was forced to rapidly expand its computer manufacturing engineering corps and facilities, thus taking up much of the slack created when the DOD left the market. In fact, in 1967 IBM built a large new manufacturing and R&D facility in San Jose California, a site hit particularly hard by the decline in advanced weapons expenditures (Ceruzzi, 1998, 160; Bolton, 1966, 93-8; Hughes, 1998, 185). And IBM was not the only firm taking up engineering labor market slack, for the compatibility aspect of the new line spawned many new commercial startups in the computer space. Numerous 'plug-compatible' startups, such as Memorex and Ampex, which sold IBM compatible peripherals, sprung up; while established computer manufacturers expanded by developing computers that could read IBM System / 360 software applications (Ceruzzi, 1998, 163-164; 191).

Most importantly, the System / 360 inspired explosive growth throughout the budding software industry.[248] Since the same software applications could now be run on a series of different mainframes, a 'corporate software products' sector suddenly appeared. Programmers exiting from defense contractors and defense-related projects relished and understood the opportunities created by the System /

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[247] "This shift outward into international operations by IBM was followed by its competitors and typified a more general shift toward foreign markets for US computer producers" (Flamm, 1988, 101). Each of which was also experiencing declining revenues in its core defense businesses I might add.

[248] In 1960 software market revenues totaled $125 million; in 1970, $1.9 billion (Campbell-Kelly, 2003, 63).

360. Thus, the defense industry exodus, in feedback loop fashion, provided the systems developers, integrators, managers, and programmers for a bevy of new VC financed software firms. For example, two well-known and seasoned aerospace contracting engineers, Fletcher Jones (who had started SHARE) and Roy Nutt (who had helped create FORTRAN), began Computer Sciences Corporation, which in 1966 became the first software company listed on the NYSE, and in 1969 took over still defense dependent SDC (the software contractor for SAGE) to become the largest software firm in the world.[249] Similarly, seven programmers left prime contractor Sperry Rand to form Applied Data Research, which introduced its Autoflow flow-chart program in 1965; Autoflow became one of the first software packages to sell in the multiple thousands. Additionally, Walter F. Bauer and Werner F. Frank left defense contractor TRW's advanced weapons systems integration computing division to form Informatics. In 1965 Informatics introduced Mark IV, the first ever data-base management software package, which quickly became the first software product to sell one million copies. The most amusing story to devolve from this period of declining advanced weapons expenditure also involves TRW: in the mid 1960s, with its defense-related revenue declining precipitously, TRW began branching into commercial work. Along with developing a database of credit information, TRW contracted with Bonneville Power to create a software program that would manage the flow of water through a series of dams on the Columbia River. John Norton, who had worked on the

[249] See footnote 215 in the 1954-1959 chapter for more on SHARE, FORTRAN, and SDC.

Apollo program, and was a legend among programmers for the quality of his work, was put in charge of the project. In the summer of 1969, Norton took two young unpaid but enthusiastic summering interns under his wing; they were none other than Bill Gates and Paul Allen (Campbell-Kelly, 2003, 52-58, 65-72, 145, 204; Ruttan, 2006, 108; Flamm, 1988, 98; Ceruzzi, 1998, 168-170, 235).

Despite the booming mainframe market of the 'go-go' late 1960s, major mainframe company boardrooms buzzed with concerned. ICs had moved surprisingly rapidly down the learning curve; were the major mainframe companies missing the next technological boat? It turns out they were, for the mid to late 1960s witnessed the rise and rapid proliferation of the minicomputer. As the name implies, minicomputers were significantly smaller and cheaper than mainframes, although, owing to the use of ICs in their processors, they still packed a powerful computing punch. The use of minicomputers therefore offered an alternative route around the batch processing bottleneck; for the first time advanced users could interact directly and personally with a small machine. These desk-sized $10,000-$50,000 computers were not the desktop $2,000-$3,000 personal computers we all came to know and love in the 1980s, but they were an important step away from room sized $150,000-$300,000 mainframe computers (Ceruzzi, 1998, 124, 206; Campbell-Kelly and Aspray, 2004, 198-199).

In the words of Campbell Kelly and Aspray (2004: 199) "The minicomputer did not come from the established mainframe computer industry... but from Project Whirlwind and MIT – via the electronics industry." They take this view because

the company that led the world into the IC driven minicomputer age was Digital Equipment Corporation (DEC). DEC was founded by Kenneth Olsen. Olsen, as a graduate student at MIT, had intensively worked on Jay Forrester's Whirlwind computer and later consulted for IBM on the SAGE project. He then returned to MIT's Lincoln Labs where he oversaw the TX-0 computer development project, a DOD funded program that sought to take the Whirlwind computer to the next level. The TX-0 was expressly designed to be more interactive and personal than the Whirlwind. In 1958, Olsen believed the timing was right to launch a company that would commercialize the interactive personalized architecture of the TX-0. Having received startup venture capital from the world's first venture capital fund, American Research and Development Corporation (ARDC),[250] Olsen and his partner, Harlan Anderson, set up shop in an abandoned woolen mill along Route 128 in Maynard MA. Olsen and Anderson mined Lincoln Labs and MIT for DEC's engineering corps, and in 1959 DEC introduced the PDP-1, which incorporated many of the TX-0's architectural, software, operating system, and circuit innovations. The system priced for $120,000 and sold poorly. Over the next five years DEC continued to mine talent from Lincoln Labs, and continued to introduce new generations of TX-0 type computers, some featuring IC processors.

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[250] ARDC was set up in 1946 by Harvard business school professor Georges Doriot, whose goal was to find a way to commercialize the scientific and technical innovations he had observed during WWII as an officer in the US Army. Ceruzzi (1998, 305) asserts that Doriot and DEC were the first to establish the defining characteristic of the IT revolution: 'startups formed with venture capital' (Ceruzzi, 1998, 305).

Each of these computers also sold poorly (Ceruzzi, 1998, 127-129; Flamm, 1988, 127).

Then, in 1964 Fairchild and TI began offering 'dual inline' IC chips, which were small, easy to install, easy to design with, and rugged. In 1965, as the DOD began exiting the high-end IC market, these new chips began rapidly descending in price. Consequently, DEC's engineers, many of which had worked with similar chips recently at Lincoln Labs, were able to design the PDP-8 – a computer that occupied 8 cubic feet of volume, weighed 250 pounds, and cost $18,000. The PDP-8, introduced in 1966, was an immediate success. Hundreds sold, and with the price dropping to $10,000 in 1968, PDP-8s began to sell in the thousands (Ceruzzi, 1998, 191-3; Campbell-Kelly and Aspray, 2004, 201; Flamm, 1988, 128).

In 1969 DEC introduced the PDP-11, which pushed the 'direct access computing' paradigm even further. Most mainframes at this time, because of their extreme cost, were rented from manufacturers; which meant that users could not tailor the machine to their personal liking. Drawing on an architecture developed for the Whirlwind and improved for the TX-0, the PDP-11 came with a standardized 56 line 'bus' architecture; which enabled users to add peripherals, extra processors, and more memory as they wished, as long as the add-ons conformed to the bus standard. The PDP-11 also had a very powerful IC processor that 'opened up minicomputers to a host of applications that had previously been the domain of mainframe computers' (Ceruzzi, 1998, 198-200).

The order of floods DEC received for the PDP-8, which quickly reached the

50,000 units sold mark, and the PDP-11, which quickly reached the 150,000 units sold mark, might have overwhelmed the tiny company. Instead DEC quickly expanded,[251] drawing engineers from the shrinking advanced weapons development industry, thus gaining labor, talent, and knowledge at a more than fair price; human capital feedback from the defense sector into the commercial sector was clearly gathering strength and pace. DEC managed to stay at the front of the minicomputer market by continually drawing upon the knowledge and skills of the MIT research community along with the wider defense industry (Ceruzzi, 1998, 129-137). The minicomputer sector did, however, rapidly become quite competitive. "Between 1968 and 1972, around 100 new companies or divisions of established companies offered minicomputers on the commercial market" (Ceruzzi, 1998, 191). Many of the leading minicomputer firms that emerged were also rooted in the history of advanced weapons defense expenditure, such as DEC's main competitors SDS, Wang Laboratories Inc., Hewlett Packard (HP), and 3-C, to name a few.[252] Still DEC looms as the revolutionizing organization; "It is impossible to understand the state of computing at the end of the 20th century without understanding computing's debt to the engineers at (DEC)" (Ceruzzi, 1998, 139). Tellingly, when

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[251] In 1965 DEC had revenues of $15 million and 876 employees; by 1970 DEC revenues had grown 9 fold to $135 million and employment had increased nearly seven fold to 5800 (Cerruzi, 1998).

[252] For a corporate history of SDS that highlights its extensive defense roots see Flamm, 1988, 129-30; and Ceruzzi, 1998, 165-7. Wang Laboratories Inc., was founded by An Wang, who had worked on the Mark Series in Howard Aiken's defense funded computer laboratory in the late 1940s and 1950s (Flamm, 1988, 131). HP had been an important defense contractor since 1952 and in 1968 HP received over $100 million in defense contracting revenue. In fact, David Packard served as the DOD Deputy Secretary from 1969 to 1971 (Lens, 1970, 41; Kovacic, 1990, 85). 3-C was founded in 1954 by Raytheon engineers who had been working on the NSA's top-secret 'Nomad' project. Nomad technology eventually found its way into 3-C's minicomputers (Flamm, 1988, 114).

Olsen sanctioned the writing of DEC's published corporate history in 1992, he made sure that the story did not start with Kenneth Olsen, nor the old woolen mill; DEC's corporate history begins with "MIT and the Whirlwind Tradition" (Ceruzzi, 1998, 140).

Before we move on to developments in computer networking during the Vietnam period, its important to note that defense expenditure on computer system R&D did decline between 1965 and 1970, but it did not entirely go away. Two incredibly important innovations that came out of a defense funded project in this period must be mentioned. The use of IC chips for RAM was pioneered on DARPA's ILLIAC IV supercomputer project in the late 1960s; the DRAM (Dynamic Random Access Memory) chips were designed and produced by Fairchild for DARPA. The use of IC ECL logic in computer processors was also invented in the late 1960s during the ILLIAC IV effort. The former would come into widespread use in the 1970s, the latter in the 1980s. Nevertheless, many of the other architectural innovations pioneered on the ILLIAC IV supercomputer project, such as massive parallel processing, have yet to widely diffuse into the commercial sphere. This then is indicative of a rising divide between the aims of defense-related computing R&D, and the direction of progress in the commercial market for computers in the late 1960s; a fissure that would continue to grow in the following decades (Ceruzzi, 1998, 161-162; Flamm, 1988, 117-118).

THE COMPUTER NETWORKING SECTOR – 1965-1970:

As previously alluded to, the IPTO's funding more than doubled between 1965 and 1970, rising to $23 million per annum (Norberg and O'Neill, 1996, 55; NRC, 1999, Chapter 4). With the still well-funded IPTO leading the charge towards networked computer systems, and the underlying enabling network technologies still immature, the Vietnam Era, as would be expected, was primarily a time of development, rather than diffusion, in the world of computer networking. During this period the IPTO continued its efforts to improve its Project MAC time-sharing technologies. New companies were brought into the project, such as Bolt, Beranek, and Newman (BBN), and new systems were designed around DEC computers.[253] In fact, at this time BBN designed two important time-sharing operating systems for the DEC PDP-10 – TOPS-10 and TENEX – under DARPA contract.[254] Meanwhile, the Project MAC system at MIT was becoming heavily overloaded. DARPA therefore initiated a program to build a larger time-sharing computer system. Called Project Multics (Multiplexed Information and Computing Service), this system was intended to serve hundreds of users at once. Such a task proved more difficult than expected and costs quickly swelled to $7 million (Campbell-Kelly and Aspray, 2004, 192; Ceruzzi, 1998, 156, 210, 352).

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[253] Interestingly, the robust economic environment for diffusion during the 'go-go' '60s did spur a number of companies to try their hand at commercializing immature time-sharing technologies. 99% of these companies failed. The main problem for time-sharing companies in this era was the faulty, slow, and unreliable nature of the technology. Additionally, programs were not well personalized (Ceruzzi, 1998, 156-158, 259; Abbate, 1999, 26; Campbell-Kelly and Aspray, 2004, 195-6).

[254] These operating systems were direct descendants of the original TX-0 system and will figure into the narrative on PC operating systems later (Ceruzzi, 2002, 118).

The Multics system was being designed around a GE computer, and Bell Labs was brought in by DARPA to write the software. By 1969 the Multics project was becoming convoluted and success seemed far off, so Bell Labs, which was also dissatisfied with the GE mainframe, opted to exit the project. When it did so, two Bell researchers working on Multics, Ken Thompson and Dennis Ritchie, lost their access to the massive GE mainframe they had been working on. Not willing to let their research go, Thompson and Ritchie opted to design a simpler version of the Multics OS that would be able to run on the DEC minicomputer they did have access to. They termed this diminished Multics OS, UNIX. UNIX was absolutely brilliant in its simplicity; it was a straightforward and uncomplicated OS that made file sharing over networks both possible and easy. UNIX was written in a new programming language called C, which likewise was developed by Richie and Thompson during the Multics project at Bell. C allowed UNIX and UNIX based programs to be portable to any type of computer system. Both UNIX and C would eventually become closely associated with the Internet, and the software that powers it. But first, UNIX had to spread. As a result of an anti-trust case, AT&T had agreed not to engage in commercial computing activities, and thus could not sell UNIX for a profit. Richie and Thompson were therefore free to become veritable Johnny Appleseeds; they happily distributed UNIX and its source code to universities around the nation. At certain universities, DARPA funding and graduate research combined to yield ever better versions of UNIX. The most famous version was designed by Bill Joy at UC Berkeley; Joy's research on UNIX

was entirely funded by DARPA. Bill Joy would later use this version of UNIX as the basis for his new company's networked workstations. That new company would be Sun Microsystems, and we will return that story in a subsequent chapter (Ceruzzi, 1998, 106, 156-7, 282-283; Campbell-Kelly, 2003, 143; Flamm, 1988, 121-2; Campbell-Kelly and Aspray, 2004, 192).

Of course, before UNIX, Bill Joy, and Sun Microsystems could become associated with the Internet, the Internet had to be created, and it is to that narrative we now return. After Licklider's departure in 1965, Robert W. Taylor, a former aerospace and NASA engineer, was appointed head of the IPTO. In 1966 Taylor had three time-sharing terminals in his office, each connected to a different mainframe computer. Frustrated by his inability to transfer files between terminals, Taylor landed on the idea of connecting mainframes in order to build giant computer 'metacommunities.' Later that year, Taylor proposed a project that would interconnect mainframes at 17 DARPA laboratories around the nation. Clearly such a network might one day have C3 applications, so the DOD gladly funded Taylor's 'ARPANET' project with an initial sum of $500,000. Lawrence Roberts, who had recently designed a two-way computer link between Lincoln Labs and the RAND Corporation, was appointed project manager (Hughes, 1998, 268-70; Abbate, 1999, 44-6; Ruttan, 2006, 115-117).

Roberts immediately began considering different architectures for the

network. In 1967 he encountered Baran's packet-switching idea,[255] was intrigued, and decided to try to implement the cutting-edge system:

> "The decision to employ packet-switching on such a large scale reflected DARPA's commitment to high risk research: if it worked, the payoff would be not only greater efficiency and ruggedness in the ARPANET itself, but also a significant advance in computer scientists' understanding of network properties and techniques. The DARPA managers could afford (indeed, had a mandate) to think extravagantly – to aim for the highest payoff rather than the safest investment" (Abbate, 1999, 39).

Roberts subsequently asked Paul Baran to consult on the ARPANET project (now being generously funded), which aimed to create a 15 node packet-switched network over a series of 56k bandwidth phone lines (to be provided by Bell Labs) (Abbate, 1999, 38).[256]

The first hurdle encountered by the ARPANET team was the inability of various mainframes to communicate with one another; each had been built with unique language implementations and architectures. The initial solution to this problem was proposed by Wesley Clark, who had worked on Whirlwind and Project SAGE. Rather than having the mainframes connect directly, he suggested

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[255] This knowledge came by way of a British researcher, Donald Davies. Davies designed a message block system a couple of years after Baran's research had circulated; Davies is actually responsible for the term 'packet-switching.' In 1966 Davies was able to convince the British National Physics Laboratory to build a packet-switching network. Interestingly however, because of inadequate funding, the lack of any real customer, and the unimportance of survivability to the NPL network, Davies was only able to construct a one node system (utilizing a Honeywell 516 computer). This system proved that digital messages could be transmitted in packets, but did nothing to prove that many various message packets could be successfully routed across a highly decentralized and robust communications network. If anything, the Davies experiment suggests that military expenditure and national security needs were indispensable to the formation of the first widely distributed packet-switched network (Abbate, 1999, 40-47; Hughes, 1998, 275). "It was only the commitment of very large financial and technical resources that were available to DARPA that assured the success of the packet-switching technology" (Ruttan, 2006, 117).

[256] "By the late 1960s, computer related projects funded by DARPA, including ARPANET, cost in the vicinity of $30 million annually" (Hughes, 1998, 258).

creating a 'layer' of inter-networked minicomputers that would do the communicating.[257] Each mainframe would connect to its own dedicated minicomputer, termed an Interface Message Processor (IMP), and the IMPs would then be networked together. In this way, all the mainframes would not have to inter-communicate; each would just have to be able to communicate with its own IMP, and then the IMPs in the IMP layer would be responsible for creating packets, distributing packets through the network, and unpacking packets once they reached their destination (Abbate, 1999, 48-53; Hughes, 1998, 271-6).

In the summer of 1968 the IPTO held a project design competition to find an IMP developer. 12 firms bid on the project, and BBN (the firm where Licklider had left from to form the IPTO, and returned to in 1965) won the contract. BBN believed the ARPANET contract represented a chance to get a leg-up in the emerging business of computer networking; and they were correct as BBN in later years generated considerable revenue from selling network services. BBN chose Robert Kahn, a Lincoln Labs alum who had worked on Project MAC, to head up the IMP project. Kahn chose a handful of other Lincoln Labs alumni to work on the project; each had previously worked on defense-related efforts at the lab.[258] A year later BBN had successfully developed IMPs capable of packing, routing, and

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[257] This was the first use of layering as applied to computer networks. Were it not for DARPA's ingenious use of layering, meta-networks would never have achieved the flexibility necessary to allow diverse forms of local networks to come together to form the Internet (Abbate, 1999, 53).

[258] Frank Heart, Severo Ornstein, David Walden, and William Crowther of BBN's IMP team had all worked at Lincoln Labs where they acquired experience with real-time defense systems. For example, Heart had worked on SAGE (Abbate, 1999, 57; Hughes, 1998, 278-283).

unpacking digital messages (Hughes, 1998, 276-283; Abbate, 1999, 57-70; Ruttan, 2006, 118).

By December of 1969, BBN had installed and connected four IMPs (also known as nodes) at UCLA, UCSB, the University of Utah, and BBN. Now the next hurdle loomed – how would the mainframes (also known as hosts) communicate with the IMPs? Roberts decided that the first step was to develop a standard host protocol, 'a general purpose set of rules for handling a network connection', and from there each mainframe would have to be adjusted to accept this protocol. "Writing the host to host protocol program proved to be one of the most difficult software problems encountered in deploying ARPANET" (Hughes, 1998, 284). UCLA Professor Leonard Kleinrock, who had also worked at Lincoln Labs on defense-related projects in the 1950s, led the effort; his team included a number of soon to be famous graduate students, notably Vinton Cerf[259] and Stephen Crocker (who are often credited with 'inventing' the Internet). The aforementioned Engelbart (the inventor of the mouse and the first windows based GUI) also worked closely on the project. The host protocol they developed, termed Network Control Protocol (NCP), allowed hosts to communicate with and transfer files across the IMP layer. By August of 1971, 15 DARPA funded sites had installed BBN IMPs, and had also implemented NCP; ARPANET had come to life (Abbate, 1999, 59-68; Hughes, 1998, 284-289).

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[259] Cerf later guided IBM into the network age (Hughes, 1998, 295).

CHAPTER 16: DÉTENTE – 1971-1977

Détente was a mutual decrease in Cold War tension starting around 1971 and ending after 1977.[260] Many different political and economic realities contributed to this improved environment for US – USSR cooperation; the recent Vietnam debacle being foremost (Ward and Davis, 1992, 96). Again, what matters here is the effect Détente had upon American military expenditure, and how American defense spending in turn affected the informational GPTs in our sectors of interest.

Not surprisingly, aggregate military expenditure, procurement expenditure, and RDT&E expenditure all fell during this period. Per annum real military expenditure was 16% lower during Détente than it was during the Vietnam War era on average (to $240.4 billion); while military expenditure as a percentage of GDP fell from 7% in 1971 to 4.8% in 1977. Real average per annum procurement expenditure was 36.4% lower in this period as compared with the Vietnam War era (to $48.5 billion), and real per annum RDT&E expenditure was 14.4% lower on average (to $24.3 billion) . Average per annum NASA expenditures plummeted by 50% in real terms during this period as compared with the prior (to $10 billion). DARPA expenditures on the other hand stabilized around $225 million ($596 million in 2000 dollars) between 1971 and 1977; while IPTO expenditures continued to rise moderately.

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[260] As can be seen in Azar's (1980) Conflict and Peace Data Bank, which quantifies the amount of 'cooperative action' and the amount of 'conflict action' undertaken by the two superpowers between 1948 and 1980 (Ward and Davis, 1992, 96).

The DARPA expenditure figures however mask an important change in the way DARPA was required to spend its appropriations. This modification was codified in the 'Mansfield Amendment', an addendum to the 1970 Military Procurement Authorization Bill inserted by Senator Mike Mansfield. It read: 'none of the defense funds authorized... may be used to carry out any research project or study unless such a study has a direct and apparent relationship to a specific military function or operation.' As a consequence, DOD funding for mathematics and computer science research reached a two-decade low in 1975, and DARPA narrowed its expenditure to projects either obviously connected to defense in an immediate way or considered as potentially critical to future defense operations (Ceruzzi, 1998, 258-9; DeLanda, 1991, 222; NRC, 1999).

Additionally, the rapid decline in defense expenditure brought the proportion of the nation's engineering manpower dedicated to defense-related programs down to approximately 30%, as compared with around 40% during the Vietnam era. Defense sector employment dropped by a third, while the jobless rate amongst engineers rose to 10% in 1971; defense-contractor cutbacks 'affected the thousands of small and intermediate firms as well as the giants' (Fox, 1974, 33; 65-67; Dumas, 1984, 142).

As defense expenditure fell, non-defense expenditure rose swiftly in this period, rising an average 8.5% per annum in real terms. Revenue did not keep up, as it rose 2.7% per annum in real terms on average; with the two progressive measures of taxation now accounting for 60% of total revenue, down from 65% in

the prior period, thus indicating a more regressive tax structure. In a normal economic environment, such a tax structure would suggest an improved environment for technological diffusion in the US, but the 1970s were far from a normal economic environment. Real gross federal debt rose at the fastest pace since WWII, leaping 20% between 1971 and 1977, to $1.65 trillion ($706 billion nominally). The Fed also continued to monetize debt, increasing its holding of public debt at an average 8.9% annual pace. Finally, the consequences of rising debt and increased money supply amid decreasing slack came home to roost in the form of a 'great inflation' (Malkin, 1987; Stabile and Cantor, 1991).[261] The CPI rose an average 6.6% from 1971 to 1977, hitting 11% in 1974. Interest rates were carried higher in the CPI's wake with 10 year treasuries averaging a 7.1% yield in this period as compared with a 5.6% yield in the prior period.[262]

As discussed in the British case and throughout the dissertation, rapidly rising inflation and interest rates result in declining investment levels, which thus negates many of the positive effects in regards to diffusion that should be expected in an environment exhibiting decreasing military expenditures and an increasingly

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[261] Undoubtedly the 1974 oil shock contributed to the great inflation. But to say it caused it would be overstating the case. Inflation had been building for a decade prior to the 1974 shock owing to the economic policies previously described. OPEC tested the market with a series of successful price increases before attempting the politically driven 1973 embargo. Given the tenuous nature of OPEC solidarity, it seems implausible that the embargo would have held were it not for the inflationary environment which facilitated a panic response by Western nations, rather than a measured political response. Moreover, had Bretton Woods still existed, the need for balancing international accounts would have greatly limited the inflationary impacts of oil. Once OPEC nations realized that the liquidity existed for much higher oil prices, the embargo held. The same logic applies to the 1979 oil crunch with the Iranian Revolution now playing the role of political matchstick lighting up the already inflationary scenario (Malkin, 1987, 160-6).

[262] Interest rates surely would have risen more than this had foreigners not rapidly increased their holding of American debt instruments. In 1970 foreigners held 5% of American public debt; in 1977 17.4%.

regressive tax structure. And although commercial diffusion of defense-related GPTs did occur in the United States, which was the center of the great inflation, it began to occur elsewhere better. For example, between 1970 and 1975 the US global share of technology intensive exports fell from 27% to 24.5%, the first decline in the post WWII era (DiFilippo, 1990). A similar pattern emerged in the increasingly international and competitive semiconductor industry during the years 1971 to 1977, to which we now turn.

THE SEMICONDUCTOR SECTOR – 1971-1977:

Integrated circuits continued to rapidly feed into the non-defense oriented world after 1970. In 1974 the defense share of the IC market fell to 20% (from 38% in 1969); by 1978 the defense share had fallen to 10%. Meanwhile the share of the IC market going to industrial end uses increased from 16% in 1969 to 30% in 1974; the share going to consumer end uses increased from 4% in 1969 to 15% in 1974. Moreover, these figures do not include the stable 35% share of the IC market that was being used in the ever more predominantly business-related computer sector (DeGrasse, 1983, 108).

Tellingly, the US began the 1970s with a wide lead in the burgeoning commercial and increasingly global semiconductor market, but this lead began to slip vis-à-vis Japan as the 1970s progressed. In 1972 the US produced 85% of combined US / Japan semiconductor output; by 1977 this percentage had declined to 68%. Decreasing US competitiveness was particularly pronounced in the newest

high growth area for ICs – computer DRAM. The US initially dominated this market, but by 1978 Japan had carved out an over 40% share of the 16K DRAM segment (Flamm, 1992, 23; 256). We will return to discuss the rise of the Japanese semiconductor industry, and the many factors that contributed to it, once the dissertation analyzes the comparative case of Japan. But before we can understand the semiconductor sector in comparative context, we must first complete the American narrative regarding the effects military expenditure had on semiconductor development and diffusion. Which brings us to the first major semiconductor sector technical breakthrough that had little if any *direct* connections to military expenditure – the invention of the microprocessor (DeGrasse, 1984, 93).

This is not to say that there are no connections between the companies that led the world into the micro-computing age and defense expenditures; it is to say that these connections are indirect and lie further back in time, with military demand now playing no role. Recall from the theory chapter of the American Case that this scenario accords well with the 'military expenditure impetus to mode of development shifts theory.' As an infrastructural GPT diffuses into the commercial sphere, demand from the deeper and more liquid commercial sector comes to overwhelm defense expenditure.[263] As a result, the infrastructural GPT begins to develop according to commercial market logic rather than defense market logic.

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[263] An informed observer noted at the time, "the sheer volume of commercial applications made it far more practical to hitch a ride by harnessing commercially available technology rather than trying to amortize high development and tooling costs over much smaller DOD procurement quantities" (Flamm, 1988, 95).

Given also that expenditure on advanced weapons procurement was declining precipitously in the 1970s, 'the military expenditure impetus to mode of development shifts theory' would predict that any new technical breakthroughs in the commercially maturing 1970s semiconductor sector would have less to do with defense and more to do with the building commercial mode of development shift, as was the case with the microprocessor.

The microprocessor is a general purpose digital computer on a chip. Prior to the advent of the microprocessor, a number of IC chips were interconnected to create a system capable of general purpose processing; with the microprocessor, an entire general purpose processing system became embedded on one chip. The microprocessor was invented at a leading American DRAM firm, Intel, in 1971. Intel Corporation was a direct descendant of the aforementioned defense-related Fairchild Semiconductor. Recall that Fairchild manufactured the first DRAM chips used in DARPA's ILLIAC IV project. Fairchild was also the lead IC manufacturer for NASA's Apollo program. With NASA's R&D expenditures on Apollo declining sharply after 1967, Fairchild burst like a spore sack fertilizing Santa Clara Valley. By the early 1970s some 41 VC financed 'Silicon Valley' companies had been started by former Fairchild employees. Two such employees, Robert Noyce (the noted inventor of the IC) and Gordon Moore, both of whose careers intersected

with prior defense efforts,[264] incorporated Intel in July of 1968 (Ceruzzi, 1998, 161-162; Flamm, 1988, 94, 117-118; Braun and Macdonald, 1982, 126).

Noyce and Moore brought to Intel an advanced knowledge of MOS DRAM, which they had developed at Fairchild (Ceruzzi, 1998, 198).[265] By 1970 Intel had established a commanding lead in the commercial DRAM market. In 1971, a Japanese firm, Busicom, asked Intel to build a set of specialized MOS chips for its line of calculators. Rather than build four different specialized chips, the Intel engineers on the project decided to build one general purpose MOS chip that included a tiny read only memory (ROM) which could be re-written to tailor the chip to any particular use. "The result was a set of four chips, first advertised in a trade journal in late 1971, which included 'A micro-programmable computer on a chip!' That was the 4004, on which one found all the basic registers and control functions of a tiny, general-purpose stored program computer" (Ceruzzi, 1998, 218-220; Braun and Macdonald, 1982, 106-110).

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[264] Noyce's defense-related roots were covered in the 1960-1964 Chapter. Moore, a northern Californian native, was working on defense-related projects at Johns Hopkins, before going to Shockley Semiconductor in the early 1960s: "Bored by his pointless, government funded defense research on subjects like the structure of planes, he was looking for a job back in the Bay Area" (Riordan and Hoddeson, 1997, 239).

[265] A metal oxide semiconductor (MOS) is a solid-state switch that is turned on by electrical pulses applied to an aluminum gate. Both its technical functioning and its developmental history are complex. In brief, MOS technology allows more logic elements to be placed on a chip while reducing power consumption. The lineage of MOS technology stretches back to Shockley's initial transistor research in the early 1950s. Bell Labs continued to work on the technology and reached a breakthrough in 1960. Subsequent crucial breakthroughs were achieved by RCA, working under an Air Force military contract during the Minuteman missile effort, in the early 1960s. Fairchild pioneered other important aspects of MOS technology during the mid-late 1960s, and Intel then brought together these diverse strands to form commercial DRAM (Ruttan, 2006, 100-2; Ceruzzi, 1998, 188, 217; Tirman, 1984, 92; Riordan and Hoddeson, 1997, 270-1).

There was absolutely no military demand for early microprocessors, as these chips were capable of only processing 4 bits per second, while defense applications of the day required processing at the megabit rate. This, however, didn't keep the microprocessor market from taking off. The feedback loop that had been established between the defense and commercial semiconductor sectors now morphed into a wholly commercially sustained developmental feedback mechanism. Microprocessors found their first application as 'industrial controllers' of capital goods producing machinery. By 1974, various defense-related semiconductor firms, such as TI, Motorola, and Minuteman contractor Rockwell, had 'reverse-engineered' and improved upon Intel's original design, and were now competing for market-share in this new sector.[266] None of these companies viewed the microprocessor as anything more than an industrial controller in this early period, but that would soon change. For in April of 1974 Intel introduced the 8080, the first microprocessor which approached the capabilities of low-end minicomputer CPUs. The personal computer was about to be born (Flamm, 1988, 25; Ceruzzi, 1998, 221; Braun and MacDonald, 1982, 110; Vayrynen, 1992, 76).

THE COMPUTER SECTOR – 1971-1977:

The story of the personal computer, as we know it today, begins at Xerox's

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[266] It should be noted that the decline in military expenditure in the early 1970s freed up the manpower necessary to developing and producing microprocessors, after military expenditure had already created a critical mass of chip designers. "Sufficient experience in logic design had been accumulated in the industry... (This) must be regarded as a precondition which enabled all the other circumstances to become operative" (Braun and Macdonald, 1982, 111).

Palo Alto Research Center (PARC), where a remarkable diffusion of DAPRA manpower, knowledge, and technology was propelled by the Mansfield Amendment. PARC was established by Xerox in 1970. "Its goal was to anticipate the profound changes that technology would bring to the handling of information in the business world." Fortuitously, and probably not coincidentally, PARC was set up just as the Mansfield Amendment was having its chilling effect upon DARPA related research centers. In the words of Paul Ceruzzi (1998: 259):

> "At a few select universities, those doing advance basic research on computing felt that they were at risk, because their work was almost entirely funded by the Defense Department's Advanced Research Project Agency. At that precise moment, George Pake was scouring the country's universities for people to staff Xerox PARC. He found a crop of talented and ambitious people willing to move to Palo Alto. DARPA funding had not been indiscriminate and was heavily concentrated at a few universities – MIT, Carnegie Melon, Stanford, UC Berkeley, UCLA, and the University of Utah – and researchers from nearly every one of them ended up at PARC."

The list of DARPA researchers who left their defense funded projects to go to PARC in the wake of the Mansfield Amendment is voluminous, but a few names stand out: Robert Metcalfe (whose importance will be noted in the computer networking section below), Alan Kay (who had worked with Douglas Engelbart on the project to develop the first mouse and widows based GUI), Bill English (who had also worked on the Engelbart project), and Robert Taylor (head of the IPTO and ARPANET visionary who left his IPTO post to accept a position at PARC). Each of these researchers soon came to work on a project aimed at improving, commercializing, and integrating DARPA's numerous GUI (graphics user

interface) inventions into a small 'personalized' computer.[267] The project was led by Taylor, and the computer was named the Alto; the goal was to build a desktop computer utilizing a microprocessor architecture that included a system of visual displays and iconic symbols that allowed humans to interact with a computer in a manner akin to the way a driver interacts with an automobile. By 1975 the researchers had succeeded. The Alto 'personal computer' looked similar to, and outwardly functioned, just like the desk-top computers we use today; it featured a bit mapped monitor, a mouse, icons, windows, drop-down menus, point-and-click, etc. The problem was the $18,000 dollar price tag, far too much for an individual user. There had to be a cheaper more intermediate step towards personalized computing; luckily there was (Ceruzzi, 1998, 258-262; Barnes, 2002, 139-141; NRC, 1999, Chapter 4).

The cheaper route toward personal computing takes us into an environment where military expenditure figured little in an immediate sense, although somewhat more in an indirect sense. In 1975, the January issue of Popular Electronics featured the Altair computer on the cover. The article therein contained all the information needed to build a general purpose digital computer around an Intel 8080 microprocessor for just $400. Although the Altair did not have a monitor, a GUI, a mouse, or many of the things we have now come to expect in our personal

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[267] "IPTO support for the development of interactive graphics... established an infrastructure for the computer graphics field through university-based research... These centers identified key research and technical problems, developed sample solutions, created tools and methods, and, above all, produced cadres of students, researchers, and teachers who became the leading practitioners in the field...They have also launched companies that laid the foundations for a worldwide market for computer graphics worth $40 billion in 1997" (NRC, 1999, Chapter 10).

computers, it was a programmable general purpose machine conforming to the Von Neumann architecture. The computer followed DEC's basic minicomputer format (which was originally modeled on the TX-0) and included a standard open bus system for add-ons. The article also suggested adding IBM's previously defense-induced magnetic disk storage technology, now in the form of a small floppy drive (Ceruzzi, 1998, 226-232; Campbell-Kelly, 2003, 201-207).[268]

The addition of the floppy drive set the stage for the PC software revolution. In order to get information to and from a floppy drive, the Altair computer required some sort of 'disk based operating system' (DOS). In 1975, Gary Kildall, a teacher at Naval Postgraduate School in Monterey, wrote an ingenious disk based operating system termed CP/M (Control Program for Micros). CP/M was written in a way that made it easily portable to any PC. It was also standardized so that programmers far and wide could create applications that would then run on any computer running CP/M. But CP/M did not come to Kildall like a bolt out of the sky. Kildall adapted CP/M from the source codes of UNIX and the DEC PDP-10 operating systems know as TOPS-10 and TENEX. The defense roots of UNIX have already been discussed, while, as also aforementioned, TOPS-10 and TENEX were created by BBN for DARPA's Project MAC during the Vietnam era (Ceruzzi, 2002, 118, 218; Ceruzzi, 1998, 195; 236; 265, 305; Campbell-Kelly and

[268] The history of IBM's disk based storage systems stretches back to the 1950s defense programs of SAGE and STRETCH, as previously discussed. The floppy disk in this incarnation was invented by David Noble at IBM for the commercially oriented System 370 (Ceruzzi, 1998, 232).

Aspray, 2004, 213-216, 234; Campbell-Kelly, 2003, 206).[269]

At the same time that Kildall was writing CP/M, Bill Gates and Paul Allen were writing a program that adapted an uncomplicated non-defense related programming language, BASIC, to the Altair system. When combined with CP/M, BASIC allowed hobbyists to write and sell simple computer games and the like. Interestingly, Gates and Allen wrote what would become Microsoft BASIC on a DEC PDP-10 at Harvard's Howard Aiken Computing Center (where the defense funded Mark series had been produced during the late 1940s and 1950s) (Ceruzzi, 1998, 204-6; 233-235; Campbell-Kelly, 2003, 205-6). Nothing could be more paradigmatic of the computer sector experience during the Détente era; an era wherein an entirely commercially sustained developmental feedback loop emerged out of the cauldron of knowledge and tools forged previously by decades-long defense expenditures.

By late 1977 a number of manufacturers were selling Altair like personal computers that came complete with BASIC, an eight inch floppy drive, a CP/M based DOS, a standardized bus, a keyboard, and a video monitor; all for under $2000. These manufacturers included Apple, Commodore, and Tandy. A plethora of small PC software companies also arose (Ceruzzi, 1998, 238-241; Campbell-Kelly, 2003, 4; Abbate, 1999, 186). But it would be a long stretch to say that the PC revolution had come to dominate the US computer sector. In 1977 mainframes and minis still composed 90% of computer sector sales (Flamm, 1988, 238).

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[269] "The foundations of PC systems software had deep roots in the very earliest days of electronic computers" (Ceruzzi, 2002, 118).

Much like in the case of semiconductors, the poor investment climate in the US facilitated the rise of foreign competition in the mainframe computer sector, which by the late 1970s exhibited a revenue structure wherein some 40% to 50% of total revenues were being generated outside the United States. The US was able to maintain dominant market share in software product development and minicomputer production. But, the international market for mainframes was slowly being ceded to foreign firms; most notably, Japanese firms such as Fujitsu, Hitachi, and NEC. Japanese firms also rose to garner dominant market-share in the plug compatible peripherals market during the Détente period (Ceruzzi, 1998, 165; Campbell-Kelly, 2003, 143, 174; Evans, 1995, 104). We'll of course analyze the rise of the Japanese computer industry in some detail as we explore the Japanese Case. For now, it is only necessary to understand that the hangover economic effects produced by unsound public finance during the Vietnam War era provided an opening for foreign manufacturers of select informational GPTs to thrive during Détente. We now turn to the computer networking sector, which remained a bastion of defense-induced technical innovation throughout the early and middle 1970s.

THE COMPUTER NETWORKING SECTOR – 1971-1977:

The main reason the computer networking sector remained predominantly influenced by defense expenditures in this period was that DARPA successfully shielded its C3 networking programs from the Mansfield Amendment by defining

them as mission critical for future security operations. In this way the IPTO was able to channel expenditures that had been previously earmarked for abstract computing research away from 'computing development' projects and towards well defined 'networking development' projects, such as ARPANET (NRC, 1999, Chapter 7; Abbate, 1999; Norberg and O'Neill, 1996, 164-179).

By 1972 the infrastructure for the ARPANET was basically in place and functioning. The network was now expanding to include military sites along with new universities.[270] Still, integration of the network into everyday activities was slow; the ARPANET, for all intensive purposes, remained an experimental project. Compatibility issues lingered and there were no signs or guideposts to help researchers understand what resources were online, or how and when they should or could be used (Abbate, 1999, 78, 87-9; Hughes, 1998, 255; Ruttan, 2006, 120). In this early period DARPA was more than happy to play the role of midwife: DARPA actively encouraged its contractors to publish their findings and provided funding for them to present papers at symposiums. By 1973 a community of ARPANET researchers were regularly attending conferences and sharing knowledge. DARPA also encouraged its contractors to turn their ARPANET experience to commercial uses. In 1974 BBN spun off a subsidiary, Telenet Communications Corporation.[271] Telenet became the first ever commercial packet-

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[270] For a site to be approved for an ARAPNET connection, someone in the organization had to have a research contract with DARPA or another government agency approved by DARPA (Abbate, 1999, 85-9).

[271] Larry Roberts, the original ARPANET project manager, left DARPA to become Telent's president.

switched network provider. Its seven city link was operational by August of 1975. In short, DARPA was training "a whole generation of American computer scientist to understand, use, and advocate its new networking techniques" (Abbate, 1999, 81).

In 1974, the IPTO began shopping around for a commercial operator to provide routine data communication services for ARPANET, as such responsibilities fell outside DARPA's now more strictly defined R&D mandate. Given the declining defense expenditure environment, along with DARPA's opinion that ARPANET technology ultimately had vast commercial potential, transferring data communication service responsibilities to a commercial telephone carrier seemed to make perfect sense. To the IPTO's surprise, AT&T rejected the opportunity; "Perhaps because the packet-switching business was too small and too different from conventional telecommunications to seem worth its while" (Abbate, 1999, 135). Here then it becomes clear, yet again, that market firms were unwilling to embrace radically new infrastructural informational GPTs in their early stages. In this case, the Defense Communications Agency (DCA) stepped in; in 1975, with the ARPANET successfully moving past its initial experimental phase, DARPA transferred responsibility for the ARPANET to the DCA (Abbate, 1999, 135-136; Ruttan, 2006, 121-3).

After the DCA takeover, the ARPANET began to be extensively used by the armed services. The network quickly became a test bed for cross-continental computerized C3 operations. As a consequence, the DCA attempted to impose

stricter use rules – complex password, log-in, and cryptographic systems were developed and applied (Abbate, 1999, 138; Ruttan, 2006, 121-124; Hughes, 1998, 293). These stricter use rules clashed with the 'killer app' that was spreading like wildfire at the ARPANET host sites – email. Here too DARPA provided the key techniques and impetuses.[272] In general 'the use of e-mail was vigorously promoted by DARPA.'[273] By the mid 1970s, more ARAPNET traffic contained email than all other applications combined (Abbate, 1999, 107-110; Hughes, 1998, 291-3).

Interestingly, a large proportion of email traffic was occurring 'intra-node.' In the early 1970s various university sites had worked with BBN to install terminals (termed TIPS) which allowed multiple users at one host site to remotely access the site's IMP (node). In an unforeseen outcome, IMPs had become 'hubs' in local area networks (LANs) – users at one university terminal were emailing other users at different university terminals through the university's IMP. Today, LANs are an extraordinarily important aspect of computer networks. And today, almost all LANs use a network technology known as Ethernet (Abbate, 1999, 64, 91-94).

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[272] Ray Tomlinson, a programmer at BBN working on the original ARPANET project, developed the first mail program that could be used on the ARPANET. The DARPA host protocol team wrote this program into the ARPANET's protocol starting in 1973. Various other members of DARPA improved the system, for example Lawrence Roberts created one of the earliest 'mail-reading' programs that presented the contents of a user's mailbox in an organized fashion. Roberts also developed the first mail program that sorted incoming mail into specifically designated folders (Abbate, 1999, 107-110).

[273] In fact, if DARPA contractors wanted to reach the IPTO chief they had to do so through email (ibid).

Much like the rise of LANs themselves, Ethernet was an unforeseen consequence of a seemingly unrelated DARPA project. In the mid 1970s DARPA received DOD approval to extend the packet-switched communicational paradigm to the medium of radio. A high speed packet-switched radio network was potentially ideal for military field operations, since radio terminals could be mobile, and packets were more easily scrambled and cryptographically concealed than analog radio waves. Moreover, a satellite radio packet communication system could potentially operate at the global level. Robert Kahn, lead ARPANET project engineer at BBN, left BBN and joined the IPTO to work on the radio packet-switching project. Kahn quickly realized that the main project bottleneck revolved around the fact that in a multi-host radio based digital packet system two messages sent at the same time over the same channel would inevitably interfere with one another. The solution landed on by DARPA researchers involved, not trying to prevent interference, but insuring that the system could recover if interference did occur. The way this was done was through 'random access' – if a packet was not received, the original transmitting terminal would wait a random amount of time and then re-transmit the packet; thus the two offending terminals were all but certain to not re-transmit at the same time since the packet re-broadcast was determined randomly (Abbate, 1999, 114-118; Ceruzzi, 1998, 291-294; Ruttan, 2006, 121).

Knowledge of this method soon reached Robert Metcalfe, a former DARPA funded Project MAC researcher who left MIT to join Xerox PARC in the wake of

the Mansfield Amendment. At PARC, Metcalfe was working on a project to interconnect a series of Alto computers so that they could all share one laser printer (the laser printer was also invented at PARC in the mid 1970s). The ARPANET model – with its expensive dedicated IMP – was not appropriate in this scenario; something new was needed. Metcalfe realized that the 'random access' method of packet radio broadcast was portable to a wire based LAN system: each computer on a LAN could be connected to any other computer or printer through a broadband coaxial cable wire, and all of the connected machines could use a random access method of packet communication. Metcalfe reasoned that such a LAN architecture would likely be fast, effective, inexpensive, and relatively simple. In 1976, after writing some algorithms that improved the 'random access' packet communications model, Metcalfe successfully hooked up a series of Alto's and a printer through a coaxial cable; high-speed Ethernet LAN had been born (Abbate, 1999, 114-118; Ceruzzi, 1998, 291-294; Ruttan, 2006, 121).[274]

Meanwhile, Robert Kahn at DARPA continued to work on improving packet radio communication. By 1976 DARPA had set up a packet-switched radio network that spanned the entire San Francisco Bay Area (it connected the many defense contractors in the region). This network, known as PRNET, was an important precursor to modern day cell phone networks.[275] DARPA at this time

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[274] Metcalfe named this technology Ethernet, as a nod to the method's radio wave roots. Ethernet's speed was unbelievable, 3 megabits as compared to ARPANET's 56K pace (Ceruzzi, 1998, 292).
[275] The system used omni-directional antennas and long-range node 'repeaters' arranged in cells. The system was also designed to keep track of the location and status of each mobile component

was also operating SATNET, a packet based satellite communications network which linked trans-Atlantic computers. Thus in 1976 DARPA was operating three separate packet-switched networks – ARPANET, PRNET, and SATNET. Kahn realized that if the three could be linked, the military would have achieved its post Cuban Missile Crisis dream of a globally spanning interactive multimedia C3 communications network. But the three networks operated by different methods and in very different mediums; connecting them would be no easy task (Abbate, 1999, 113-122).

That year Kahn brought Vinton Cerf (who had worked on NCP for ARPANET) onto the project, and together they wrote a proposal for a military inter-network; for an Internet.[276] They succeeded in obtaining funding and Cerf proceeded to put together a team that included Stephen Crocker (who had also worked on NCP at UCLA); Jon Postel (a USC DARPA researcher who had similarly worked on NCP), and Metcalfe (who continued on at PARC while working on the Internet project). The legendary work of these researchers has been recounted before and will be recounted many times more. Briefly, they decided to create a system that would allow individual networks to transfer information across the meta-level Internet regardless of the particular inner workings of any individual network. Building on the Ethernet model, the Internet team opted to eliminate

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without human assistance, and as users moved from one cell range to the next, new repeaters could take over routing without human assistance (Abbate, 1999, 118-120).

[276] "The ARPA managers, who ultimately had to justify the program in military terms, wanted the system to support the complex requirements of the armed services." Cerf commented at the time: "The conclusion is that many different transmission technologies are needed for military operations and therefore, a sensible C3 system must incorporate a strategy for the inter-operation of dissimilar computer communication networks" (Cerf quoted in Abbate, 1999, 124).

IMPs and have all hosts link directly with their network by using a standardized protocol that enabled hosts to internalize packet-switching and routing responsibilities. The advantage of such a system was that it kept the meta-network simple, thus it would be easier to interconnect various network architectures. The drawback was that to implement a new robust standardized common host protocol would involve substantial work on the hosts now using the existing networks (i.e. ARPANET mainframes would have to be updated). "For Cerf and Kahn, the efficiency and flexibility of having a common protocol were worth the effort of converting the older system" (Abbate, 1999, 128). Once developed, the new protocol was termed Transmission Control Protocol (TCP). "Cerf and Kahn planned for TCP to replace NCP as the ARPANET's host protocol and be the standard host protocol on every subsequent network built by ARPA" (Abbate, 1999, 122-130; Ruttan, 2006, 122-3; Hughes, 1998).

Now the Internet team had to figure out a way to 'scale'[277] together disparate networks using TCP, but operating in different broadcasting mediums. The team made a decision to add a 'gateway layer' to the already existing 'host layer.' Internet gateways are specialized computers that sit at the intersection of two or more networks. Gateway computers (termed routers) convert packets to the proper medium and then transfer them across networks. The gateway layer buffers the meta-level Internet from having to know anything about individual networks. Owing to gateways, new networks using TCP can be added (scaled-in) to the meta-

[277] As in 'to go upward in stages or steps' (Webster's).

network Internet without changing any aspect of the overall system, thus making the Internet an incredibly flexible, modular, and infinitely 'scalable' system. In implementing the gateway layer, the Internet team realized that if gateways also used TCP they would be repeating a series of steps that were already being performed at the host layer, thus slowing down the system. Since slow packet transmission was anathema to defense-related C3 needs, the Internet team wrote an addendum protocol specialized for the gateway layer. This gateway layer protocol was termed Internet Protocol (IP).[278] Thus was born TCP/IP, the meta-network protocol that makes the diverse, variegated, decentralized, modular, and scalable Internet function as we know it today (Abbate, 1999, 122-130; Ruttan, 2006, 122-3; Hughes, 1998).

In late 1977 DARPA conducted the first test of the Internet by sending packets from a van traveling on a California freeway through PRNET to an ARPANET gateway on the West Coast, then through the ARPANET to a SATNET gateway on the East Coast, over SATNET to an ARPANET gateway in Europe, and finally back through the ARPANET to California. Cerf was quick to emphasize the military potential of this, and all following demonstrations, each of which displayed how 'connections between radio, satellite, and telephone networks could be used during wartime':

> "What we were simulating was a situation where somebody was in a mobile unit in the field, let's say in Europe, in the middle of some kind of (hostile)

[278] Cerf argued "the stripped down functionality of IP would make military networks more robust and therefore more likely to meet the requirements of operation under hostile conditions" (Abbate, 1999, 130).

> action trying to communicate through a satellite network to the United States, and then going across the US to get to some strategic computing asset... There were a number of such simulations or demonstrations like that, some of which were extremely ambitious. They involved the Strategic Air Command at one point, where we put airborne packet radios in the field communicating with each other and to the ground, using the airborne system to sew together fragments of Internet that had been segregated by a simulated nuclear attack" (Cerf quoted in Abbate, 1999, 131-132).

This telling statement by one of the founding fathers of the Internet leaves very little doubt – the Internet was indeed an infrastructure born of aggression.

After a series of successful demonstrations, DARPA forced all of the ARPANET hosts to install TCP/IP, and a number of new TCP/IP based C3 defense networks were scaled into the Internet. To encourage widespread adoption of TCP/IP, DARPA began funding software development programs that made TCP/IP portable to various operating systems. For example, DARPA funded BBN to incorporate TCP/IP into the UNIX operating system; the aforementioned Bill Joy working under a DARPA contract also made sure that UC Berkeley's popular version of UNIX could run TCP/IP. DARPA additionally funded implementation programs for IBM and DEC machines along with a number of other proprietary operating systems. In this way DARPA began to spread the Internet's TCP/IP seeds in a non-proprietary and open-ended way. And for good reason: The US DOD wished that the entire world would adopt TCP/IP as the globally preferred standard meta-network protocol. Then the American military's worldwide C3 communications network would be able to interface with any other nation's networks, commercial or otherwise; encrypted US military gateways could then be

turned on and off as the Defense Department saw fit in order to maintain security or extend reach (Abbate, 1999, 133; Ceruzzi, 1998, 296). This would endow the DOD, or more importantly the NSA, with a level of communications command theretofore unimaginable. As we will see in the next chapter, the heightened security concern and enormous military expenditure fostered by the final leg of the Cold War enabled the DOD to bring this vision to fruition. Counterintuitively, the world is a more open, interconnected, and perhaps, even a better place as a result.

CHAPTER 17: THE FINAL COLD WAR YEARS – 1978-1989

In 1977 the relatively cordial Détente atmosphere began to fade. The Pentagon was circulating a series of reports which suggested that Soviet military expenditures had actually been much higher than previously assumed during Détente; 50% more than the 1960s levels and 40% more than the US was spending (Mintz, 1992, 3; Nincic, 1982, 16). These reports did not fall on deaf ears, and in 1978 the Carter administration began increasing defense expenditure. Thus, the final long stretch of heightened Cold War military expenditure actually began mid-way through the Carter administration, and not with the accession of Reagan, as many assume (Boies, 1994, 18). Although, of course, Reagan did push military expenditure to heights far beyond what Carter might have had he stayed in office. Given the continuing economic hangover from the poor public deficit finance policies of the 1970s, along with increasing capacity utilization in the 1980s, it seems clear that heightened military expenditure caused important crowding out effects during the last leg of the Cold War, as will now be detailed.

At the aggregate level, real military expenditure in the US averaged $319.4 billion per annum from 1978 to 1989, which was 33% higher than average per annum real defense expenditure during Détente. Moreover, the Reagan era increases were notable for their heavy focus on expanded advanced weapons procurement and RDT&E.[279] Real procurement rose an average 8% per annum over the entire period and at a 13.5% per annum clip between 1981 and 1985. Real

[279] DOD R&D grew by more than 80% from 1980-8 in real dollars, while civilian R&D fell by 25% (Yudken and Black, 1991, 176).

RDT&E expenditures rose an average 6.3% per annum over the entire period and at a 12% per annum pace from 1982 to 1986. As a result, employment of professional and technical personnel performing military work in industry mounted swiftly, rising by 41% between 1980 and 1985, thus rapidly pushing the share of the nation's engineering corps devoted to defense-related efforts from around 30% to approximately 50% (DiFilippo, 1991, 9; Allison, 1985, 289). Real NASA expenditures also rose, at an average 3.6% per annum pace. Real DARPA expenditures increased incredibly rapidly during the first half of this period, more than doubling between 1978 and 1984, from $547.5 million to $1.3 billion; aggregate DARPA expenditure stabilized at this higher level thereafter. Real IPTO expenditures continued to rapidly climb after 1984, rising from $117.6 million in 1984 to $287.7 million in 1987, a gain of 145%.

Increased IPTO expenditures in this period undoubtedly helped to advance nascent Internet technologies, as will be shown, but the same logic does not quite apply to the older more commercially mature semiconductor and computer sectors. Although the Reagan era expenditure intensifications focused specifically on advanced weapons (Mintz, 1992, 192; Higgs, 1990), the advanced weapons pursued (such as SDI) had little commonality with prevailing commercial trends in the 1980s semiconductor and computer sectors (DiFilippo, 1990; Stowsky, 1992). The divide between defense-related technical needs and market-based commercial development, which had been growing in the semiconductor and computer sectors for some time, gaped into a chasm during the 1980s. Defense expenditure rapidly

increased while the mode of development shift veered swiftly towards a predominantly commercial orientation. The consequences of this divergence will be discussed in some detail below, but before we get there, let's see how well the American government and economy shouldered the burden of increased defense expenditures during the final leg of the Cold War.

To summarize, neither shouldered the burden particularly well. As military expenditure rose, so too did real non-defense expenditure, which increased at a comparatively slow 3.3% average per annum rate. Real total revenue rose at a similar 3.6% per annum average rate from 1978 to 1989, which given the ramp up in defense expenditure, was insufficient to prevent yawning deficits. The average yearly real deficit between 1978 and 1989 was $208 billion, which was an astonishing 20% shortfall in total revenue, equating to 3.6% of GDP. As a consequence gross federal debt exploded by 121% in real terms, and by a stupefying 306% in nominal terms, reaching 52% of GDP in 1989. As these numbers indicate, inflation continued to rise briskly during the final leg of the Cold War, averaging 6.2% across the entire period (as measured by the CPI), and 11.7% between 1979 and 1981. Fed chief Paul Volcker eventually did break the back of the great inflation by reducing the Fed's holding of public debt from a high 19% in 1978 to a more reasonable 11% in 1986, although at great cost to the economy. Interest rates soared with yields on 10 year T-bills reaching an unpleasantly high 14% in 1980 and remaining elevated thereafter. With public debt soaring, inflation still brisk, interest rates well over 10%, capacity utilization averaging over well

80%, and defense expenditures ramping upwards, the final Cold War era provides the classic textbook case for crowding out. As would be expected, the rate of growth in private fixed investment did notably decline in this period, to an average 2.75% per annum pace in real terms, down from an average 4.73% per annum pace during the Détente period (Hormats, 1988, 22-4).

Swimming against the crowding out tide in the 1980s was the regressive tax structure established under President Reagan. The 1981 Economic Recovery Tax Act (ERTA) was designed to cut income taxes by a total of 25% over three years in order to boost investment rates in the US (Veseth, 1990, 169). It is likely that the ERTA prevented domestic private investment growth rates from eroding further during the 1980s, although, the tax provisions enacted seemed to augment real estate investment rather than manufacturing investment (Veseth, 1990; Hormats, 1988). What is indisputable is that the tax structure became significantly more regressive in the US during the 1980s. Together personal income and corporate income taxes accounted for 56% of total revenue on average from 1978 to 1989, which was down from 60% in the prior period; social insurance and excise taxes combined to account for 39% of total revenue during this period, up from 34% during Detente. Interestingly, similar tax regimes were instituted in America's major trading competitors during the1980s, and these nations were not spending heavily on defense at the time (Sturm and Muller, 1999, 131). Thus in a comparative sense America was not able to mitigate defense expenditure induced crowding out through a more regressive tax regime during the final leg of the Cold

War. To wit, the US trade balance in high technology products fell from a surplus of $31 billion in 1980 to a deficit of $2 billion in 1986 (DiFilippo, 1990, 20). Let's now explore how crowding out played out in our specific sectors of interest.

THE SEMICONDUCTOR SECTOR 1978-1989:

With approximately 50% of the nation's engineers engaged in defense related efforts, nearly all of which now involved advanced semiconductor technologies in some way, the cost of engineering and technical manpower in the American semiconductor industry rose briskly during the 1980s (DiFilippo, 1990). Additionally, the specs on the chips used in advanced weapons increasingly decoupled from what was necessary or preferred in the commercial sphere (Stowsky, 1992; DiFilippo, 1990). To make matters worse, the investment environment in the US was not particularly conducive to large new expenditures; which are a perennial must in the swiftly evolving semiconductor space.[280] As a result, American semiconductor firms rapidly ceded market share to foreign competitors between 1978 and 1989. In 1975 US firms retained an approximate 65% share of the overall semiconductor market, by 1981 that percentage had slipped to 60%; it continued to fall to 45% in 1986, and then fell further to 38% in 1988. Market share for Japanese firms, which were not at all involved in defense-related efforts, rose from 20% in 1975, to 29% in 1981, continued to rise to 45% in

[280] In 1982 leading US semiconductor firms spent 15% of sales on cap ex; Japanese semiconductor firms spent 25% (DiFilippo, 1990, 30).

1986, and then surpassed US market share reaching 51% in 1988. In the DRAM segment the story was even more dismal. US firms controlled 78% of the commercial DRAM market in 1978, by 1983 US share had fallen to 48%; from there US share continued to plummet all the way down to 28% in 1988. Japan's share of the DRAM market rose like the American share fell: 22% in 1978, 48% in 1983, and 65% in 1988. And as if that weren't bad enough, market share for US firms in the semiconductor production equipment industry fell from 75% a the beginning of the 1980s to 40% by the end of the decade (Angel, 1994, 18, 68; Flamm, 1996, 23; Vogel, 1992, 58; Alic et al., 1992; Varynen, 1992, 76-77).[281]

A brief description of the massive DARPA Very High Speed Integrated Circuit (VHSIC) program serves to illustrate the detrimental crowding out effects wrought by military expenditure in the US semiconductor industry during the 1980s. The VHSIC program lasted from 1980 to 1988 and cost a total of $1 billion. DARPA initiated the program because the DOD was becoming dissatisfied with the VLSI chips being produced for the commercial market.[282] Although these chips were wonderful for commercial mainframes, minis, and PCs; they didn't exhibit an architectural design, ruggedness, or capacity well suited for the next generation of intelligent cruise missiles. Wanting only the best, DARPA sought to

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[281] It should be noted that dominant US share of the commercial microprocessor segment, which currently sits atop the value added chain in the semiconductor industry, eroded much less precipitously (Flamm, 1996, 23; Ceruzzi, 1998, 214; Gilder, 2005).

[282] VLSI refers to very large scale integration. Scale refers to the number of transistor logic gates crammed onto one chip. Integrated circuit chips of the mid 1960s were considered medium scale integration and contained between 100 and 1000 gates per chip; 1970s DRAM chips and early microprocessors were considered large scale integration and contained over 1000 gates; by the 1980s the industry had achieved VLSI chips with gates in the hundreds of thousands (Helpman and Trajtenberg, 1998, 112; Braun and Macdonald, 1982, 103; Campbell-Kelly and Aspray, 2004, 203).

include all of the leading US semiconductor firms on the VHSIC project. Motorola, TI, Fairchild, and National Semiconductor joined the program, while Intel shrewdly declined. Intel opted out of the project because Noyce and Moore foresaw a very limited defense-only type market for the chips DARPA was looking to produce. And Noyce and Moore did not want Intel diverted from the commercial VLSI 'war' already underway in the civilian market. Diverted they would have been. Not only did the DOD impose heavy national security restrictions in regards to information and sales of VHSIC technology, but the chips ended up being highly specialized, incredibly expensive to produce, and procurement occurred only in small batches. Moreover, by the time VHSIC chips were finding their way into weapons systems, commercial VLSI chips had surpassed them in density and speed. In short, "the VHSIC program deflected firms from seeking higher density designs that might have paid off over longer production runs" (Stowsky, 1992, 128-137, 232; DeGrasse, 1984, 94; Varynen, 1992, 78; DeLanda, 1991, 153).

Unsurprisingly, many political economists in the 1980s and 1990s pointed to the VHSIC program as perfectly illustrative of the harmful effects brought on by 'excessive' military expenditure (Stowsky, 1992; DeGrasse, 1984, 94; Varynen, 1992, 78; DiFilippo, 1990). Some even made the mistake of extending the scope of their argument back past the 1980s commercial IT trade wars (Dumas, 1995; Bischak, 1995; Melman, 1991; DiFilippo, 1990). In light of the 'military expenditure impetus to mode of development shifts theory', what the VHSIC

program clearly illustrates is just how far the informational mode of development had progressed passed its original defense roots. During the 1980s, no amount of defense spending in the crucial infrastructural, indeed foundational, semiconductor sector was going to match the commercial developmental momentum fomented by the rapidly maturing informational mode of development shift; although, as many US firms found out, military expenditure could still divert momentum.

THE COMPUTER SECTOR – 1978-1989:

The commercial computer sector in the United States entered the final leg of Cold War on fire. Between 1976 and 1979 investment in computer equipment and peripherals rose from $4.4 billion to $10.2 billion, averaging a 30% pre annum growth rate. From there growth in computer and peripheral investment began to slow, averaging a still highly respectable 25% per annum growth rate between 1980 and 1984. In 1985 however the bottom fell out; computer investment grew at a meager 6% rate, and in 1986 computer and peripheral investment actually declined by $850 million in the United States. Over the next three years computer investment averaged an 8% growth rate, thus completing the slowest 5 year average annual growth rate in the index since 1960, the year the OMB began compiling computer investment statistics. This drop off was surprising given that real GDP in the US grew at a relatively robust 3.7% per annum pace from 1985 to 1989. It was even more so given that computer investment continued to boom around the world.

As a consequence, the US share of world computer production plummeted from 65% to 43% in the space of two years, between 1985 and 1987 (US Industrial Outlook, 1993). The fact that this decline occurred in lockstep with the most sustained and rapid growth rate for defense RDT&E expenditures since the early 1960s suggests that the American computer sector did indeed suffer from detrimental crowding out and preemption effects during the second half of the final leg of the Cold War.[283] Especially given that defense spending on advanced computer R&D and data processing rose by 142% between 1983 and 1987, with most of this expenditure going to commercially inapplicable supercomputing efforts (Goldstein, 1991, 31-41; NRC, 1999, Chapters 4 & 10; Flamm, 1988, 19, 254-255).[284]

IBM's experience is once again representative. By the early 1980s it was clear that the mainframe era was dying a slow death. IBM embarked on a two-pronged strategy in order to make this death less painful. First, it vigorously pursued defense contracts, of which there was no great shortage. In 1978 only 1.8% of IBM's revenue was defense-related; in 1987 21% of IBM's revenue

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[283] Real RDT&E rose 14% in 1985 and 17% in 1986, by far the fastest growth witnessed since the 28% rate posted in 1961.

[284] Painting the DOD's many 1980s computing projects with such a large brush is somewhat unfair. The numerous new computing and software programs initiated were extremely ambitious and revolved around Artificial Intelligence technologies such as pattern recognition, language recognition, virtual reality, and expert systems. Undoubtedly the DOD programs pushed these fields forward in many important and novel ways. Recounting these ways here is neither possible nor necessary as the subject matter is exceedingly complex and AI technologies are just now making themselves felt in the commercial world. Given that the temporal scope of the dissertation ends before the commercial proliferation of AI technologies the reader is better served by looking elsewhere for the DOD's role in pushing AI technologies forward. Delanda, 1991; NRC, 1999; and Ruttan, 2006 are good places to start.

originated from defense contracts (Tuomi and Vayrynen, 1982, 60; DiFilippo, 1990, 139). In the short-term this was certainly a successful strategy, as IBM's revenues, profits, and stock price continued to grow, even as its share of the declining mainframe market fell. However, as will be discussed more in the next chapter, IBM's focus on defense contracting revenue during the 1980s did divert its attention away from important emerging commercial trends, especially those related to computer networking. This diversion was particularly powerful in that the defense-related computer projects IBM worked on in the 1980s involved advanced software architectures and parallel processing techniques; technologies which, for the most part, have not, as of yet, had profound impacts upon commercial computing (DeLanda, 1991; NRC, 1999; Ruttan, 2006).

The second tact that IBM took to counter the demise of its mainframe business revolves around the famous IBM PC. Prior to 1978, IBM produced all of its computer components in-house; it was completely vertically integrated, producing its own cases, semiconductors, disks, etc. But with the introduction of the Intel 8086 microprocessor in 1978, IBM realized it could no longer compete with the specialized chip makers. Company management therefore decided to pursue a new strategy; one which was being increasingly utilized amongst computer manufacturers and would soon come to define the informational mode of development. IBM opted to horizontally integrate the production chain for its flagship PC; nearly all of the machine's components were manufactured by

independent firms and vendors (Evans, 1995; Harrison, 1994; Campbell-Kelly and Aspray, 2004, 226).

The IBM PC, which debuted in 1981, exhibited a standard bus architecture and a CP/M type OS.[285] IBM chose to keep the PC architecture open so that a wide variety of firms could produce add-on hardware and software. Management believed that openness would enable their PC to stay at the cutting edge of the rapidly changing PC computer market. This strategy worked. IBM expected a total production run of 250,000 for the machine, and ended up selling 250,000 per month. Between 1982 and 1983 IBM's PC revenues grew by approximately $2.1 billion (Flamm, 1988, 227; Ceruzzi, 1998, 252-272; Campbell-Kelly, 2003, 207).

There was a downside however to IBM's new approach. The problem was that the vendors and firms now included in IBM's production chain were free to sell their wares to other manufacturers. In fact, the only thing that made an IBM PC an IBM PC was the proprietary code in its ROM chip. Sensing an important emerging opportunity, three semiconductor engineers (Rod Canion, Jim Harris, and Bill Murto) left Texas Instruments to from Compaq computer in 1983. In Compaq's warehouse Canion, Harris, and Murto squirreled themselves away and 'reverse engineered' IBM's proprietary ROM code; which was perfectly legal as long as the engineers could prove they had no prior privileged knowledge of the IBM ROM code. So began the rise of the clones. By 1985 Compaq was one of the top ranked computer manufacturers in the world. Dell followed closely on its

[285] The IBM PC was designed by Don Estridge who joined IBM in 1951 and cut his teeth on the SAGE project (Campbell-Kelly and Aspray, 2004, 227).

heels. But in the following four years, as previously described, computer investment in the US fell off; thus paving the way for foreign entrance into the PC space. Hence, the poor investment environment in the US during the second half of the 1980s, which should surely be partially, if not totally, attributed to crowding out, provided an important opening for Asian, Southeast Asian, and European PC makers to get a leg up in the rapidly expanding and evolving personal computing sector (Ceruzzi, 1998, 252-277; Campbell-Kelly, 2003, 207, 237-239; Evans, 1995).

What is perhaps most astounding about this era, however, is that American firms retained total domination of the exploding global software products market.[286] Plainly, this owes mainly to the vast software programming manpower established in the US by defense expenditure prior to the 1980s. Unlike computer hardware manufacture, software production is inherently labor intensive. It involves a trained individual writing code; and no amount of machinery, automation, or technology has changed that basic fact. Since labor is far less mobile than, say, manufacturing equipment, the US was able to maintain its dominant market share in the software sector on the back of its strong programming labor force; which was undoubtedly a consequence of decades-long defense-induced training (Campbell-Kelly, 2003; Ceruzzi, 1998).[287] A brief review of the

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[286] In the early-mid 1980s US firms accounted for well over 80% of the approximately $10 billion software products industry (Campbell-Kelly, 2003, 2; 166).

[287] A view asserting defense expenditure as the principal driver of software sector development and training prior to 1970 is rather non-controversial; as is a perspective that incorporates this fact into explanations of how and why the US has retained dominance in the software sector through to the

major PC software programs of the day supports this view. For example, nearly all the PCs in the world during the 1980s ran Microsoft DOS (Campbell-Kelly, 2003, 207). MS DOS was a rather direct descendant of Kildall's CP/M; the defense related roots of CP/M have already been traced. The world's first spreadsheet program, VisiCalc, was written by two software programmers, D. Bricklin and R. Frankston, who had met while working on DARPA's Project MAC at MIT; VisiCalc was written using DARPA's Mulitcs system. The leading PC database application in 1984, dbase II, was developed by W. Ratcliffe, a programmer at NASA's Jet Propulsion Laboratory. The original Adobe Photoshop program was written by two software engineers, J Warnock and C. Geschke, both of whom left the University of Utah's DAPRA funded computing research center in the wake of the Mansfield Amendment to join PARC, where they wrote the software for the first laser printer. The list goes on, but I believe the point has been made (Campbell-Kelly, 2003, 203-219; Ceruzzi, 1998, 269; Ceruzzi, 2002, 120).

Of course no discussion of the 1980s PC sector is complete without a mention of the Apple Macintosh, which was released in 1984 to great fanfare roused by an Orwellian Superbowl commercial. What made the Mac so unique was its GUI and mouse. In a DOS OS users interacted with the computer through a 'command line interface.' For ordinary users this system was incredibly confusing. So the lead designer on Apple's Macintosh project, Jeff Raskin, decided to implement some of the ideas he had encountered at PARC while as a visiting

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present. For a more detailed description of the history see Ruttan, 2006; Campbell-Kelly, 2003; Flamm, 1988; Ceruzzi, 1998.

scholar from Stanford's DARPA funded Artificial Intelligence Laboratory. Also, "many histories describe a visit by Apple cofounder Steve Jobs to PARC in 1979 as the pivotal moment in transferring PARC's technology to a mass market." In fact, after the visit, Jobs convinced the lead design engineer for PARC's Alto computer, Larry Tesler (yet another DARPA / Mansfield Amendment refugee), to come join Apple Computer (to Xerox's profound chagrin). The Macintosh GUI, introduced in 1984, incorporated all of the key attributes of Engelbart's original GUI, by way of the PARC Alto (which as discussed featured a mouse, icons, windows, drop-down menus, bit mapping, etc.). Amazingly, Steve Wozniak, Apple's head engineer and co-founder, had somehow managed to get all of this into a very compact machine for the incredibly low price of $2500 (Campbell-Kelly and Aspray, 2004, 238-242; Ceruzzi, 1998, 274; Campbell-Kelly, 2003, 247). The PC age as we know it had officially begun; the computer networking age was sure to follow.

THE COMPUTER NETWORKING SECTOR – 1978-1989:

Throughout the 1970s mainframes and minicomputers lived in a kind of uneasy symbiosis, occupying different niches of the market. Minicomputers were increasingly powerful but still did not approach the processing power embodied in a mainframe system; while mainframe systems could not provide personalized computing in an economic manner. In the 1980s this symbiosis was forever changed. During the middle and late 1970s simple time-sharing networks had

proliferated into corporate office spaces. These systems were composed of 'dumb' terminals linked to central mainframes dedicated to one specific task, such as word processing.[288] The rise of such systems gave currency to a new computing paradigm – the 'distributed model.' The distributed model proposed a system wherein a cluster of networked minicomputers worked in a coordinated fashion to attain the power of a mainframe, while at the same time providing direct access personalized computing to individuals. Getting a cluster of minicomputers to work in a coordinated fashion, however, was neither easy nor cheap in the late 1970s, thus the mainframe time-sharing model still prevailed (Ceruzzi, 1998, 178).

The advent of LAN technology, high speed Ethernet, and UNIX based network architecture fundamentally altered the relationship between minicomputers and mainframes. "Clusters of small computers now, finally, provided an alternative to the classic model of a large central system that was timeshared and accessed through dumb terminals" (Ceruzzi, 1998, 282). DARPA researcher Eric Metcalfe, now at PARC, was, as the inventor of Ethernet, in a perfect position to grasp the fundamental revolution under foot. In 1981 Metcalfe left PARC to form 3Com Corporation, an outfit aiming to commercialize Ethernet technologies. The timing was right, for in 1982 Sun Microsystems was founded. Sun Microsystems was started by Andy Bechtolsheim, Vin Khosla, and the aforementioned Bill Joy.[289] In many ways, Sun Micro was a DAPRA project spin-off. In 1980

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[288] The terminals were termed 'dumb' because they had no processing power.
[289] Scott McNealy, longtime Sun CEO, was also there at the beginning. He provided the business acumen.

Bechtolsheim and Khosla were working on a DAPRA funded project to create a 'Stanford University Network' (SUN) of 'workstations.'[290] SUN workstations were basically advanced minicomputers integrated with sophisticated engineering peripherals. Bechtolsheim and Khosla decided to run Berkeley UNIX on these workstations because its open architecture was best for local area networking and multitasking. Bechtolsheim and Khosla convinced Bill Joy, who designed Berkeley UNIX with DARPA funding and had recently incorporated TCP/IP into Berkeley UNIX under DARPA contract, to join the project team. The team then decided to use Metcalfe's Ethernet technology to link their UNIX based workstations, as the speed and simplicity of Ethernet could not be beat. By 1981 the team had successfully constructed a distributed network of UNIX based workstations which allowed for the sharing and interactive use of complex peripherals and graphically advanced design data (Ceruzzi, 1998, 282; NRC, 1999, Chapter 4).

DARPA was so impressed with the Stanford University Networked workstations that it encouraged the team to commercialize their efforts, which, as a bonus, would give a boost to Metcalfe's fledgling company as well. Commercializing SUN UNIX workstations also served DARPA's higher purpose of spreading the TCP/IP protocol inter-networking standard. So was born Sun Microsystems in 1982. Sun Microsystems's networked workstations initially sold for $20,000. DARPA extended funds to a number of academic institutions

[290] The SUN project was part of the 1978 DARPA VLSI program. For more see NRC, 1999, Chapter 4.

enabling them to purchase Sun workstations for institutional users and networks. Such purchases accounted for 80% of Sun Microsystems' sales in its first year of business. After that, commercial sales mounted rapidly; Sun and 3Com suddenly became two of the fastest growing companies in the world. The flexibility and openness of the UNIX OS when combined with the speed, simplicity, and scalability of Ethernet LAN provided a powerful new tool for any manufacturer using Computer Aided Design (CAD) to develop complex capital goods (planes, automobiles, missiles, semiconductors, etc.). In the mid 1980s CAD using capital goods manufacturers began linking their workstation LANs to those of other firms in horizontally networked design chains through TCP/IP wide area networks (WANs). A virtuous cycle of open-network sharing and product evolution began to take hold as the mainframe era gasped its last breaths (Ceruzzi, 1998, 282-292; NRC, 1999, Chapter 4). In its ashes rose a system we call today flexible volume production; the informational mode of development infrastructure was rapidly fusing (Borrus and Zysman, 1992, 20-1; Castells, 1996, 1998).

The brisk commercial diffusion of network workstations and Ethernet LAN technologies in the 1980s raises an important question. Why did these defense-induced innovations diffuse widely into the commercial milieu in the United States during a period of heightened military expenditure accompanied by a less than halcyon investment environment? The answer lies in the mounting mode of development shift. Prior proliferation of minicomputers and time-sharing systems highlighted the potential utility of a distributed minicomputer LAN. Thus a

powerful vacuum had opened in the advancing mode of development shift; the vacuum called for a technology that would enable minicomputers to be arranged in a profoundly new organizational structure which potentially offered up the possibility of infinitely distributed processing power. Fortuitously Ethernet and UNIX provided a cost effective way of implementing this structure. Thus networked UNIX workstations using Ethernet LANs began diffusing as soon as Ethernet and UNIX were commercially ready. This is not surprising – local area networking was one of the final pieces in the informational mode of development's infrastructural puzzle; and what that puzzle might look like when it was finished had become clear by the mid 1980s. All that was missing was a functional and flexible wide area network (WAN) at the global level that could scale-in new LANs and LAN architectures as they emerged.

Of course, by the late 1970s DARPA had succeeded in creating an experimental flexible WAN, with infinite scalability potential, that also operated at the global level – the TCP/IP Internet. But it wasn't the only WAN in existence. As knowledge of the ARPANET spread, a number of telecommunications carriers and computer manufacturers in various developed nations had created their own experimental packet-switched networks. These networks were proprietary and non-scaleable. Proprietary in the sense that they were designed to work with only one manufacturer's line of computers; technical specifications and protocols were kept secret or licensed at great cost. Non-scaleable in the sense that the proprietary protocols were incapable of interfacing with TCP/IP, Ethernet LAN, radio and

satellite packet-switching, i.e. just about any protocol or medium outside the one for which the proprietary network was designed (Abbate, 1999, 149-164; Ceruzzi, 1998, 247-252).

By the early 1980s network protocol standards were becoming Byzantine in their complexity. This concerned the DOD greatly, for the power and reach of its C3 networks would be considerably diminished if the world was populated by incompatible and inaccessible (at least to the DOD) localized proprietary WANs.[291] The DOD therefore began to vigorously promote TCP/IP – the only protocol that would allow an infinite number of networks utilizing any communicational medium to integrate seamlessly at the global level. DARPA, flush with Cold War currency, coerced and cajoled the world community to adopt TCP/IP as the global networking standard in several ways. A $20 million dollar fund was established to subsidize any computer manufacturer's effort to make their proprietary operating system TCP/IP ready. "All the major computer companies took advantage of this opportunity, and by 1990 TCP/IP was available for virtually every computer on the American market" (Abbate, 1999, 143). DARPA initiated Internet router development programs, and lucrative contracts were signed with any new US company entering the nascent Internet router market; as long as their routers used TCP/IP and TCP/IP only. Cisco Systems, which went on to dominate the global

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[291] From a 1983 Pentagon report: "Exclusive use of (proprietary) protocols fails to utilize inherent capabilities of these broadcast media which have been acquired at considerable effort" (Abbate, 1999, 164).

router market in the 1990s, was a primary beneficiary of such measures.[292] Additionally, in 1985, the DOD signed off on a $200 million National Science Foundation (NSF) project to create a civilian oriented TCP/IP Internet that would link to the ARPANET.[293] This Internet, NSFNET, was designed to be faster and have more broadband capacity than any WAN in the world. As a result, university research centers and science laboratories around the globe wanted to connect to the NSFNET, which quickly became the center of gravity for many advanced national and international research programs. The ARPANET served as NSFNET's network backbone as it was being constructed, therefore, if any research or science organization wanted to access NSFNET during or after its construction, the organization had to be running TCP/IP; as long as this condition was fulfilled, just about any domestic or international non-profit organization was free to join the NSFNET Internet.[294] "This would've been a rather extraordinary move for a commercial network; however, DARPA was not in the business of selling Internet service, so its managers had no incentive to restrict access for economic purposes" (Abbate, 1999, 149-163, 184-194; Hughes, 1998, 294; Ruttan, 2006, 124). Finally,

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[292] Cisco Systems was founded in December 1984 by two members of Stanford's computer research support staff, Len Bosack and Sandy Lerner. They began developing routers in 1981 after their DARPA supported Stanford research center received a series of Alto's that the center then networked together using Ethernet. Bosack and Lerner designed a 'multiprotocol' router that allowed their research center's LAN to connect to the DCA Internet. By the time Cisco routers appeared on the marketplace, they were compatible with the TCP/IP protocol only (Carey, 2001).

[293] It should also be noted that in the early 1980s the US military became increasingly concerned with security, especially given the new round of Cold War tension. The DOD therefore began spinning off a series of defense-only TCP/IP networks from the original ARPANET, including two NSA restricted networks, two DCA restricted networks, and one less restricted network known as MILNET (Abbate, 1999, 143; Ruttan, 2006, 124; Hughes, 1998, 351).

[294] At this point the number of computers with Internet access began to explode. In the fall of '85 there were 2000 computers on the net; by the end of 1987, 30,000; by October '89, 159,000 (Abbate, 1999, 186).

DARPA worked through US and International standardization bodies to make sure that TCP/IP was accepted as one potential international protocol standard. Given that TCP/IP was the only international protocol standard that permitted access to America's global level WAN (which was by far the world's fastest and widest WAN), given that TCP/IP was the only protocol that came without a licensing charge, and given that the US market for TCP/IP routers was by far the most competitive and well capitalized (thus offering the best and cheapest routers), it was all but certain that TCP/IP would be adopted throughout the world as the preferred protocol standard; which it of course was (Abbate, 1999, 172-177; Hughes, 1998, 294).

In this way DARPA was able to 'surmount proprietary standards that would have limited the commercial, social, globalizing and revolutionizing potential of the Internet'; all while pursuing the DOD's selfish interests (Abbate, 1999, 176). By 1989, DARPA's vision of a global, dense, flexible, modular, and scaleable meta-network capable of interfacing with the DOD's own encrypted networks when, where, and how the DOD, the DCA, and the NSA saw fit had come to fruition. And truly, the timing could not have been more ironic. For in 1989 the Berlin Wall fell and the Soviet Union collapsed; the Cold War was over. Was this near synchronized timing mere coincidence? Manuel Castells (1996; 1998) has powerfully linked the rise of the Internet and the demise of the Soviet Union: 'The incapacity of statism to assimilate and use the principles of informationalism embodied in new information technologies collapsed the whole statist system'

(Castells, 1996, 13). Gorbachev himself hinted at this ultimate outcome in a 1988 address to the UN: "The world economy is a single organism… The (present) growth of the world economy reveals the contradictions and limits inherent in the traditional type of industrialization" (Gorbachev quoted in Castells, 1998, 5). Clearly, the world economy was transitioning to something new, something past industrialism; informationalism was upon us. How would the US compete in this new world order that was forged in the crucible of the Cold War system but now resembled its progenitor but little? We turn to answer that question as we enter the post Cold War decade.

CHAPTER 18: THE POST COLD WAR DECADE – 1990-1999

With the fall of the Berlin Wall in 1989, and the subsequent collapse of the Soviet Union, defense budgets commenced a long gradual decline in the US. Real military expenditure fell 5% in 1990, and another 12% in 1991, which marked the largest back to back decline in real aggregate military expenditure in the US since just after the Korean War. After rising 7% in 1992 (a result of the brief but sharp 1991 Persian Gulf War), real military expenditure resumed its decline, falling by 19% between 1993 and 1996. By 1999, real military expenditure stood at $281 billion, or 2.97% of GDP. The nation had not experienced a military expenditure aggregate lower than 3% of GDP since 1940, thus marking the beginning and end of the temporal parameters of the American case.[295]

Understanding that the cuts underway were more permanent and structural in nature than anything the nation had experienced since WWII, defense contractors slashed their employment rolls. Between 1987 and 1995 defense employment fell 32% (Weber, 2001, 72-81). Conversion became the theme of the day. Of course, America's post Cold War defense contractor conversion was entirely market mediated. Plant and equipment were sold off and facilities were closed; while mergers, leveraged buyouts, and increased dividend payouts led to a dispersal of contractor's financial assets onto American capital markets which redistributed the

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[295] Real procurement expenditure fell precipitously as well, declining at an average 6% clip between 1990 and 1992, and then dropping 52% between 1993 and 1997. Real RDT&E expenditure also declined, falling 13% between 1990 and 1991 and then receding at a 2% per annum average rate between 1992 and 1999. Real NASA expenditures stabilized at around $15 billion in this period.

new liquidity to higher growth sectors (Weber, 2001).[296]

Tellingly, all of the symptoms of crowding out gradually disappeared in the Post Cold War decade. The average annual deficit in real terms fell by 25% in this period as compared with the prior, marking the longest sustained decline in deficit totals since the Eisenhower administration. In 1998 and 1999 the nation achieved a combined real surplus of $200 billion; by far the largest real two year surplus in the nation's history. Surprisingly, the surplus was not used to pay down real gross federal debt, which rose 57% between 1990 and 1999. Nevertheless, interest rates declined rapidly, aided by a friendly Fed and a boost in foreign holding of American debt from 18% of total US public debt in 1990 to 35% of total US public debt in 1999. Three month T-bills averaged a 4.9% yield in this period as compared with an 8.8% yield in the prior. Inflation also moderated greatly, with the CPI averaging 3% in the post Cold War decade as compared with 6.2% during the final leg of the Cold War. Meanwhile, the tax structure remained relatively regressive with personal income taxes and corporate income taxes accounting for 56% of total revenue (the same as in the Reagan era); and social insurance taxes and excise taxes accounting for 40% of total revenue (up ever so slightly from 39% during the Reagan era).

With military expenditure declining, the symptoms of crowding out receding, and a tax structure conducive to investment being maintained, the 'military expenditure impetus to mode of development shifts theory' would predict

[296] During the 1990s the number of prime aircraft integrators declined from 7 to 2; the number of missile manufacturers fell form 14 to 4 (Ruttan, 2006, 174).

renewed American competitiveness during a period of heightened diffusion and informational 'take-off' as the informational infrastructure fused in the post Cold War decade. And indeed this is what occurred. In fact, from the final quarter of 1991 to the third quarter of 2000, America experienced the longest economic expansion in the nation's history, accompanied by the highest productivity growth in nearly three decades (a point to which we will return below) (Greenspan, 2000). Additionally, America's trade balance in high tech goods production (especially in regards to information technologies) went back into surplus in the 1990s;[297] and American market share in high tech value added production reached a globe leading 40% in 1996 (NSF, 2006, Chapter 6).[298] Undoubtedly, this resurgence in American competitiveness was aided by the ongoing exodus of engineers from the defense sector, as illustrated by this 1993 reference; 'with military shrinkage, talent that was designing military electronics is now being diverted to digitalizing any part of the commercial world that isn't already digitized' (Gregory, 1993, 115; 197). Let's see how renewed American competitiveness amid heightened informational 'take-off' looked in our three sectors of interest during the post Cold War decade.

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[297] The technology products surplus was $22.4 billion in 1994 (NSF, 1996, Chapter 6). The US undoubtedly emerged as the world leader in digital transmission, micro-processing, digital storage, and data compression technologies in the 1990s (Gregory, 1993, 124).

[298] "Beginning in 1996 and for each year thereafter, U.S. high-technology manufacturers generated more domestic production (value added) than the EU or any other single country. Estimates for 2003 show U.S. high-technology industry accounting for more than 40% of global value added, the EU for about 18%, and Japan for about 12%" (NSF, 2006, Chapter 6).

THE SEMICONDUCTOR SECTOR – 1990-1999:

The US semiconductor industry experienced rapid growth in the 1990s. The value of shipments from US semiconductor firms had stabilized around $25 billion between 1988 and 1990, but then rose by 13% in both 1991 and 1992, leapt by 32% in both 1993 and 1994, rose by 38% in 1995, and rose another 20% in 1996 and 1997 (US Industrial Outlook, 1995; 2000). Market share for US semiconductor firms also turned up in lockstep with the end of the Cold War (Gregory, 1993, 14). After a decade long decline, US market share in the overall semiconductor global industry rose from 38% in 1989, to 40% in 1991, to 45% in 1994, to 54% in 1998 (Angel, 1994, 18; Anchordoguy, 2005, 189; Flamm, 1996). Between 1989 and 1993 the US share of combined US / Japanese firm semiconductor output increased from 40% to a majority 52% share, and continued higher thereafter. In the highest value-added segment of the semiconductor industry (microprocessors, digital-analog converters, etc.), US firms (led by Intel and TI) achieved and then retained a majority share of the world market throughout the 1990s (Gregory, 1993, 140-147; Flamm, 1996, 23; Gilder, 2005). And in the semiconductor equipment industry the US share of the global market increased from around 40% in the late 1980s to 53% in the mid 1990s; with Japanese firms now experiencing the mirror image decline from a majority share to a 38% share (NRC, 1999, Chapter 4). These numbers clearly indicate a broad American resurgence in the global semiconductor industry during the post Cold War decade.

THE COMPUTER SECTOR – 1990-1999:

After growing at a 3.7% per annum rate between 1985 and 1990, investment in computer and peripherals equipment in the US grew at a 15% per annum clip between 1992 and 1999. By 1997 the US had regained the lead in the NSF's 'office and computer machinery' manufacturing index, achieving a 40% share of global production in this broad index (NSF, 2006). This broad index also likely understates the US value-added share of the global computer and peripherals market. For by the 1990s the computer market was all about international chains of production; no manufacturer in any aspect of computer production was autarchic. Such a structure makes today's computer industry difficult to measure by conventional means. However, it is clear that in terms of the value added chain, being an 'internationally connected systems integrator' manufacturing 'innovative, proprietary point of sale systems' is the best constellation (Evans, 1995, 180). Clearly, US firms achieved this constellation best in the 1990s as indicated by 1998-1999 global PC point of sale market share statistics which showed Compaq in the lead (14.5% share of the world market), Dell in second (9.1%), tied with IBM (9%), followed by HP (6.6%). The first non-US manufacturer appeared on the list in fifth – NEC (6.5%), but the next two companies were American – Gateway (4%) and Apple (3.7%) (Gaba, 2007).

Since we have traced IBM's narrative starting with its entry into the computer business in 1950, it is only fitting that we wrap up the IBM narrative here. Interestingly, IBM stumbled into the 1990s; it then quickly and stupendously

recovered (Garr, 1999). In 1987 20% of IBM's revenue had come from defense contracting. This percentage declined precipitously after 1989, leaving IBM in a revenue crunch. Moreover, IBM was out of step with current commercial trends, where PC networking was increasingly the focus. During the late 1980s many computer manufacturers had updated their PC designs to incorporate networking capabilities. IBM had done so, but not particularly well; a partial result of its defense-induced supercomputer orientation no doubt. As a consequence, IBM posted its first ever back to back to back losses from 1991 to 1993; losing a combined $15.8 billion. After an impressive effort by then CEO Lou Gerstner to streamline IBM and reorient its focus towards providing network and software services, IBM returned to profitability in a big way in 1995. Indeed, IBM's stock price rose from $10 to $140 between 1995 and 2000 (Ceruzzi, 1998, 294, 368; Garr, 1999).

Additionally, US firms retained majority market share in the software products industry in the 1990s, although at a lower percentage market share than the approximately 80% achieved during the early-mid 1980s (an inevitable consequence of the exponentially exploding and increasingly competitive international market for software). Between 1990 and 1999 market share for US firms in the global software products industry fluctuated between 50% and 60% (Campbell-Kelly, 2003, 9).

THE COMPUTER NETWORKING SECTOR – 1990-1999:

Of course, no sector illustrates improved American competitiveness in a period of heightened informational take-off better than the computer networking sector during the 1990-1999 interval. In 1990 the ARPANET was decommissioned and folded into the much faster and more modern NSFNET backbone. 'The passing of the baton from ARPANET to NSFNET marked the end of military operation of the Internet' (Abbate, 1999, 195). The Internet continued to expand by orders of magnitude, and as it did, the NSF became deeply embroiled in ideological debates regarding public vs. private control. As a public domain, the NSFNET was inaccessible to commercial entities and firms; and yet the commercial potential for a globally scoped Internet was unmistakably humungous. US commercial firms pushed for access; but if foreign commercial firms were also given access the American government (through the NSF) would be subsidizing foreign competition in what was clearly the emerging leading growth sector of the dawning 21st century. NSF managers therefore came to realize that the only politically feasible way to accommodate commercial users on the Internet was to remove the network entirely from government operation. In 1994 the NSF turned over the hubs of the NSFNET to a series of new commercial 'Internet Service Providers' (ISPs). All commercial restrictions on the Internet were lifted and the Internet became open to the public for purely commercial, social, or recreational activities (for a price, of course) (Abbate, 1999, 195-210; Ruttan, 2006, 16, 126).

Fortuitously, US PC manufacturers had gotten ready for just such an event.

As alluded to above, by 1990 most domestically manufactured PCs were TCP/IP networking ready (thanks in large part to DARPA's Cold War computer manufacturer subsidies). Still, inexpensive PC microprocessors had trouble handling the multitasking required for smooth real-time networking. Borrowing a final page from PARC, US firm Novell developed a PC networking model based around a 'file server' – a dedicated PC with a high capability Intel microprocessor, generous mass storage capacity, and improved I/O devices.[299] In a Novell 'client-server network', a series of PCs were connected to a file server through Ethernet LAN, and all network responsibilities were then farmed out to the server (Ceruzzi, 1998, 294-297).

At this point coalescing Internet technologies were rapidly approaching critical mass; the detonation required just a few more electrons. Not surprisingly, given the scenario of declining military expenditure amidst a fusing informational mode of development, these final inventions appear as the first major Internet technologies to have no obvious connections with defense expenditure. In the early 1990s Tim Berners-Lee at CERN, a high energy physics laboratory on the French-Swiss border, pioneered the universal resource locator (URL), hypertext transfer protocol (HTTP), and hypertext markup language (HTML). He called the multimedia world of interlinked files these technologies combined to create 'the World Wide Web' (www). The 'web' is in fact a set of servers and hyper-text applications that reside in the underlying TCP/IP Internet infrastructure; although

[299] The term server originated in a 1976 paper on Ethernet co-authored by Metcalf at PARC (Ceruzzi, 1998, 294).

of course today 'web' has become synonymous with 'Internet' (Abbate, 1999, 187, 214-220; Ceruzzi, 1998, 301-4).[300]

Then, in 1993 Marc Anderseen working at the NSF's National Center for Supercomputer Applications at the University of Illinois invented the first 'web browser', named Mosaic. In 1994 Anderseen incorporated Netscape Communication, an outfit hoping to profit from the commercialization of Mosaic. Netscape went public on August 8, 1995. Its share price more than doubled on that day, moving from $25 to $58; after three months more, one share of Netscape was worth $150. The dot-com explosion had begun in earnest. A few usage figures will serve to highlight the point: In 1990 there were just 313,000 computers attached to the Internet. By 1995 there were 10 million servers attached to the Internet, conveying Internet access to some 78 million worldwide users; there were also 5 million LANs connected to the Internet in 1995. By 2001 there were over 100 million servers connected to the Internet conveying access to some 513 million users worldwide (Ceruzzi, 1998, 301-4; Campbell-Kelly and Aspray, 2004, 255; 271-2; Abbate, 1999, 187, 214-220; Harris, 1998, 146; Internetworldstats.com).

There can be no doubt that US firms have led, and continue to lead, the world into the Internet age. This accords well with the 'military expenditure impetus to mode of development shifts theory' in that the initial defense-related

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[300] The first conception of hyper-textually inter-linked documents was put forth by none other than Vannevar Bush, the head of the WWII era US OSRD. Bush called his imaginary device for infinitely linked library documents a 'memex' (DeLanda, 1991, 218-219; Ceruzzi, 1998, 367). I find it simply astounding that the story of the informational mode of development shift begins with the man who pioneered the idea of a hypertext library and crests with the advent of a global-wide hyper-textually linked informational cyberspace.

adoption of TCP/IP by US firms and manufacturers conferred an early competitive advantage to US Internet companies (Abbate, 1999, 179); while the detrimental crowding effects spawned by heightened military expenditure during the last leg of the Cold War waned prior to the post-1995 era of rapid Internet technology diffusion. Hence, dissimilar to what occurred in the 1970s and 1980s semiconductor and computer sectors, US firms have retained an untarnished advantage in the Internet sector.

For example, early in the 1990s American firm Novell attained an over 50% market share in the burgeoning client-server networking space (Ceruzzi, 1998, 294). Cisco Systems emerged in the mid 1990s as the Internet router powerhouse. By 1999 Cisco had attained an incredible 75% share of the $10 billion-plus world market for routers; in 2000 its share increased to 86%. Its closest competitor was Nortel Networks, a Canadian company that benefited enormously from its proximity to the US market, garnering around 7% of the router market. Following Nortel, two more American firms appear on the 1999–2000 router market-share round-up: Metcalfe's 3Com (2%), and Noyce and Moore's Intel (2%). Cisco also won the market for Ethernet LAN switches in 1999, garnering an approximate 36% share. Following closely on its heels in this market was 3Com with a 30% share. Nortel rounded out the top three with a 13% share (International Data Corporation, 2001).

US startup firms similarly came to dominate those Internet sectors which are more difficult to measure by conventional metrics. The names are of course

familiar – EBay in the auction space, Yahoo! in the search engine space, Amazon in the retail space, Netscape in the browser space, AOL in the on-line services space, and Norton and Symantec in the security space.[301] Most of these firms germinated in the 'greenhouse' of Silicon Valley, where decades of DARPA spending interacted with the university milieu to spread knowledge of TCP/IP networking. Abundant venture capital aimed at developing the unending commercial potential embodied in the new technology then lit up the Valley. Interestingly, rather than generate their own domestic startups, foreign nations one by one imported American Internet companies in the 1990s; spawning AOL Europe, Amazon Brazil, Yahoo! Japan, EBay China, etc. Really, in order to perceive the early lead the US Internet industry gained as a consequence of the US being the privileged birthplace of the technology, one merely needs to ponder the fact that accessing the American network today does not require a special extra suffix, such as is required for every other nation-state (Campbell-Kelly and Aspray, 2004, 275-277). Perhaps US supremacy in Internet technology during the 1990s is best indicated by this insightful 1999 observation made by Kenneth Cukier:

> "The myth that the Internet is a ganglion of interconnected networks may be true domestically, but internationally, it looks more like a hub and spokes system, with the United States at the center and circuits spiking out worldwide. No Asian country has more than 155 mbps of bandwidth to any other country in the region, while capacity from Asia to the United States is around 2 gbps. In Europe, no two nations are connected by more than 700 mbps, while US bound bandwidth sailed to well over 4 gbps in 1998."

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[301] Advanced data encryption continues to be indispensable to the commercialization of the Internet. The US DOD and NSA have long been the driving force in encryption technology. For more on the military's crucial contributions to data encryption and compression, and the commercializing role of US firms in the 1990s, see NRC, 1999, Chapter 8.

Thus by 1999 informational space had not only collapsed, it had inverted; with Singapore sending information to its neighbor Indonesia (900 km away), by way of the US Internet backbone, some 13,000 kilometers away. As might be expected, US ISPs retained a leading percentage share of global ISP revenue in the 1990s (Cukier, 1999).

THE PRODUCTVITY PARADOX MORPHS INTO THE PRODUCTIVITY MIRACLE:

In the early 1990s American economists were lamenting the 'productivity paradox.' The US was spending nearly $1 trillion a year, or almost half the nation's total capital expenditures, on information technologies, and yet productivity had yet to take a sustained turn upwards (Akera and Nebeker, 2002, 3). No one is absolutely certain as to what caused the productivity paradox, or the generalized post 1970 worldwide decline in productivity growth for that matter, but few if any respected theorists continue to cite military expenditure as either a main, or even a contributing factor. Most economists now believe that the paradox and the associated global productivity decline were transitional symptoms; in counterintuitive fashion radically new information technologies had interrupted productivity growth via a number of mechanisms, including: mounting obsolescence of fixed and human capital, a vast and requisite inward and outward restructuring of corporate organizational forms, and aggregate data measures clearly unsuited to capturing new informational investment and consequential growth (Helpman, 1998, 10; Helpman and Trajtenberg, 1998, 72-3; Howitt, 1998,

219-248; Lipsey et al, 1998, 23; Parkin, 1995; Doms, 2004; Fernand et al, 2007; Ruttan, 2006; Sichel, 1997). This perspective gained traction in the latter half of the 1990s as the productivity paradox suddenly broke and the 'new economy' materialized.

> "After a quarter century of lackluster gains, the U.S. economy experienced a remarkable resurgence in productivity growth during the second half of the 1990s. From 1995 to 2000, output per hour in non-farm business grew at an average annual rate of about 2-½ percent, compared with increases of only about 1-½ percent per year from 1973 to 1995" (Oliner and Sichell, 2002).

Productivity continued to rise to a 4% per annum growth rate between 2001 and 2004 (Ruttan, 2006, 167). There is widespread consensus that this resurgence in productivity growth, which underpinned the longest economic expansion in American history, was largely an effect of the evolving and coordinating power of the Internet. Computers in isolation were inadequate to usher in the new age; millions of computers connected to a multitude of networks which themselves were connected to one meta-network proved sufficient (Oliner and Sichell, 2002; Doms, 2004; Fernand et al, 2007; Ruttan, 2006).

In the historic words of Alan Greenspan (2000):

> "What should be indisputable is that a number of new technologies that evolved largely from the cumulative innovations of the past half century have now begun to bring about awesome changes in the way goods and services are produced and in the way they are distributed to final users. Those innovations, particularly the Internet's rapid emergence from infancy, have spawned a ubiquity of startup firms, many of which claim to offer the chance to revolutionize and dominate large shares of the nation's production and distribution system."

Around the same time, Ethernet developer Robert Metcalfe theorized that 'the impact of a network varies with the square of the number of devices that it interconnects.' If this theory holds, and the vivid success and effect of the Internet suggests that it will, then we have only now begun to scratch the surface of what the informational mode of development portends for America and the world (Randell, 2002, 49).

As one peacefully surfs the TCP/IP Internet, enjoying multimedia applications on a bit mapped monitor, interacting with the applications through a mouse, barely noticing the assemblage of semiconductor and disk devices quietly humming away in the background, it is difficult to evoke the defense-related roots of these serially interconnected architectures and technologies. This reality, however, underscores the potent transformative synergies intrinsic to the 'military expenditure impetus to mode of development shifts theory'; for it is not decades long defense expenditure alone that has initiated the two historical global mode of development shifts heretofore witnessed, it is decades long defense expenditure in combination with a well constructed institutionally sound liberal political economy insulated from war. In the end, it is the market that propels the process; and in the end, it is the market alone that drives the new mode of development to novel revolutionary and evolutionary heights far beyond what any individual or organization could possibly envision. Nevertheless, left to its own devices, the market tends to evolve along the path of least resistance (Ruttan, 2006, 11-12; Helpman, 1998, 2; Nelson and Winter, 1982; Vayrynen, 1992, 105; Goldstein,

1991, 29). And transitioning to a new mode of development, as we have seen, is hardly the path of least resistance. Therefore, an exogenous long-term large-scale impetus was required to prompt the market to 'switch rails' towards a radically new infrastructural and organizational configuration capable of enhancing and producing productivity gains in new and unexpected ways in both the British and American cases. Which begs the questions: What impetuses prompted informational change in America's trading partners during the Cold War and how did these impetuses connect to, interact with, and differ from the military expenditure impetus described in the American case? It is upon these questions we now focus as the dissertation turns to analyze Japan's transition to Informationalism during the Cold War era.

CHAPTER 19: THE CASE OF JAPAN – 1945-1999

The case of Japan, 1945-1999, helps to illuminate the causal mechanisms operating in the 'military expenditure impetus to mode of development shifts theory' by way of a negative comparison: Japan in the Post WWII era was constrained from spending militarily and yet became an early and successful entrant into the production of select information technologies relative to other OECD nations. Hence, an analysis of Japan, 1945-1999, serves to isolate the causal effects of military expenditure in regards to the formation of informational production and development. What is found is that the Japanese state was able to cultivate an economy wherein certain firms became quite adept at reverse-engineering some of the key informational technologies that evolved out of the crucible of the American system of military expenditure. Japan was therefore able to 'free-ride' on the costly defense-inspired shotgun like developmental processes obtaining in the US by borrowing winning radical technologies once they emerged, and then targeting R&D capital in a rifle like fashion in order to incrementally improve key manufacturing processes.[302] Although the Japanese state was able to

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[302] The use of the term 'free ride' should not suggest that technological borrowing in Japan was somehow costless. The use of the term here devolves from the rational choice theory analysis of collective goods behavior as famously expressed by Mancur Olson (1965), and indicates that Japan experienced significantly lower costs to acquire powerful, already developed and tested technologies, as compared with the costs shouldered by the United States in order to innovate, develop, and test these powerful technologies. This cost divergence occurred primarily as a consequence of three collective goods provided by the hegemonic United States in the postwar era: 1) provision of defense security for Japan, 2) the maintenance of an open international trading order, and 3) tolerance of Japan's numerous deviations from the norms of the international trading order. This is not to say that Japan was a passive beneficiary; creating conditions supportive of successful technological transfer was just one in a myriad of complex developmental goals achieved by the Japanese state (Johnson, 1982, 16-17; Pyle, 1996, 244; Olson and Zeckhauser, 1967, 27-45).

generate conditions that enabled Japanese IT firms to, at times, out-compete US IT firms in sectors where extensive diffusion had already taken place, it will be argued below that the developmental system that obtained in Japan from 1945 to 1999, which contained each of the state / market institutional variables in the 'military expenditure impetus to mode of development shifts theory' but lacked a domestic military expenditure impetus, could not have, and would not have, of its own accord, fostered a mode of development shift away from industrialism. In other words, the institutional and state structural organization of the Post WWII Japanese political-economy provided fertile ground for technological development, and yet, Japan did not indigenously originate infrastructural information technologies. The case is thus made that US military expenditure was an essential component in the processes activating the informational mode of development shift; while the burdensome and at times inefficient mechanisms involved permitted Japanese firms to advantage from the opportunity costs devolving there from.

It is accepted that postwar Japan developed a system overtly aimed at 'catching up' to America (Anchordoguy, 2005; Pyle, 1996; Kennedy, 1987; Johnson, 1982). The state-directed / market-embedded system that was fashioned proved incredibly adept at this, and in the 1980s it looked as though Japan would soon leave the US behind in some crucial IT markets. However, once Japan had caught up, the Japanese system of development encountered trouble in regards to charting novel innovative informational technological trajectories. Japan failed to

domestically generate new foundational infrastructural information technologies capable of propelling the burgeoning mode of development shift forward; although as will be shown, Japanese firms allied with developmental state agencies did attempt, unsuccessfully, to pioneer influential infrastructural informational technological systems during the 1980s (Anchordoguy, 2005; Castells, 1998; Flath, 2000; Salus, 1995; Beason and Patterson, 2004). By the final decade of the 20th century, the US economy, unencumbered by crowding out, was once again blazing new informational trajectories, with the globe following in its wake. The role that military expenditure played in shaping this dynamic will of course be our main preoccupation below – namely, the presence of long-term large-scale advanced weapons expenditures in the US helped to foment an economy primed for radical technological innovation while at the same time burdening the economy; the absence of military expenditure in Japan supported the development of an economy primed for technological borrowing and commercial competition, but also seems to have limited the formation of institutions and organizations suited to the radical discontinuous type technological advances necessary to the indigenous generation of groundbreaking infrastructural information technologies.[303]

In order to support this thesis the following case will contrast the Japanese 'non-defense-inspired model of technological advance', 1945-1999, against the US defense-inspired model previously described. We will proceed by first comparing

[303] "Japan's landscape was littered with many large firms with capacities suited to manufacturing, not technological breakthroughs" (Anchordoguy, 2005, 214).

each of the pertinent discrete but interacting variables in the 'military expenditure impetus to mode of development shifts theory' across the two cases: military expenditure, which of course varied profoundly; along with the institutional prerequisites to economic development, efficient taxation, sound public deficit finance, and state-directed embedded autonomous processes of navigating technological trajectories, all of which, as will be shown, manifested in relatively consonant manners across the two cases.[304] In this way the theoretical causal mechanisms pertaining to military expenditure will be isolated and disaggregated from other potentially relevant effects arising from slight variation in the comparatively 'controlled' (i.e. non-defense-related) variables. The case will then move on to analyze the differential outcomes produced by Japan's non-defense-inspired model of technological advance in the dissertation's three informational infrastructural sectors of interest – semiconductors, computers, and computer networking.

DEFENSE EXPENDITURE IN POSTWAR JAPAN:

It is of course common knowledge that defense expenditure in Japan was constrained after WWII. Under Prime Minister Shigeru Yoshida (1948-1954), Japan willingly committed itself to spending no more than 1% of GNP on a self-defense force prohibited from projecting power outside of Japan, as enshrined in Article 9 of the Japanese Constitution. In exchange for military bases, the US

[304] Each state was insulated from attack, 1945-1999, so nothing more will be said of this variable.

agreed to place Japan and Japanese sea lanes under its nuclear and conventional defense umbrella. This arrangement has persisted, with little modification, into the 21st century (Kennedy, 1987, 468; Vogel, 1992, 71; Flath, 2000, 217). Clearly, the absence of a significant defense burden in Japan has allowed Japan to 'define its national aims in narrow economic terms' while also increasing the resources available to the Japanese state for capitalization of its competitiveness programs (Kennedy, 1987, 468; Pyle, 1996, 225, 239; Castells, 1998). But such a banal assertion does not quite capture the nuanced argument being made here. Even if post WWII Japan had funded a normal level of military expenditure aimed mainly at munitions, like say South Korea or Taiwan or other various developing states, post WWII Japan would still not meet the requirement for a positive assessment in regards to the primary operative variable in the 'military expenditure impetus to mode of development shifts theory.' In order to pass that test, defense expenditure needs to be decades-long, massive (between approximately 6% and 15% of GDP as it was in the US and British cases), and aimed mainly at capital intensive weapons development. The point being made here is not that the Japanese economy grew because of a lack of military expenditure (the postwar South Korean and Taiwanese cases would likely present some difficulties for that kind of theory); the point being made here is that postwar Japan exhibited a certain type of technological growth, where process and incremental innovations manifested at a rapid rate, but radical discontinuous innovations were difficult and largely lacking, precisely because of the absence of long-term large-scale advanced weapons expenditures. This then is

a qualitative argument related to the type of technological growth exhibited, rather than a purely quantitative argument.

The key configurations that allow Post WWII Japan to act as an ideal negative case comparison designed to draw out and highlight the mechanisms in the dissertation's theory, not only relate to its nearly entire lack of defense expenditure, but also to its embracing of market-oriented institutions and liberal democratic state structural formations. For these institutions and organizational configurations helped Japan to become an early prime mover in select information technologies markets, where, for a time, it out-competed every nation on the planet. Let's now explore how market-oriented institutions and liberal democratic state structural formations evolved in modern Japan.

THE EVOLUTION OF THE INSTIUTIONAL AND STATE STRUCTURAL FOUNDATIONS FOR ECONOMIC DEVELOPMENT IN MODERN JAPAN:

Being that Japan was late to industrialize, the institutional and state structural foundations universally necessary for market generated economic development and technological advance evolved rapidly and within the same time frame in modern Japan. Hence, the following section will be organized temporally rather than by variable. The overriding contention will be that at the macro-economic level of formal political structure, the institutional prerequisites for economic development (property rights, low transaction costs, and parliamentary governance), along with efficient centralized bureaucratic tax administration, and sound public deficit finance, manifested within modern Japan in ways that are

reasonably consonant with the way said variables operated in the US case, so that these variables can be considered sufficiently 'controlled.' In controlling for these variables, I hope to convince the reader that the institutional political-economic structure of post WWII Japan was quite capable of fomenting a mode of development shift, and yet did not, owing mainly to the absence of advanced weapons expenditures.

In order to trace the materialization of an economy with an enhanced capacity for technological development in Japan, we must briefly reach back in history to 1868, the year of the Meiji Restoration. In that year, a faction of forward looking samurai overthrew the Tokugawa shogun, established an oligarchy with the young emperor Meiji serving as a figurehead, and began to modernize the still feudalistic Japanese economy. By 1872 a central government had been established, feudal domains had been abolished and replaced with prefectures which were now governed by central government appointees rather than landed 'daimyo', and all feudalistic type barriers to interregional domestic trade and market exchange had been removed (Pyle, 1996; Flath, 2000; Sagers, 2006; Goldsmith, 1983). Perhaps the most important reform of these early years was the 1873 land tax reform. This reform transformed the land tax from an in-kind levy based on harvest yield payable to the local landed daimyo, to an in-cash levy based on a fixed percentage of land value payable to the central government and collected by a centralized meritocratic administrative bureaucracy. Additionally, land was made fully alienable, land surveys were conducted, land values were assessed, and deeds were

issued to owners. For the first time in Japanese history 'private property had been established as the ordering principle of the economy' (Sagers, 2006, 114; Pyle, 1996; Goldsmith, 1983; Ramseyer and Rosenbluth, 1995; Ishi, 1993, 20-34).

Moreover, government revenue was now predictable, thus setting a foundation for the development of modern public deficit finance. In the early years of the Meiji Restoration nearly 100% of revenue was being consumed by the payment of samurai stipends dating from the Tokugawa era. By 1876 the Meiji government had attained sufficient stability, power, revenue, and credit to commute these lifelong samurai stipends into interest bearing bonds payable at 8% and maturing in twenty years, thus substantially reducing the young government's obligations. Two years later a stock exchange was opened in Tokyo where bonds could be exchanged. At the same time the Meiji oligarchy promulgated legislation calling for the establishment of a system of privately held national banks modeled on the American national banking system. Many samurai shrewdly invested their commutation bonds in the privately held national banks thus capitalizing the national bank system. The new financial structure not only reduced transaction costs for domestic exchange, but also lent stability to the newly minted national currency, known as the yen. Six years later a central bank, known then and now as the Bank of Japan (BOJ), was established and given sole control over currency issue (Goldsmith, 1983; Flath, 2000; Pyle, 1996; Sagers, 2006).

The Meiji government also imported technology from the West; pilot factories owned by the government were established to acquaint domestic

entrepreneurs with new techniques and manufacturing methods. In the early 1880s these pilot plants were sold to private parties, thus indicating "a broad acceptance of private enterprise as the engine of future economic development upon which... nationalist aspirations rested" (Sagers, 2006, 91). In 1885, patent legislation was enacted in Japan; known as the Patent Monopoly Act, this law was closely derived from French patent laws of the time. Finally, in 1889, bowing to domestic and international pressures, the oligarchy promulgated a constitution which established a strange and complex mix of checks and balances that arrogated a significant amount of power to a cabinet appointed by the Emperor, whose power was entirely derived from the oligarchy, but also included a bicameral Diet with an elected lower house given institutionalized veto power over fiscal legislation. In the 1890s the Diet passed an "avalanche of complex and mostly western inspired legislation: the Civil Code, the Commercial Code, the Code of Civil Procedure, and the Code of Criminal Procedure" (Ramseyer and Rosenbluth, 1995, 80; Pyle, 1996; Flath, 2000). Taken together, these and other various measures established secure property rights, lowered transactions costs, and instituted a modern capitalistic political-economic structure in Japan; as evidenced by the decline in interest rates charged on Japanese government bonds in the London market – 9% in the 1870s, 7% in the 1880s, and by 1899 redeemable 55 year Japanese bonds were carrying a rate of 4% (Goldsmith, 1983, 57; Flath, 2000, 36; Ramseyer and Rosenbluth, 1995, 184; Ishi, 1993, 20-34).

In the thirty or so years following the turn of the century, "an approximation

of laissez faire was in vogue" in Japan (Johnson, 1982, 33; Flath, 2000, 192). Over this period the Meiji oligarchs passed, party politics took center stage, and suffrage was vastly extended. But the strange and complex system of checks and balances established under the Meiji constitution left open a channel for enlarged amounts of power to be arrogated to the military.[305] As crisis descended upon Japan in the late 1920s, this channel was progressively taken. Crisis mixed with nationalism soon became militarism in the 1930s, and Japan drifted deeper into war, first with China, and later with the United States. During this period, government control over economy and society was greatly enhanced. A series of laws were passed that established state command of trade, resources, prices, entry, investment, and cartel management. Just prior to WWII the state was able to separate ownership rights from management rights, and then usurped all management functions in the economy, but either refrained from, or was unable to, completely abrogate the private ownership rights of the larger firms. The militaristic state established de jure or de facto control over all economic decisions in Japan during WWII, and finally in 1944, nationalized the entire economy, which by that time had been completely decimated (Pyle, 1996, 189-198; Johnson, 1982, 109-115; Flath, 2000).

The end of WWII was followed by seven years of American occupation

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[305] The defense minister post had to be filled by an active status high ranking military officer. By withholding this appointment, the military could bring down the cabinet and force new elections, thus giving the military de facto control over the legislative system (Ramseyer and Rosenbluth, 1995).

during which time the Supreme Commander of the Allied Powers (SCAP)[306] attempted to re-establish and then strengthen democratic and capitalistic institutions in Japan. What emerged was a system of formal capitalist democratic institutions embedded in informal communitarian norms that stressed nationalist principles over unadulterated profit maximization (Anchordoguy, 2005; Johnson, 1982). For the purposes of this study, it is the operation of the formal institutions that are of utmost importance. And at that level, it is clear that parliamentary governance, capitalist property rights, efficiently administered bureaucratic taxation, and sound public deficit finance were sufficiently established in postwar Japan so that the potential for state-led market-generated technological development certainly existed; and indeed did occur, albeit in an altered form as compared with the United States, leading to a discrepant outcome on the dissertation's dependent variable, owing to the absence of the military expenditure impetus, as will be discussed in quite some detail below.

But before we fully engage that argument, let's first briefly survey the formal institutional structure of parliamentary governance, property rights (focusing on knowledge rights), efficiently administered bureaucratic taxation, and sound public deficit finance in postwar Japan. For there is some variation in the ways these formal institutions manifested as compared with the United States. The argument will now be made that these cross-national variations were not decisive in the causal mechanisms that yielded a contradictory outcome on the dependent

[306] SCAP was originally the title given to General MacArthur during the Japanese occupation but soon came to denote the entire occupation administration (Pyle, 1996, 214).

variable in this study.

The Japanese Constitution sets up a series of formalized checks and balances and electoral procedures that would not seem unfamiliar to anyone cursorily familiar with parliamentary political systems. There is a bicameral Diet, legislative processes, supermajority amendment requirements, a majority based premiership and cabinet, a bill of rights, a supreme court with the right of judicial review which also serves as the court of last appeal in an independent judiciary, etc. (Flath, 2000, 73; Pyle, 1996, 220; Johnson, 1982). Recall that parliamentary governance is important to this study mainly because such governance guarantees secure property rights by couching rulers in a codified system of checks and balances preventing the abrogation of property rights thus maintaining incentives to exchange and insuring that public credit instruments indebt the entire nation rather than just the nation's rulers. Clearly, the postwar Japanese political system fulfills these conditions (Flath, 2000; Pyle, 1996; Johnson, 1982; Solo, 1991, 49; Castells, 1998, 215-218). In regards to this study's overarching theory, as long as these conditions are filled, the breadth or depth of democratic participation and / or party change is not particularly important.

This brings us to a noteworthy difference between the Japanese and American political systems that can be addressed: A conservative faction of the electorate aligned with the bureaucracy, known as the Liberal Democratic Party (LDP), ruled in Japan without interruption for nearly four decades beginning in 1955. Moreover, most legislation in Japan is drafted within the bureaucratic

ministries aligned with the LDP, rather than in congressional committees as is typical in the US. Indeed, the Diet is far more likely to pass legislation drafted in the ministries than it is legislation drafted in the more representative lower or upper houses (Johnson, 1982; Pyle, 1996; Flath, 2000).[307] It is important to remember, however, that although bureaucratic ministerial power is strong in Japan, it is far from supreme. To begin with, the Japanese bureaucracy is extremely fractionalized and discordant. Extra-bureaucratic 'deliberation councils' are many times the mechanism through which struggles and conflicts within the bureaucracy are settled, thus giving civilians a prominent role in determining the direction of policy emanating from the bureaucracy (Johnson, 1982, 48). Plus, the LDP itself is less of a party and more 'an agglomeration of a half dozen cliques' masquerading as a party (Goldsmith, 1983, 147). The less powerful factions in the LDP are given voice in order to maintain party unity, and this has created an LDP and bureaucracy that are fairly responsive to the broad electorate (Johnson, 1982, 46; Pyle, 1996; Flath, 2000). The Diet thus has "served as a mediator between the state and society, forcing the state to accommodate those interests that can not be ignored... and on occasion, requiring the state to change course in response to serious problems such as pollution" (Johnson, 1982, 50). Nevertheless, it is clear that the state administrative bureaucracy enjoys a higher level of power, independence, and freedom in Japan than is the case in the US. Interestingly, this factor endows Japanese bureaucratic ministries with an increased ability to effect technical change

[307] In 1958 for example the cabinet introduced 175 bills and saw 144 enacted, the lower house introduced 68 bills and saw 15 enacted (Johnson, 1982, 47).

as compared with bureaucratic agencies in the US, such as the DOD. Augmented bureaucratic power, when conditioned by adequate checks, monitoring, examination procedures, and norms of national service, as it is in Japan (Johnson, 1982, 57; Pyle, 1996; Anchordoguy, 2005; Flath, 2000; Goldsmith, 1983; Ishi, 1993), actually presents a more streamlined and effective mechanism for the state-guided technological developmental processes inherent to the 'military expenditure impetus to mode of development shifts theory' as previously described. Thus, if anything, the Japanese political system is more conducive to state-led / market-embedded technological transformation than is America's political system. Hence, variation in the organization of political structure cannot account for the negative outcome on the dependent variable that obtained in Japan as compared with the positive outcome that obtained in the US.

Before we move onto the fiscal independent variables in the Japanese case, a word can be said about variation in patent laws across the two cases. Recall that of all the various property rights protected by the state, none is more important to the operative mechanisms in the 'military expenditure impetus to mode of development shifts theory' than patent laws (for market-generated technological innovation will not occur without them). As already mentioned, Japan's first patent law was passed in the late 1880's. The last significant amendment was in 1959, and "under the laws of both Japan and the United States, an invention must meet standards of novelty, utility, and non-obviousness if it is to be patentable." But the novelty requirement is somewhat diluted in Japan as compared with other countries

and a "minor modification of an already patented invention is far more likely to be considered new and, to that extent, itself worthy of patent protection in Japan" (Flath, 2000, 337; Pyle, 1996). Japanese patent laws are written in this way in order to promote rapid technological diffusion by promoting the early revelation of discoveries and encouraging the licensing of inventions on terms advantageous to users. This has helped Japan to successfully and swiftly adopt foreign innovations. It has also created a bias in Japanese technical markets in favor of incremental process innovations over innovations of a radical discontinuous nature (Flath, 2000, 7; 334-337). For obvious reasons, such a bias may have conditioned outcomes on the dependent variable in this study. Two points may serve to clarify why I believe this slight bias in favor of process technical change created by variation in patent laws across the two cases does not obviate the cross-national comparison now being conducted. To begin with, it is entirely plausible and likely that the Japanese state would have instituted patent laws more biased toward radical innovation had there been a defense sector in Japan that was constantly turning out new fangled radical technologies and technological systems, which of course leads us back to the primary independent variable of interest. More importantly (and less tautologically), the Japanese state has at times proven adept at inducing Japanese firms to engage in R&D aimed at farsighted innovation regardless of patent law minutiae, as indicated by the future oriented Pattern Information Processing Systems Program of the 1970s, or the Fifth Generation Computer Program of the 1980s, both coordinated by the famous Ministry of International Trade and Industry

(MITI). These programs and their sponsoring ministry will be discussed below; the point being made here is that, like in the US, market firms in Japan were unlikely to engage in high-risk technological innovation absent state inducements, and both the American and Japanese states became quite adept at providing those inducements whenever and wherever deemed necessary. Crucially, however, the methods and aims of the inducements often differed, and these differences, rather than variation across patent laws, did condition outcomes on the dependent variable, as will be thrashed out further subsequently.

Prior to the commencement of that discourse, slight cross-national variation in the fiscal variables will be surveyed. The first fiscal independent variable in the 'military expenditure impetus to mode of development shifts theory' is efficient centralized bureaucratic tax administration and collection. As previously alluded to, the bureaucracy in Japan has been meritocratic and hierarchical for over a century, dating back to the Meiji era, when the oligarchs sought to insulate the bureaucracy from political party pressure by instituting rigorous methods of examination and hierarchical promotion (Pyle, 1996, 123-5; Ramseyer and Rosenbluth, 1995). During the post WWII occupation, SCAP reforms reinforced the Weberian nature of tax administration by attaching a 'National Personnel Authority' to the cabinet which was in charge of overseeing the tax bureaucracy, conducting regular examinations, setting pay scales, and holding grievance hearings (Johnson, 1982, 42; Ishi, 1993, 31). Since that time, tax assessment and collection in Japan has been amazingly centralized and efficient (Ishi, 1993). It has

been both more centralized and more efficient than tax collection in the postwar US.[308] Additionally, as is well known, the postwar Japanese tax structure was explicitly designed to be widely supportive of investment in capital goods and technological development and diffusion, and has again, been more supportive of such investment than the US postwar tax structure.[309] Thus the type of variation exhibited in the tax incidence variable across the two cases suggests that the state in postwar Japan had an augmented capacity to lead a less burdened market toward the indigenous origination of novel infrastructural informational technologies. Hence, variation in the tax administration / tax structure variable across the two cases cannot account for the discrepant outcome on the dissertation's dependent variable.

The second fiscal variable in the 'military expenditure impetus to mode of development shifts theory' is sound public deficit finance. As previously described, Japan had developed a modern public deficit finance system prior to WWI. During WWII and immediately after, public deficit finance was anything but sound; although it was quite modern in form, the Japanese banking system

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[308] The Japanese government is much less federalized than the American government. Nearly 2/3 of all taxes in Japan are collected by the central government, a proportion significantly higher than in the US. Since tax collection by the central government as compared with local in both Japan and the US is more efficient when measured by the amount of tax collected per administrative employee, a more centralized system can be presumed to be more efficient. Also, when looking at aggregate tax collection, tax revenue collected per administrator is significantly higher in Japan than in the US thus indicating a higher level of efficiency in assessment and collection (Ishi, 1993, 56-62, 248-253; Flath, 2000, 218).

[309] "The government wished to enable Japan to revive its postwar economy more rapidly; thus, it... used the tax system more effectively to promote private economic growth. It is not easy to describe briefly the special character of Japan's tax policy in the 1950s and 1960s... there are two strains of postwar tax policy that are of interest: 1) an incentive tax policy to achieve specific policy goals; and 2) a successive tax cutting policy to maintain a lower level of tax burden" (Ishi, 1993, 38-9).

monetized government debt with abandon. Inflationary deficit finance was halted when SCAP imposed what became known as the 1949 'Dodge Line.'[310] The Dodge Line left the same basic public deficit finance structure in place, with the addition of some procedural curbs which limited the banking system's capacity to monetize debt.[311] Most importantly, the Dodge Line called for a strict annual balanced budget, a policy followed in Japan, for all intensive purposes, until the mid-1970s (Pyle, 1996; Ishi, 1993; Johnson, 1982). Thus the primary relevant difference between the US and Japanese systems of public deficit finance in the postwar era arises from the fact the US clearly used its public deficit finance system to fund defense-oriented radical technological development, while Japan did not use its system at all until the mid-1970's, and even then, public deficit finance funded social spending in Japan rather than technological development (Flath, 2000, 222; Ishi, 1993, 53-55). This should not at all suggest that the Japanese state did not fund and direct technological development and advanced R&D in the postwar era; it most certainly did. In fact, as will be shown, it did so through an autonomous state / market embedded mechanism remarkably similar to that used in the US DOD advanced weapons procurement system. However, the financing of embedded autonomous technological development in Japan took a somewhat altered form. Additionally, the aims were of an entirely different character. These alternate manifestations arose as a consequence of the defense-inspired nature of

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[310] Named for Joseph Dodge, a Detroit banker brought in by MacArthur to halt runaway inflation in Japan (Johnson, 1982, 187-190; Pyle, 1996).
[311] See Flath, 2000, 268-272, for more on these curbs.

the US embedded autonomous system of technological development as compared with the entirely civilian nature of the Japanese embedded autonomous system of technological development, and thus bear directly upon the discrepant outcome on the dependent variable in this study. To understand the why and how of it, one must first have a working knowledge of Japanese style state-led technological development, a topic to which we now turn.

THE JAPANESE DEVELOPMENTAL STATE:

The rapid rise of the Japanese economy to the top tier of industrialized nations had, by the 1980s, spawned a virtual cottage industry spinning out monographs seeking to illuminate and analyze the instruments of the Japanese developmental state. That being said, here only the broad outlines of the Japanese industrial planning model can be sketched. Our main purpose will be to draw out the similarities and differences between the Japanese developmental model aimed at achieving broad industrial advance, and the American defense developmental model aimed at providing national security. In so doing the case will be made that large-scale advanced weapons expenditure in postwar America helped to foment an economy primed for originating, adjudicating among, and incorporating radical discontinuous technological advances, while the lack of large-scale advanced weapons expenditure in postwar Japan contributed to the advent of an economy primed for incremental process innovation but deficient at generating, adjudicating among, and incorporating radical discontinuous innovations.

We begin where most studies analyzing Japanese industrial planning begin – with MITI. MITI is commonly considered the 'pilot' agency directing industrial development in Japan (Evans, 1995, 48; Johnson, 1982, 26). Although MITI is typically cited as the key coordinating agency, MITI is in fact only one among several bureaucratic agencies that have, at different times and in different sectors, coordinated industrial development in Japan. The tech-sector narrative below will focus on three: MITI which has been charged with the broad task of advancing the overall technological capacity of the Japanese economy, along with the Ministry of Posts and Telecommunications (MPT), and the administrative bureaucracy of Nippon Telegraph and Telephone (NTT – Japan's state subsidized telecommunications provider), which have both been charged with the narrower task of developing an advanced telecommunications infrastructure in Japan. Since these tasks often overlap in regards to information technologies, we frequently see these three bureaucracies cooperatively coordinating technological advance in the dissertation's informational infrastructural sectors of interest (Anchordoguy, 2005, 139; Castells, 1998, 221; Evans, 1995, 48-52).

There have been a plethora of interacting mechanisms used by Japanese ministries to direct and guide technological advance in sectors that have been targeted for state-led industrial development, including but not limited to: protection of domestic industry from foreign competition through the use of tariffs, quotas, and other measures; direction of resource distribution and private firm managerial decision via pervasive control over foreign exchange and technological

transfer; management of domestic competition through broad powers of licensing review; pooling of private corporate resources through induced formation of cartels, consortiums, and cooperative arrangements; direct subsidization and coordination of vast cooperative R&D efforts; and the accumulation and channeling of capital investment via the pervasive use of corporate tax incentives (Johnson, 1982; Anchordoguy, 2005; Flath, 2000; Castells, 1998; Solo, 1991).[312]

Japanese ministries have also often used what is known as 'administrative guidance' to steer private firms towards developmental goals. Administrative guidance can be defined as "private correspondences between bureaucrats and businesses that have projected Japanese government influence beyond the legally prescribed domains of regulation" (Flath, 2000, 197). Such informal guidance has allowed the Japanese state to successfully tread the sometimes thin line between overt governmental command and genuine private firm independence:

> "The government did not normally give direct orders to businesses, but those businesses that listened to the signals coming from the government and then responded were favored with easy access to capital, tax breaks, and approval of their plans to import foreign technology or establish joint ventures. But a firm did not have to respond to the government" (Johnson, 1982, 24).

Pertinently, 'administrative guidance' in Japan has been made effective by the many formal and informal embedded channels linking large Japanese firms to autonomous directive state bureaucracies. These embedded links have enabled

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[312] Requirements of parsimony prevent an in depth treatment of each of these mechanisms here. For an in-depth treatment of all the mechanisms of Japanese industrial planning see Johnson, 1982; Anchordoguy, 2005; Flath, 2000; Solo, 1991 amongst many other studies of Japanese industrial planning.

autonomous state agencies, such as MITI, MPT, and NTT, to negotiate technological trajectories through the use of informal contacts and formal contracts, along with arrangements that fall somewhere in between.[313] The intense Weberian nature of the Japanese bureaucracy has been touched on above – all of the ideal type conditions are filled or approximated, including meritocratic examination and promotion, hierarchal organization, prestige-laden long-term career paths, rigorous internal and external monitoring, etc. (Johnson, 1982, 55-67; Evans, 1995, 50; Solo, 1991, 46-48; Castells, 1998, 222; Pyle, 1996, 257-8). The links that embed autonomous state agencies in the Japanese market are similar to those in the US defense procurement system which were previously described – 'deliberation councils' where bureaucrats, business leaders, and academics discuss current and future economic prospects and potentials; numerous other formal and informal, continuously operating 'forums for exchanging views, reviewing policies, obtaining feedback, and resolving differences'; and most importantly the formal practice of amakudari (descending from heaven) where ministry alumni accede to key positions not only in individual corporations, but also in the industry associations and quasi-governmental organizations where decisions over production are often made (Evans, 1995, 50; Anchordoguy, 2005, 41; Johnson, 1982, 70-71, 318).[314]

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[313] Informal contacts have historically been more important than formal contracts in Japan's extra-legal form of administrative guidance (Johnson, 1982, 85).

[314] Interestingly, few if any social theorists here or abroad decry amakudari. In the eyes of the American left such interconnections when present in the defense industry smack of predatory corruption; when switched to the milieu of Japan, such connections transform into an institutional

One further aspect of the Japanese developmental state that needs to be broadly outlined before we can proceed to analyzing the differential outcomes that arose as a consequence of the non-defense-inspired model of state-guided technological advance in Japan, as compared with the defense-inspired model present in the US, relates to the funding of developmental projects. Whereas the US has used a classic public deficit finance model to fund technological development for national security, postwar Japan has used a very different model of finance to fund broad industrial advance, as previously suggested. In the Japanese system, the Ministry of Finance (MOF), and MITI in a secondary more advisory role, manages a 'second budget' known as the Fiscal Investment and Loan Program (FILP). Most of the funds that capitalize Japan's developmental programs come from FILP. FILP was established in 1953 when the MOF pooled domestic Japanese postal savings accounts and pensions. By far the largest source of funds for FILP is the postal saving system, which was established in 1875, and through preferential tax treatment, grew in the postwar era to become one of the largest depository institutions in the world.[315] In order to protect this large pool of savings, but at the same time make it available for targeted investment in strategic industries, the MOF chartered, in 1951, the Japan Development Bank (JDB) – a not for profit financial intermediary charged with investing FILP funds for the

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basis for a wonderfully successful state led corporate program of industrial and technological transformation. Although it should be mentioned that exchange of personnel between state agencies and private firms in Japan rarely involves movement from the private to the public sector as it often does in the US (Peck and Scherer, 1962; Weber 2001; Gregory, 1993; DiFilippo, 1990; Johnson, 1982).

[315] During 1980 the total amount of postal savings was estimated at nearly ¥55 trillion, or four times the assets of the Bank of America, the world's largest commercial bank (Johnson, 1982, 210).

betterment of the Japanese national economy.[316] The JDB, using FILP savings, makes large conditional loans at below market interest rates to Japanese firms. These loans are designed by the MOF to spur corporate investment and outlays in order to achieve the targets and goals delineated by MITI. Thus, rather than selling bonds on the international market to raise capital for expenditure, the Japanese system of raising funds for development capitalizes upon the Japanese citizenry's propensity to save by making household savings accessible to the JDB, which in turn loans the savings out at advantageous rates to firms participating in MITI's developmental programs (Johnson, 1982; Flath, 2000; Anchordoguy, 2005).

Although the JDB's total outstanding loan portfolio typically amounts to no more than that of one major Japanese 'city bank', a JDB loan indicates to the numerous large city banks of Japan that a sector and its major corporate players have been targeted for development. Hence, private Japanese banks come to view this sector as less risk laden, and they too begin offering loans at competitive rates to the major firms in the targeted industry. This has led to a pattern of financial dependencies in Japan in which "a group of enterprises borrows from a bank well beyond the individual companies' capacity to repay, or often beyond their net worth, and the bank in turn over-borrows from the Bank of Japan. Since the central bank is the ultimate guarantor of the system, it gains complete and detailed control over the policies and lending decisions of its dependent private banks" (Johnson,

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[316] The Japanese Export-Import Bank is another state controlled financial intermediary that has access to FILP funds. Since the Export-Import Bank deals mainly with balance of trade issues rather than domestic technological development, it will not be a focus here (Johnson, 1982; Anchordoguy, 2005).

1982, 203). However, the BOJ has become, after a fierce struggle in the 1950s which the BOJ lost, little more than 'an operating arm of the Ministry of finance' (Johnson, 192, 10). Thus it becomes clear that the maze of financial dependencies created by the Japanese developmental state's method of financing industrial planning has empowered the MOF and MITI to wield "tremendous indicative powers over the whole economy as a result of their decisions to make or refuse policy loans" (Johnson, 1982, 201; Anchordoguy, 2005; Flath, 2000; Goldsmith, 1983).

Perhaps the most significant consequence of this extraordinary method of financing industrial advance is that it allowed the Japanese developmental state to operate on a balanced budget for the two decades between 1955 and 1975; a time in which the size of the Japanese economy multiplied some 55 fold, with industrial production rising nearly 1500%, amid low inflation (Johnson, 1982, 6; Solo, 1991, 52). In the US, on the other hand, the average yearly deficit over this same period was approximately $7.4 billion, the economy multiplied just over 2.5 fold, and inflation was stoked sufficiently to unleash a historic price rise upon the world.[317] By channeling Japanese disposable income into savings (via a variety of tax incentive and other structural measures), and by loaning this pool of savings to firms, rather than deficit financing pure expenditure, the Japanese state was able to promote industrial capital goods development while at the same time maintaining a pitch perfect environment for rapid technological diffusion (Johnson, 1982;

[317] Data sources as reported in the US case.

Anchordoguy, 2005; Ishi, 1993). However, as will be discussed in some detail below, this formula for financing technological advance, which proved wonderful at stimulating incremental process-oriented innovations in established high-tech sectors, was not at all conducive to the indigenous origination of radical type innovations of a discontinuous nature.

Now that the organizational forms and institutional processes of the Japanese developmental state have been broadly sketched, let's focus a bit closer on the similarities between this system and the US system of defense development; then we'll focus more intensively on the key differences and differential outcomes produced by the two alternative systems. The similarities at the level of effect are fairly obvious, although at times the methods employed have been somewhat distinct, for example: The Japanese protect domestic industries targeted for development through the use of tariffs and quotas, while strictures of national security insure that the US market for defense production is protected from international competition; Japanese bureaucratic ministries manage domestic competition via broad powers of licensing review, the DOD manages competition in the defense industry by distributing contracts in manners that maintain a competitive but not overly competitive industrial base for defense production; MITI will often compel technological transfer within a targeted industry, US defense agencies will often do the same; lead Japanese ministries often suggest mergers and consortiums in key industries, so too does the DOD; in Japan MITI and NTT often subsidize and organize cooperative R&D efforts, the DOD does this

as well, although it tends to farm out systems integration tasks to a wider variety of firms and universities than is the case in Japan; Japanese ministries guide fixed capital investment in targeted industries through the pervasive use of tax incentives and credits, and as discussed in the American case, the DOD does the same in the defense sector (Johnson, 1982; Flath, 2000; Flamm, 1996, 109; Hooks, 1990; Peck and Scherer 1962; Scherer, 1964; Fox, 1974; Weber, 2001).

The embedded autonomous nature of both the Japanese industrial planning system and the US defense procurement system have been outlined above so little more in regards to this structural similarity needs to be said here. It is interesting, however, to note that the systems look similar specifically because Japan deliberately modeled their industrial planning techniques on the procurement methods of the DOD.[318] With the main caveat being that Japan intended to apply the US defense procurement model much more widely and with an altered goal of broad technological 'catch-up' rather than advanced weapons production (Anchordoguy, 2005, 74-93).

This of course brings us to the first consequential difference between the US embedded autonomous defense-inspired system of technological advance and

[318] The first national developmental project in Japan after the occupation revolved around constructing a modern telecommunications infrastructure. In order to attain this goal, the Japanese bureaucracy quite intentionally set out to ape the organizational forms exhibited by the Pentagon and its allied contracting firms: "The Diet was given the authority to approve NTT's budgets, investment plans, and price changes... like the US Pentagon, NTT and its labs were to nurture a strong family of firms that would provide the essential technological underpinnings of the electronics industry... NTT's main lab was reorganized... and modeled after the Bell Labs system"; 'NTT acted as a surrogate Pentagon'; NTT paid its contractors on a cost-plus basis; 157 top executives at the top ten telecommunications construction firms were former NTT officials, etc. (Anchordoguy, 2005, 74-92).

Japan's more widely applied model; rather than focus on defense, the Japanese ministerial bureaucracies "stimulated the movement of capital and labor out of declining industries such as coal and textiles and into promising new industries with high growth potential – first into electronics, steel, petrochemicals, and automobiles, and later into computers, semiconductors, and biotechnology" (Pyle, 1996, 247; Johnson, 1982; Anchordoguy, 2005; Hooks, 1990; Solo, 1991). The clearly articulated goal of the Japanese state in doing this was to utilize peaceful economic competition in order to "obtain leverage over other countries and bolster their own national security and autonomy" (Anchordoguy, 2005, 25). The first step in the state's articulated process of attaining security through heightened economic competitiveness consisted of quickly and cheaply importing advanced foreign technology in key 'strategic' industries; the next step consisted of applying this technology to domestic industry intelligently and extensively; next came 'catching-up' to the current industry leaders; finally, the goal was to permanently surpass the current industry leaders (Johnson, 1982; Evans, 1995, 216; Flath, 2000; Pyle, 1996). In regards to the key infrastructural informational technological sectors focused upon in this study, the Japanese state proved incredibly adept at each step of this articulated process, *excepting the last* (Anchordoguy, 2005; Beason and Patterson, 2004; Flath, 2000; Flamm, 1996). The case will now be made that a conspicuous lack of advanced weapons expenditures left Japan with an economy ill-suited to leadership in the rapidly changing infrastructural information technology sectors that were originally born of US defense expenditure aimed at

radical technical change. The deficiencies were masked in the1980s owing to the deleterious effects of continued massive weapons expenditure in the US, but became uncovered in the post Cold War 1990s, a period of heightened informational take-off wherein radical discontinuous innovational design capability trumped incremental process-oriented innovational competence.

The overarching abstracted theoretical hypothesis being employed here can be stated thusly: *In conditions of rapid technological change characterized by high degrees of uncertainty, an economic system will work best if it 1) provides a wide diversity of technical options, and 2) has flexible mechanisms enabling an effective narrowing of the technical choices opted for (Ruttan, 2006; Johnson, 2001).* During the 1990s, a decade wherein the informational mode of development shift progressively accumulated and reached critical mass, US firms out-competed Japanese firms precisely because the US economy scored better on measures 1 and 2 above. It did so as a partial albeit significant consequence of decades-long advanced weapons expenditure. Conversely, the Japanese economy did not score well on measures 1 and 2 largely because they were comparatively deficient in the institutional structures and processes that facilitated radical discontinuous innovation and market adjudicated technological diffusion in the post WWII US – institutions and processes which developed primarily as an unintended consequence of outsized advanced weapons expenditures intermittently interacting with the underlying commercial market, as previously depicted throughout the American case.

In regards to measure 1 above, it is has already been shown that the US defense procurement system was designed to attain as much novel radical innovation as possible, with hardly any strictures on cost or objective. The Japanese state, on the other hand, clearly targeted for development only those few infrastructural informational technologies which had already emerged as global winners. Japanese ministerial bureaucracies provided select large firms in Japan with the subsidies and incentives they needed in order to be able to successfully reverse-engineer these technologies and then further enhance production processes for them through incremental innovation (Anchordoguy, 2005, 140; DiFilippo, 1990; DeGrasse, 1983; Solo, 1991; Flamm, 1988; Flamm 1996). In this way, a few large, essentially vertically integrated, Japanese firms (Hitachi, NEC, and Fujitsu most notably) were able to 'catch-up' to US firms in some key infrastructural information technology sectors – such as DRAM semiconductors and mainframe computers– by the mid 1980s. But then, just as leadership in these sectors was passing to these Japanese firms, the firms began to falter (Anchordoguy, 2005; Flamm, 1988; Flamm, 1996).

As will be demonstrated in the narrative section following this theoretical section, there were three main reasons for this. The first relates to the cartelized and state dependent nature of the leading Japanese firms that became competitive in DRAM and mainframe production. The magnitude and 'over-loaned' basis of these mega-firms' capital investments made it impractical for these firms to exit DRAM and mainframe production once it had become clear that the highest value-

added segments of the computer and semiconductor industries were revolving away from mainframe and DRAM production and towards PC production and micro-processing design. Failure of these mega-firms, with tentacles in nearly all aspects of Japanese economic production, was simply unconscionable. Therefore, these firms, with the support of the Japanese developmental state, concentrated even more intensively on segments of informational production that were obviously declining, to their ultimate detriment (Anchordoguy, 2005; Flamm, 1988; Flamm, 1996).[319] Because defense spending in the US had promoted the formation of fairly diverse and competitive information technologies markets characterized by a plethora of horizontally integrated specialized firms, and since the capital investment decisions of the resultant commercial information technologies firms

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[319] Marie Anchordoguy (2005) has persuasively argued that Japan's heightened attentiveness to communitarian norms contributed to this pronounced inflexibility and inability to transition. I would not necessarily take issue with that point. However, I am arguing that this inflexibility can also be understood, by looking through a comparative prism, as an outcome driven by postwar Japan's inexperience with independent radical innovation; experience that surely would have been gained had there been a long-term need for advanced weapons development. To support this argument I have shown how the American market, when left to its own devices, also did not produce the kind of radical discontinuous commercially inapplicable technical advances inherent to and embodied in infrastructural informational technologies. Only defense expenditure was capable of fomenting such advances, and, as has been shown and will be discussed a bit more below, the commercial American economy in aggregate only developed the institutions necessary to rapidly and flexibly incorporate radical IT innovations after decades of interaction with massive advanced weapons expenditures. If it is shown that the crucial institutions that post WWII Japan needed, but lacked, in order to be able to develop and incorporate radical technical IT innovations, originally formed in the US as a result of advanced weapons expenditures, then the case for military expenditure as a crucial explanatory factor accounting for discrepant outcomes on the dependent variable has, I believe, been made. In any case, firms from just about every developed nation on the planet encountered more difficulty transitioning to the informational age than did winning US firms. Many of the firms that encountered transitional difficulty hailed from nations with a conspicuous lack of communitarian norms, such as Great Britain. Great Britain, like Japan, spent very little on advanced weapons development; rather, Britain's advanced weapons were imported from the US. Analyzing post WWII Britain further would perhaps pose some difficulties for Anchordoguy's thesis vis-à-vis my own, but it would also take us too far a field from the important Japanese comparison now being conducted.

were not state directed or subsidized, the US semiconductor and computer sectors, in aggregate, had little trouble making discontinuous transitions, with new firms rising and old firms falling as necessary (Flamm, 1988, 1996; Cerruzi, 1998; Ruttan, 2006).[320]

The second reason why Japanese leadership in informational industries faltered just as it was getting started pertains to the acquired capacities of the Japanese engineering labor pool. In the US, defense expenditure aimed at radical innovation and discontinuous advance produced an American labor pool of IT engineers capable of incredible feats of designing and programming in conditions of pervasive uncertainty. This was not at all the case in Japan, where the Japanese focus on reverse-engineering and process-oriented change left Japan with a notable dearth of software and hardware design engineers capable of generating novel products appropriate for a rapidly and unpredictably changing market (Anchordoguy, 2005; Campbell-Kelly, 2003; Flamm, 1996; Cerruzi, 1998).

Thirdly, the funding system employed in the Japanese model of development greatly constrained the potential for risk taking, both in terms of technological development, and in terms of the market selection mechanisms for capital investment in new, uncertain, and unproven applications of information technologies. As previously described, the Japanese developmental state was able

[320] As show in the American Case, due to the need for innovative high performance products the US military was particularly inclined to take a chance on new specialized firms – for example, in 1959, new specialized firms provided 69% of the Pentagon's semiconductor purchases (Flamm, 1996, 32; Ceruzzi, 1998; Tilton, 1971, Hughes, 1998). As a consequence, new firms offering innovational design advances quickly rose and sometimes developed into 'giants' in the US, whereas there is a 'virtual absence' of specialized IT firms in Japan (Braun and Macdonald, 1982, 160-1; Flamm, 1988, 1996; Anchordoguy, 2005).

to promote and guide industrial advance on a broad front, while not stimulating inflation, owing to a rather unique method of funding developmental projects which entailed low cost loans distributed from the FILP. This mechanism proved proficient at supplying funds to large firms which were attempting to catch-up to US firms in already diffused and highly profitable technology sectors, but could not provide sufficient funds for leadership to be maintained in these sectors. It basically comes down to a matter of risk, along with the potential costs of failure. The US model of finance for defense-related technological advance could bear practically any level of risk, and any amount of failure, for any plausible length of time, until the desired technical advance was achieved. This was because defense contracting firms were not receiving loans from the DOD that one day had to be paid back. They were receiving CPFF contracts, which came with unlimited cost expansion possibilities. These CPFF contracts were backed by exchangeable publicly held bonds that drew from a massively large international pool of lenders that viewed the bonds as, for all intensive purposes, risk free. In other words, the funds available to the American state for radical defense-related innovation during the Cold War was essentially unlimited; whether the innovations one day yielded commercial applications and profits, or even important defense applications, was not particularly important.[321] The Japanese model of finance on the other hand was *over-loaning* 10% to 20% of the Japanese public's aggregate household assets to firms that were expected to make good and pay those loans back (Flath, 2000, 199-

[321] See the American case, especially the section describing the massively expensive SAGE project, which never ended up providing defense against any realistic threat.

200; Johnson, 1982; Anchordoguy, 2005). The only way to insure that these loans would one day be paid back was to target only those industries, and technological trajectories within those industries, where some level of profit was already assured (Johnson, 1982; Anchordoguy, 2005). It was paramount that the security of the public's savings and the loans of all the banks in the layered over-loaning system be maintained at all times. Otherwise, the entire economy might collapse; or at the very least, the stable non-inflationary / non-deflationary environment upon which continued high growth rested would be destroyed (Castells, 1998, 228; Anchordoguy, 2005; Johnson, 1982). Thus the risk bearing ability of the Japanese developmental model was profoundly curtailed by the method of finance employed by the Japanese state. Because the capacity for large expenditures where the likelihood of risk and failure was great was constrained in Japan, there emerged far less potential for radical discontinuous innovation.[322] For obvious reasons then, the American defense-related developmental system was far

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[322] A cursory glance at the funding levels provided by Japanese ministries for radical innovation as compared with US defense agencies in any particular time period serves to highlight this point. For example, between 1971 and 1980 MITI spent approximately $65 million on a program known as the Pattern Information Processing System (PIPS). No Japanese firm was willing to participate in PIPS via the typical loaning mechanism because PIPS had no immediate commercial applications. Thus MITI had to induce firms to participate by directly providing the funding for PIPS (Flamm, 1996, 82; 83; Coates and Holroyd, 2003, 25). Interestingly, PIPS was so far-sighted and vast, including research into areas such as advanced computer architecture, advanced software programming, peripheral development, lasers, all sorts of materials, spatial modulation devices, and LSI circuits, that it becomes somewhat comparable to US IPTO expenditures over this period. The IPTO was generally researching similar phenomena, although the IPTO's focus was actually narrower, thus making this comparison more favorable to the Japanese. Nonetheless, whereas MITI spent approximately $65 million on PIPS between 1971-1980, IPTO expenditures during this period totaled approximately $500 million. Total DARPA expenditures in this period, which is perhaps a more fair comparison, accumulate to just over $2.5 billion (Norberg and O'Neill, 1996). The point being that far more state-funding was available to US firms for radical innovation than was the case in Japan.

more likely to, and capable of, indigenously generating a smorgasbord of novel information technologies than was the non-defense-related Japanese developmental model. And as stated above, in conditions of rapid technological change characterized by high degrees of uncertainty, an economic system will work best if it provides a wide diversity of technical options (Johnson, 2001).

Moreover, continuous interaction between advanced weapons innovations and the commercial economy in the US during the Cold War engendered market institutions capable of efficiently adjudicating among various radical novel technologies; such mechanisms were lacking in Cold War Japan. Specifically, I am referring to the US venture capital market. As described in the American case, active and well capitalized venture capital markets became the primary intermediary mechanism enabling the rise of new specialized innovative IT manufacturing firms in the US; these oftentimes transitory startups allowed established US commercial firms to obtain, try out, and when successful, inexpensively incorporate radically new information technologies. Hence, it is not at all surprising that the rise of the US venture-capital market was intimately connected with the presence of a defense sector that was constantly spewing out new fangled information technologies (Ceruzzi, 1998; Ruttan, 2006; Braun and MacDonald, 1982; Riordan and Hoddeson, 1997; Saxenian, 1994; Campbell-Kelly, 2003).[323] There are other issues besides the absence of military expenditure that

[323] See the American case for some key links; specifically those related to the world's first VC fund named ARDC, which arose in order to spin-off WWII innovations and which also spawned DEC and the Route 128 explosion. Most Silicon Valley semiconductor firms and many early US

have limited the development of a Japanese VC market, such as communitarian norms viewing outsized profits deriving from capital investment as immoral (Anchordoguy, 2005, 54); so one cannot be sure that Japan would have developed a VC market even if the Japanese state had funded massive weapons expenditures. Nevertheless, it is clear that the US VC startup market, which became a crucial mechanism enabling US firms to attain and maintain global leadership in informational industries, arose as a partial and unintended consequence of advanced weapons expenditures (Saxenian, 1994; Cerruzi, 1998). Absent this crucial distributed market-mechanism for adjudication, Japan was unable to achieve lasting leadership in informational industries during the conditions of high uncertainty bred by the fusing mode of development shift of the 1990s. When combined with the non-radical process-oriented innovational system fomented in Japan during the decades of catch-up, along with the associated emergence of large inflexible firms dependent on a state guided system that was itself reliant on risk sensitive loans, the potential for Japanese firms to originate and blaze new influential informational trajectories was greatly reduced. This deficiency became particularly salient once catch-up had been realized in the mid 1980s (Anchordoguy, 2005; Flamm, 1996; Beason and Patterson, 2004). With the end of the Cold War in 1989, crowding out effects waned in the US, and flexible specialized US IT firms reoriented towards the commercial market, thus assuring the demise of Japanese leadership in the three key infrastructural information

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software firms were also rooted in defense spending (often via the indirect mechanism of human capital diffusion), and connected to the VC market as well (cites as reported in the US case).

technology sectors that compose the objects of interest in this portion of the dissertation, as will now be detailed.

THE JAPANESE SEMICONDUCTOR SECTOR – 1945-1999:

It is only fitting that we begin with the Japanese semiconductor sector for "in no high technology sector did Japan come as close to reaching its goal of global leadership as it did in semiconductors" (Anchordoguy, 2005, 177). The rise of Japanese firms in the semiconductor industry was predicated first upon the licensing of key technical breakthroughs and innovations from US defense-related firms, second upon production for a heavily protected domestic market, and later upon incremental improvements in chip manufacturing processes (Braun and Macdonald, 1982, 159; Flamm, 1996, 6, 45; Anchordoguy, 2005; DeGrasse, 1984, 96).

Japan's first semiconductor research was undertaken at NTT's Electrical Communication's Laboratory (ECL) and MITI's Electro-Technical Laboratory (ETL) beginning in 1952. The labs were given open access to Bell's pioneering 1947 research on germanium point contact transistors, and with this in hand, were able to reproduce the original Bell design in 1953. But the labs could not interest large Japanese industrial conglomerates in the fragile device, which most likely owes to the fact that there was no defense market in Japan; at this time defense applications provided the only notable market for transistors (Flamm, 1996, 39-41; Braun and MacDonald, 1982).

One small Japanese company, Sony, did however see potential in the device. In 1953, Sony's co-founder, Akio Morita, was sent to America to secure a license for germanium transistor technology from Bell Labs, "and he returned with a provisional signed agreement and a mountain of technical information" (Flamm, 1996, 43).[324] In late 1955, a year after TI had initiated and then abandoned transistor radio production in order to focus on the more profitable defense sector, Sony introduced a transistor radio; it became an immediate hit. Sony's transistor radios used inexpensive low-end hand soldered germanium transistors. Meanwhile, US semiconductor firms had moved onto producing high-margin high-frequency capital-intensive silicon transistors (Riordan and Hoddeson, 1997; Flamm, 1996; Braun and MacDonald, 1982; Vayrynen, 1992).

As it became clear that there would soon be a fairly wide market for transistors, the large industrial conglomerates of Japan, such as Hitachi, NEC, Toshiba, and Fujitsu, began manufacturing low-end low-yield germanium transistors for internal use in consumer electronics. Although US industry was extremely accommodating in regards to technology transfer in the 1960s, the quality of Japanese transistors continued to lag far behind that of American firms (Flamm, 1996, 45-8; Anchordoguy, 2005, 178). Nevertheless, due to the labor intensive nature of the low-end germanium transistor manufacturing process, Japanese firms were able to out-compete US firms in the early 1960s consumer electronics sector, where cost rather than performance was critical (Flamm, 1996,

[324] Note that Bell at this time had been directed by the military to maintain an open licensing policy for nations allied with the American Korean War effort, which Japan was (Flamm, 1996, 43).

48). The defense sector, however, remained the most profitable segment of the semiconductor industry, and US firms retained dominance there, as well as in the industrial capital goods market which was slowly incorporating high-end silicon transistors into production processes (Braun and Macdonald, 1982, 154; 159).

By the mid 1960's, decreasing costs of high frequency silicon transistors had made them more attractive for consumer applications, and a resurgence of American producers in the consumer electronics segment obtained. But as margins for silicon transistor production eroded, American firms increasingly shifted towards IC production, where profit rates were higher; once again leaving the consumer electronics segment to the Japanese (Flamm, 1996, 51; Braun and Macdonald, 1982). Recall from the American case that after 1965, a boom in business computing occurred, with business mainframes increasingly exhibiting IC architecture. This IC computer boom spurred MITI into action. MITI initiated an $80,000 IC R&D program, authorized a ten year JDB loan program worth a (relatively paltry) $16 million aimed at stimulating investment in IC production, and issued a ban on the importation of all ICs with over 34 circuit elements (DOD procured ICs approached 1000 elements at this time). Nevertheless, in 1966 imported ICs accounted for over 2/3 of Japanese chip consumption (Flamm, 1996, 60).

By 1970, US semiconductor firms had attained a commanding lead in the production of MOS LSI ICs (over 1000 circuit elements), which were increasingly finding their way into calculators. With MITI's help, Japanese firms had

developed a commanding presence in the domestic calculator market, but now came under increasing pressure to use powerful US MOS LSI ICs. Even with MITI support and the open licensing policies of US firms, Japanese firms had terrible difficulties mastering MOS LSI technology. MITI thus relaxed import restrictions on US LSI ICs, which were rapidly coming down in price as advanced weapons expenditures waned in the US. In 1971 American producers held 75% of the 'mushrooming' Japanese MOS LSI market (Flamm, 1996, 71-3; Anchordoguy, 2005, 181; Braun and MacDonald, 1982, 160).

In the mid 1970s, the federal share of semiconductor R&D in the US declined dramatically (again a consequence of waning weapons expenditures), just as it was rising dramatically in Japan (Flamm, 1996, 36, 113). Starting in 1973, MITI initiated a 2 year $123 million package of loans and R&D subsidies aimed at establishing competitive MOS LSI production facilities at Japanese semiconductor producing firms; the effort was successful, and by 1975 the US share of the Japanese IC market had fallen to 20% (Flamm, 1996, 85; Anchordoguy, 2005, 183). Still, Japanese industry was commonly viewed as being 2-3 years behind the US in regards to production of the most advanced ICs; a situation which MITI and NTT now sought to remedy. In 1975, NTT initiated a program targeting VLSI chips (over 100,000 circuit components) which was budgeted at $67 million over two years. Later that year this program was coupled with a MITI led VLSI program, budgeted at $236 million over three years, which subsidized and coordinated the semiconductor research of five large Japanese industrial

conglomerates – Fujitsu, Hitachi, NEC, Toshiba, and Mitsubishi. The goal was to produce higher capacity DRAM chips than commercially feasible at the time by researching different production techniques in order to figure out "how best to draw narrower lines on wafers and thereby be able to more densely integrate circuits." Tellingly, a quarter to a third of the project's funding was 'spent on the purchase of the most advanced semiconductor manufacturing equipment available in the US'; Japanese technicians then reverse-engineered and improved upon the American machinery (Flamm, 1996, 102-111). Combined, both VLSI program efforts ended up spending approximately $460 million between 1975 and 1979, with roughly half of the funds provided by the state, and the other half provided by the firms which were receiving low interest JDB loans (Flamm, 1996, 93-98; Anchordoguy, 2005, 136).[325]

The results of the Japanese VLSI programs were indisputably spectacular: in 1978 Japanese firms captured 40% of the global 16K DRAM market; later that year the VLSI consortium beat American firms in the race to prototype the first 64k DRAM; by 1981 Japanese firms had attained a 70% share of the US 64k market; in 1988 Japanese firms captured 65% of the overall global DRAM market

[325] Although such figures may seem large, the expenditures should not suggest a heightened appetite for risk on the part of MITI and NTT. By this point the aggregate value of global IC production had reached approximately $2 billion per annum (Tilton, 1971; Braun and MacDonald, 1982). Japan's aggregate VLSI program expenditure for one year (approximately $92 million) divided by the total annual international market yields a ratio of .046. Such a low ratio indicates limited risk; the effort was all but guaranteed to result in some profitable applications given the size of the market. In any year prior to 1963, such a ratio for US federal expenditure in the IC market would yield over 1, as US defense procurement accounted for the entire IC market and R&D expenditures would also need to be added to this (Tilton, 1971; Braun and MacDonald, 1982). By this metric, US expenditure in the early IC market should be viewed as significantly more risky than any subsequent Japanese expenditure.

(Anchordoguy, 2005, 184; Flamm, 1996, 23, 99; Varynen, 1992, 76). This meteoric rise of Japanese market share in DRAM production was also buttressed by the terribly poor climate for fixed capital investment that obtained in the US during the mid 1970s to mid 1980s; a significant consequence of the defense expenditure related 'great inflation.' Just as leading US semiconductor firms were encountering increasing difficulties in raising capital for fixed investment, the MOF directed Japanese banks to increase their lending to domestic DRAM producers. This enabled Japanese semiconductor firms to invest 31% of sales in plant and equipment in 1983, while US firms invested only 13% (Flamm, 1996, 15).

Before we move on to the 1990s, it is important to recognize that the Japanese VLSI programs did not actually produce any new IC forms or architectures; rather, manufacturing processes were enhanced. Japanese VLSI "was not intended to produce major breakthroughs in the fundamental technologies of the integrated circuit; it did however do a remarkable job of extending and improving on technological concepts already developed or under development overseas" (Flamm, 1996, 100). Interestingly, "The abstract logical design of a DRAM is simplicity itself, the endless repetition of a simple cell, and easily mastered; the details of its implementation and manufacture are everything" (Flamm, 1996, 9). Thus, DRAM manufacture meshed well with Japan's technological strengths, which in the postwar era have rested on process rather than design innovation. Such process innovations typically flow from production in large vertically integrated conglomerates, and this was essentially the case in Japan

(Anchordoguy, 2005; Flamm, 1996; Braun and MacDonald, 1982). Conversely, American comparative advantage in high-technology markets during the postwar era has, as previously discussed, tended to rely on design innovations flowing out of independent specialized firm production. This difference is surely a partial, if not total, consequence of decades-long advanced weapons expenditures in the US (Ceruzzi, 1998; Flamm, 1996; Tilton, 1971; Braun and MacDonald, 1982).[326] Indeed, the importance of specialized design to advanced weapons procurement guaranteed that US semiconductor firms would on aggregate be quite preoccupied with defense orders during the defense expenditure rich 1980s (DiFilippo, 1990; Vayrynen, 1992; Goldstein, 1991; Gregory, 1993).

The rise of PCs and distributed computer networking in the US foreordained a shift in the semiconductor industry where design would come to take precedence over process. Large integrated process-oriented Japanese semiconductor firms were not well prepared for such a shift (Anchordoguy, 2005, 178). After the Cold War ended US semiconductor firms with a comparative advantage in design turned to take advantage of the distributed network / PC trends. Consequently, the capabilities of American made microprocessors multiplied while prices plummeted. As crowding out effects abated, US semiconductor firms increased their capital investment from 14% of sales to 22% of sales between 1991 and 1994; with the increased investment being tightly aimed at enhancing

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[326] See note 320 above. Also, 'Japan did not follow the US pattern of independent specialized semiconductor firms. 72% of Japanese semiconductor production in the 1970s was undertaken by firms that had been participating in the vacuum tube based electronics market since the 1950s' (Braun and MacDonald, 1982, 160-1).

microprocessor design and production. Meanwhile, Japanese semiconductor firms found themselves locked into DRAM production; these vertically integrated behemoths had tied up so much of their capital in DRAM fabrication that quickly exiting DRAM production would be tantamount to a declaration of insolvency. Besides, process-oriented Japanese semiconductor firms had no comparative advantage in the exploding microprocessor market where design had become paramount. As a consequence, the Japanese state endorsed continued large-scale investment in DRAM production, even though the market for DRAM was rapidly taking on characteristics of a low value added commodity (Anchordoguy, 2005, 184-194; Flamm, 1996, 426). By 1998, amid a PC networking boom, US firms had once again attained a majority share of the worldwide semiconductor market at 54%, while Japan's share had plummeted from a high of 51% in 1988 to a nadir of 28% in 1998 (Anchordoguy, 2005, 189).

After three decades of playing catch-up, Japanese firm leadership in the semiconductor sector persisted for less than a decade. The leadership period was characterized by a market preference for DRAM semiconductors where process trumped design; and was buttressed by, first, a terribly poor climate for capital investment in the US, and then, by an American semiconductor industry preoccupied with defense production (Flamm, 1996; DiFilippo, 1990). Merely three years after the end of the Cold War, the share of the global semiconductor market held by US firms surpassed that of the Japanese (Anchordoguy, 2005, 189). Over the course of the Post WWII era, US military expenditure undoubtedly proved

to be, at varying intervals, both a gift and a curse to American semiconductor firms. Given Japan's 'free ride' supported rise to the zenith of the global semiconductor production hierarchy, and its precipitous 'innovational design-incapacity inspired' fall, the same could be said for Japan. In light of Japan's inability to sustain leadership in the semiconductor sector, it becomes all too apparent that the Japanese non-defense-inspired model of technological advance would have proven insufficient to indigenously originate semiconductor technologies had the US defense-inspired model of technological development not already done so; thus indicating that military expenditure was an indispensable element in the processes fomenting the informational mode of development shift.

THE JAPANESE COMPUTER SECTOR – 1945-1999:

The history of the Japanese computer industry largely parallels that of the Japanese semiconductor industry. Success was achieved via MITI coordinated technological transfer and inter-firm cooperation, the domestic market was heavily protected well into the 1970s, and Japan gained comparative advantage in mainframe and peripherals production through process oriented improvements to manufacturing techniques. However, in this sector, leadership was never quite wrested from American firms which adapted more flexibly to rapidly changing conditions than did their Japanese counterparts (Flamm, 1988; Anchordoguy, 2005; Evans, 1995).

Japan got off to a late start in computer production. In 1955 MITI's ETL completed work on the nation's first domestically produced digital computer, which was modeled on a dated IBM machine. In 1957 a broad consensus formed within MITI and its related ministries that Japan would require computers if it was to attain competitiveness with the US, and that a domestic computer industry should therefore be created (Anchordoguy, 2005, 127). In the late 1950s MITI initiated financial assistance to selected manufacturers; various protectionist measures were put in place; inter-firm cooperative R&D efforts were organized; inter-firm cooperative cartels were formed; loans from the JDB were extended; and tax credits and benefits for capital investments in line with MITI's administrative guidance were enacted.[327] The three main corporate beneficiaries of these targeting measures were Fujitsu, NEC, and Hitachi; which all offered computers on the commercial market by the early 1960s. However, these computers lagged far behind those being offered by American firms in regards to quality, reliability, speed, processing capability, memory capacity, memory mechanism, and overall architecture (Flamm, 1988, 176-179; Anchordoguy, 2005).

Undoubtedly, "IBM was the standard by which MITI and the industry measured its success during catch-up from the 1960s through the early 1980s" (Anchordoguy, 2005, 128). In order to access IBM technology, MITI used its broad powers over licensing and foreign exchange to acquire IBM patents cheaply in return for production rights in Japan. Outside of this deal, Japanese controls on

[327] The total worth of R&D subsidies awarded for computer development in Japan over the years 1957-1961 was less than a $1 million (Flamm, 1988, 179).

foreign computer investment were tight; most investment was repelled, restricted US investment was only allowed in exchange for broad technology transfer rights, and majority owned foreign subsidiaries were strictly forbidden. Still, by 1963, only 3 full sized computer systems had been domestically produced and installed in Japan, approximately 70% of the installed base of small and medium sized computers in Japan were American made, and "It was not until 1965 that the first truly large-scale computer built in Japan, by Hitachi, went into operation" (Anchordoguy, 2005, 128; Flamm, 1988, 178-182).

During the late 1960s and early 1970s MITI coordinated a handful of programs aimed at 'catching-up' to the IBM System / 360 computer series. The most notable of these was the 'Super High Performance Computer Project', to which the government committed approximately $33.5 million between 1966 and 1972. The effort did not create a computer line competitive with the IBM System / 360, but it did bring Fujitsu, NEC, and Hitachi computers closer to IBM's in terms of memory capacity and speed. Interestingly, 25% of the projects funds were devoted to the development of what was intended to be Japan's flagship software company, the Japanese Software Company (JSC). With the US DOJ forcing IBM, in 1969, to unbundle its software and provide details on the inner workings of its OS so that outside companies could produce software that would run on IBM machines, one would imagine that JSC would meet with some success. However, JSC went bankrupt in 1972. A lack of capable software design engineers and a stubborn refusal on the part of the fiercely protectionist Japanese mainframe

producers to standardize and open their proprietary operating systems sealed the fate of JSC (Coates and Holroyd, 2003, 24; Anchordoguy, 2005, 133, 154).

Meanwhile, in the US, software design engineers were leaving the defense industry in droves, raising venture capital, and starting small firms. These firms participated in what became a 'packaged software' boom in the US. As described in the American case, decades of advanced weapons expenditures built up a deep labor pool of software design engineers in the US, basically from scratch. The knowledge, skill, and innovational capacity of this labor pool was transferred to the commercial market via the venture capital market which itself was a concomitant consequence of advanced weapons expenditures (Ceruzzi, 1998; Saxenian, 1994; Campbell-Kelly, 2003; Campbell Kelly, and Aspray, 2004). Absent a domestic pool of accomplished software design engineers and a VC market capable of bringing small specialized firms to the surface, Japan's software industry never really got off the ground (Anchordoguy, 2005, 147-177).

Nevertheless, MITI and the big Japanese computer three continued to push forward in mainframe hardware markets. MITI's officially titled New Series Project (3.5 Generation informally), which cost the state $235.5 million over the years 1972-1976,[328] was "perhaps the most critical project in terms of helping domestic firms gain a comparative advantage in hardware" (Anchordoguy, 2005, 13). The project enabled Fujitsu, Hitachi, and NEC to manufacture mainframes

[328] Again this expenditure seems less large and not at all risky when one realizes that the international computer industry was by this time generating many multiple billions in revenue per annum (Ceruzzi, 1998; Flamm, 1988).

and peripherals on par with the popular IBM System / 370. Notice that this state-subsidized project coincides with the terribly poor economic environment for private capital investment bred by the US centered great inflation. Major US mainframe manufacturers, such as RCA, GE, and Honeywell exited the market; state-supported Japanese firms rose to fill the breach (Flamm, 1988, 192-4; Coates and Holroyd, 2003, 25; Anchordoguy, 2005, 135).

As crucial as the New Series Project was, it was perhaps less important to Japanese competitiveness in mainframe and mainframe peripherals production than Fujitsu's 1972 investment in the Amdahl Company. Amdahl Company was started in 1970 by Gene Amdahl, whom had worked on computers in the US during WWII before moving onto IBM where he participated in the SAGE and STRETCH defense projects. Amdahl also was a lead design engineer on the IBM / System 360 development team (Ceruzzi, 1998; Flamm, 1988). By 1972 Amdahl Company had fallen on hard times and was in desperate need of a capital infusion; given the economic climate in the US, it is not surprising that this infusion came from abroad. "In 1972, for the purchase of 24% of Amdahl's equity, Fujitsu was given the right to exchange technical information with Amdahl." In 1974 Fujitsu began manufacturing computers in Japan for Amdahl to sell into the US market. This was a critical turning point for the Japanese computer industry. At last it "acquired the ability to produce computers competitive with the latest IBM models." In the late 1970s the head of Fujitsu was asked how his company was able to maintain technical parity with IBM and he replied "If you want me to come right out and say

it, our method is the Amdahl Company; highly reliable information is funneled through Amdahl" (Flamm, 1988, 195; Evans, 1995; Anchordoguy, 2005).

By the early 1980s Japanese firms presented a significant threat to US firm leadership in high speed mainframe hardware and peripherals, especially in international markets (Calder, 1989, 13). MITI sought to push growing Japanese advantage. For two decades Japan had chased IBM in the race to build more powerful, more capable, faster mainframes and peripherals. Leadership was now within grasp, just one more technological leap and Japanese firms would indisputably front the pack. So began 1982's Fifth Generation Computing Systems Project, a ten year MITI orchestrated program budgeted at $900 million, with the state providing 50% of the funding and the big computer three providing the other 50%. The goal was to build an epochal commercially marketable parallel processing supercomputing mainframe with vast artificial intelligence capabilities (Anchordoguy, 2005, 160-2; Ruttan, 2006).

Meanwhile, in the US, the distributed processing paradigm was taking hold. Small general-purpose computers arranged in distributed networks were consigning mainframes to the dustbin of history. Firms like DEC, HP, SDS, Apollo, and Sun Microsystems, which had taken the defense-related market-based VC route to success, were slugging it out in the fiercely competitive minicomputer / workstation market. Underneath this segment of the market their brewed a PC revolution, where design knowledge that had been gained via advanced weapons development was being transmogrified though commercial market interaction and

indirectly applied. The US computer market was taking a decisive and largely unanticipated shift; new firms were rising and old firms were falling as the gales of creative destruction blew through the computer and software industries (Ceruzzi, 1998; Campbell-Kelly and Aspray, 2004).[329]

By 1990, it had become clear that MITI and the Japanese big computer three had entirely misread the tea leaves. "Because all of the firms had followed each other and the state in focusing on large centralized computers, they failed to foresee the shift in technology leading towards smaller, cheaper machines" (Anchordoguy, 2005, 163). To add insult to injury, the Fifth Generation program failed in almost all of its objectives; the press labeled the effort an 'abject failure', 'a fiasco', a perfect example of state-led technological planning gone awry (Castells, 1998, 222; Flath, 2000, 210). Most importantly;

> "When computing technology changed from centralized to distributed computing... Japan had no champions for the new technology. All of its computer makers were in the same business of producing mainframes. Users had to buy machines from DEC and HP. Soon afterward, when workstations emerged as the preferred approach for engineering, Japanese firms had no products to offer. Businesses had no choice but to purchase Apollo and Sun Microsystems machines or forgo the services these machines offered. The state and the firms had put all their eggs in one basket; they had supported a set of firms unable to adapt quickly to new technological paradigms" (Anchordoguy, 2005, 127).

By 1992 US dominance of the PC industry was a fait accompli. Windows-based GUI's powered by Intel, TI, and AMD microprocessors inside Dell, Compaq, HP, IBM, Apple, and Gateway computers began sweeping the globe. The international PC software sector, which, outside of low margin game production,

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[329] See the American case narrative for further associations, linkages, facts, figures, and sources.

contained no noteworthy Japanese manufacturers, was suddenly the fastest growing, highest value-added, multiple-billion dollar industry on the planet. MITI and the big Japanese computer three awoke from the dream of impending leadership into a nightmarish reality where competitiveness was slowly slipping away. The Japanese developmental state and its vertically integrated computer minions proved too big, too confident, and too centralized to compete with the distributed, flexible, specialized, design competent, US computer industry; an industry that through decades of interaction with advanced weapons expenditure had developed not only the tools necessary for broad scoped innovational capacity in conditions of wide ambiguity, but also effective market institutions capable of flexibly directing capital to winners as they emerged out of the cauldron of uncertainty inherently created within the confines of the radical, rapid, and discontinuous informational mode of development shift (Anchordoguy, 2005; Gaba, 2007; Ceruzzi, 1998; Campbell-Kelly, 2003; Castells, 1998).

THE JAPNESE COMPUTER NETWORKING SECTOR – 1945-1999:

No IT sector was marked by more uncertainty during its development than computer networking. As the crowning wave in an increasingly chaotic technological transformation, computer networking left no clear path to follow. The Internet emerged and mutated into an all encompassing entity with a palpable suddenness rare in human technological history. Thus it should come as no surprise that the Japanese developmental state turned out to be incapable of

charting a successful path for computer networking in Japan. Indeed, centralized, entrenched, state-based interests in Japan fashioned a veritable straight-jacket prohibiting Japan from 1) developing flexible decentralized modular computer networks, and 2) adopting American type network technologies and architectures once it had become clear that to not do so posed an immediate threat to future Japanese competitiveness; as will now be detailed.

We commence the narrative in 1976. The ARPANET had been in operation for five years and DARPA was experimenting with TCP/IP – a decentralized, flexible, open, non-proprietary, scalable, modular method of interlinking the DOD's growing portfolio of assorted networks. Around the industrialized world, monopolistic public telephone carriers (PTTs), such as Japan's NTT, were becoming increasingly aware that there was rising demand for digital data transmission. NTT decided to enter into an agreement with the European PTTs to develop their own inter-networking digital transmission protocol which would allow the monopolistic carriers to incorporate the growing market for data transmission into their existing monopolies (Abbate, 1999, 153).[330]

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[330] Interestingly, AT&T opted not to support this effort to widen the monopolistic scope of the public telephone carriers; there were two main reasons for this: 1) the DOJ had initiated an anti-trust lawsuit against AT&T in 1974 which sought to reduce AT&T's monopolistic privileges, especially in regards to computer networking (Quarterman, 1990, 649). 2) AT&T had already attempted and failed to thwart the DOD's efforts at implementing non-proprietary decentralized protocols for digital networking during its reluctant participation in the ARPANET effort. AT&T was 'at first resolutely committed to analog systems and dismissive of digital ones', viewing digital transmission as a potential competitor to their advanced analog systems, which had been attained at great cost. AT&T also did not support diversity in networking, and although the company agreed to participate in the ARPANET project, the creators of the ARPANET found AT&T 'unenthusiastic' about providing ARPANET's high speed telephone connections (Hughes, 1998, 274; Abbate, 1999, 163).

NTT and the European PTTs dubbed the protocol they eventually developed X.25. The first successful long-distance data transmission using X.25 occurred in 1978; one year after DARPA had achieved a global multi-network multi-medium computer to computer transmission using TCP/IP. Importantly, the PTTs conceived of digital data communications as little more than a simple extension of telephony; the point to point inflexible centralized architecture of X.25 certainly reflected this. In fact, NTT and the European PTTs were deeply disturbed by DARPA's radical vision of networking where computer to computer intercommunication had no central control mechanism; how would the PTTs charge for service? X.25 was designed so that all control over data transmission – its ordering, its timing, its routing, and its recovery – devolved to network switches centrally controlled by the public communications carriers. TCP/IP on the other hand let host computers and the message bits themselves determine these things; which was a radically new, decentralized, anti-hierarchical, less controllable, and therefore potentially much less lucrative method of organizing data transmissions. Moreover, X.25 was meant to work in only one communicational medium – telephone wires. X.25 had no gateway mechanisms to translate between communicational mediums; no gateways meant no modularity, no scalability, and no new network forms. The PTTs clearly preferred that new network mediums, new network architectures, basically new networks period, didn't emerge, as these would present competitive threats to their monopolies. Hence, X.25 was not decentralized, flexible, scalable, modular, or LAN compatible; all of the things that

make the Internet the revolutionizing force that it is today (Abbate, 1999, 152-166; Salus, 1995, 36).

In the early 1980s DARPA became entrenched in a pitched battle to compel adoption of the TCP/IP protocols; as described in the American case, the DOD did not want to be locked out of interfacing its powerful networks with the WANs of other nations. This would surely be the outcome if the PTTs of developed and developing nations opted to build X.25 networks en masse. Of course, this was just the sort of thing NTT and the European PTTs had in mind. Given the wild uncertainty surrounding WAN protocols, the Japanese Ministry of Posts and Communications (MPT), which had jurisdiction over protocols but had long ago been captured by the NTT bureaucracy, deferred to NTT amid US delegation protestations (Calder, 1989; Abbate, 1999). Never mind that X.25 was slower, more expensive, and more cumbersome than TCP/IP; profitability and nationalism dictated that Japan's data communications networks be built around X.25. By 1988, there were 8 domestic WANs in Japan that supported computer communication; all of them running X.25 (Quarterman, 1990, 624-5).

Of course, as detailed in the American case, DARPA eventually emerged victorious in the protocol wars. By 1989, NSFNET was up and running at T1 speed (1.54 million bits per second). Japan's X.25 networks were running at 9600 bps – six times slower than the original ARPANET and 160 times slower than the NSFNET. Absurdly, the Japanese X.25 networks also had no mail capabilities (Quarterman, 1990, 542; Salus, 1995, 200). Moreover, Japan's X.25 networks

were extraordinarily expensive to access and use, while connecting to the NSFNET required a onetime only set up fee for a connection line and router (Quarterman, 1990, 547; Abbate, 1999). After the Soviet collapse, Russia and the Eastern European States began building TCP/IP networks and LANs rather than X.25 networks; this was because the technology was in the public domain and thus 'no fees were payable.' Indeed, nation after nation began to queue seeking approval to connect to the US based TCP/IP NSFNET backbone (Salus, 1995, 124; Abbate, 1999, 209; Coates and Holroyd, 2003, 47).

Even though TCP/IP was clearly proving to be the globally preferred protocol, NTT and its associated cuckolded state ministry, MPT, remained unreasonably committed to X.25 during the late 1980s and early 1990s. NTT and its suppliers foisted X.25 technology upon the Japanese public, while MPT prohibited the importation of smaller, more powerful, more efficient, and cheaper TCP/IP routers for commercial use. Numerous Japanese network enthusiasts applied for MPT approval to build private TCP/IP networks; licenses were not granted. As European nations gave up on X.25, Japan's digital networks became increasingly isolated. In fact, the nation's only notable connection to the exploding world of international cyberspace was a small campus based UNIX network (JUNET) featuring pathetically narrow bandwidth (Coates and Holroyd, 2003, 46; Anchordoguy, 2005, 97-8; Quarterman, 1990, 542-543).

In the early 1990s, the NSFNET became the privatized international Internet backbone. American companies, which had been given a head-start in

TCP/IP applications by DARPA, exploded to the forefront of the Internet revolution. Once again, the US VC market acted as the crucial intermediate mechanism enabling the rise of new firms, and also allowing for the (sometimes not quite discerning enough) adjudication of winners and losers. Thus, as the 1990s progressed, it became increasingly evident that NTT and MPT were standing in the way of the Internet revolution in Japan. "On a wide variety of issues, Internet rates, telecommunications regulations, rules governing foreign companies, and the like, the Japanese government seemed oblivious to the needs and opportunities of the Internet" (Coates and Holroyd, 2003, 50).

After the mid 1990s, the NTT imposed straitjacket was gradually loosened, but it was already far too late; Japan was being consigned to second or third rate status amongst OECD nations in the burgeoning realm of TCP/IP communications and commerce (Coates and Holroyd, 2003; Anchordoguy, 2005).[331] In 1995 Japanese ISP providers offered miniscule bandwidth and spotty geographical coverage; only with the lifting of restrictions on foreign ISP presence did the Internet revolution truly begin in Japan (Coates and Holroyd, 2003, 49). In 1998 Japan was host to just over a million websites; by far the most popular of these was Yahoo! Japan. Meanwhile the US was home to well over 16 million web hosts and "the American military alone had as many websites as Japan" (Coates and Holroyd, 2003, 99; 127). Japanese communications equipment suppliers had been, for all

[331] In 1994 Japan had one twentieth the amount of networks as the US while nations which fell somewhere in the middle range of developed nations, such as Australia, had approximately double the Internet traffic of Japan. Japan continued to lag "woefully behind" in regards to Internet use and e-commerce into the 21st century (Coates and Holroyd, 2003, 40-49).

intensive purposes, shut out of the TCP/IP router, server, and storage markets, where American firms such as 3com, Cisco, Sun, Oracle, and Intel reigned supreme. Finally, in 2000, the Japanese government and NTT formally embraced IP technology, thus tolling the last death knell for X.25. NTT's unreasonable commitment to X.25 had not only cost the Japanese hundreds of billions of countless dollars in lost revenue, it also delivered an incalculable blow to international confidence in the institutions and organizations that the entire developing world had less than two decades ago endeavored to emulate (Anchordoguy, 2005, 115-221, 206-235; Coates and Holroyd, 2003, 62). Japan Inc. had been cast adrift on the seas of uncertainty stirred up by the informational mode of development shift.

By the time DARPA was experimenting with TCP/IP technology, Japan had already surpassed most OECD states in terms of technological maturity and advantage. Thus the Japanese case provides an apposite example of how computer networking might have developed sans military spending. Clearly, the 21st century world would be quite a different place if US defense spending had not brought the globe TCP/IP. The Japanese narrative in regards to the computer networking sector also gives us some idea of how the Japanese developmental state might have gone about developing technologies had there been no American lead to follow. Undoubtedly, multi-decade massively-financed shotgun-scoped radical inventiveness would not have been on the agenda. This is not to say that the Japanese nation would not have risen to the vanguard of global production if it had

no roadmap to follow, it probably would have; for effective state-led embedded autonomous technological development, when backed by institutions that 1) protect private property rights, 2) provide for efficient tax administration, and 3) guarantee sound public deficit finance, will assuredly promote rapid economic growth of a sort. However, it is exceedingly unlikely that the growth promoted would be of a sort intrinsic to a radical discontinuous mode of development shift absent the military expenditure impetus, as the cross-national US-Japanese comparative analysis has, I believe, plainly indicated.

CHAPTER 20: CONCLUSION

In the famous words of Mark Twain; "History does not repeat itself, but it does rhyme." This dissertation has been an exercise in identifying and isolating the rhyming mechanisms regarding the causative role of long-term large scale military expenditure during both the Industrial and Informational Mode of Development Shifts. The following dialogue will briefly review these rhyming mechanisms, but rather than proceed on a case by case basis as the dissertation has, the ensuing discussion will follow the variable by variable contours of the 'military expenditure impetus to mode of development shifts theory' as outlined in chapter one, and throughout.

We of course begin with our prime causal variable of interest, long-term large-scale military expenditure. Between 1689 and 1784, Britain, an ever strengthening great power, engaged in 50 years of capital intensive battle over the course of five massive wars, expending roughly 10%-12% of national income on average during those years of war (reaching a zenith of 16% during the Seven Years War and a nadir of 9% during the War of the Spanish Succession). Excepting the one 25 year interval of peace in between the War of the Spanish Succession and the War of the Austrian Succession, the average interval of peace during the British epoch was approximately six years. Between 1940 and 1999, the United States of America, indisputably a great power, spent 40 of 60 years expending an average 11% of national income on capital intensive defense efforts (reaching a zenith of 37% during WWII and a nadir around 6% during the final

Cold War years). The only three stretches of consecutive multi-year declining aggregate defense expenditure in the American epoch occurred during the four post WWII years, the six years of Détente, and the post Cold War decade. In short, both nations engaged in long-term national security efforts on an entirely unprecedented scale, and not coincidentally, both nations generated a mode of development shift.

As discussed, the institutions and organizational configurations that guided procurement in both nations were exceedingly similar. Autonomous state bureaucracies directed private market-based entrepreneurial firms, through the use of formal contracts and profitable inducements, to furnish weapons as the state needed. To be sure, the embedded links connecting the US defense departments to their market-based contractors were far more dense and numerous than those linking the British state defense departments to their market-based contractors. Additionally, the American defense departments used their densely embedded links to more formally and consciously effect technical change. Nevertheless, the commonalities in the two systems of procurement given the two century difference in temporal occurrence are striking. And in both cases, military expenditure became an effective force of demand propelling technical change in critical infrastructural sectors in ways that markets had failed to previously.

Of course, it was not only the structure of contracting in the two nations that made military expenditure an effective agent of demand; the transformative force of military expenditure would not have materialized absent sound fiscal practices. In regards to taxation, the main difference across the two cases arises from Britain's

increasing reliance on indirect taxes as the temporal period under analysis progressed versus America's overwhelming reliance on direct taxes throughout. This again owes to the large temporal interval dividing the two cases, two centuries wherein a developed infrastructure for successful direct tax assessment and collection emerged all around the developed world (Gordon, 1997). More importantly, the main similarity across the two cases in regards to taxation is the utilization of centralized, bureaucratic, and efficient methods of assessment and collection. These effective mechanisms of assessment and collection in turn enabled a rising burden of taxation amidst an increasingly regressive incidence, thus sufficiently capitalizing public deficit finance and military expenditure, while not over-restricting wealth accumulation in the hands of the classes with a higher propensity to invest.[332]

In regards to public deficit finance, the US essentially imported Britain's system of debt, which had been shaped, tried, and tested in war prior to the formation of the United States; thus it comes as no surprise that the systems were, for all intensive purposes, analogous. What is more interesting then is the parallel progression of ample economic slack amid low inflation and low interest rates, giving way to decreasing economic slack amid rising inflation and rising interest rates, that obtained in both cases as each respective mode of development shift

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[332] In the US case, total revenue as a percentage of GDP rose rather steadily from an average 12% during WWII to over 18% during the Post Cold War Decade. The tax incidence in the US became increasingly regressive after 1960, prior to the widespread diffusion of infrastructural informational technologies. The unmistakable trends toward a heavier tax burden amid rising regressiveness in 18th century Britain were evidenced and discussed extensively during the British and French case analyses.

incubated, diffused, and fused. It is notable that both mode of development shifts originated in an economic environment initially characterized by underutilized resources of similar kinds (for instance, high aggregate unemployment and unexploited technical knowledge). Military expenditure drew these resources into the fusing mode of development shift until slack had been driven out of the economy; thus ushering in a new relationship between military expenditure and technological development – one where crowding out was more prevalent and damaging.

Is economic slack therefore a necessary precondition to the initiation of the operative mechanisms of the 'military expenditure impetus to mode of development shifts theory'? This is a difficult question to answer, for there is no telling a priori what technical knowledge and resources lay hidden within the minds of men, societies, and their economies; in other words, economic slack, especially as relating to scientific capabilities, is difficult to precisely specify. For example, few could have known that esoteric quantum physics in the decades prior to WWII had created a treasure trove of technical knowledge waiting for application in the commercial sphere. There is also no telling in real-time whether crowding out is actually benefiting the long term evolution of the underlying economy by transferring purchasing power away from strictly civilian commercial enterprise and towards defense contractors developing cutting edge fixed capital goods, despite the short term corrosive effects bred by crowding out. For example, during both the War of American Independence (1775-1784) and the Final Cold War

Years (1978-1989) crowding out was fairly intense, thus causing inflation and interest rates to rise; and yet, both respective mode of development shifts persistently gathered pace and potency as the war years proceeded. In fact, in both eras military expenditure continued to propel crucial infrastructural technological innovations. It may well be impossible to systematically weigh such long-term beneficial economic effects against concurrent short-term negative consequences in an evenhanded manner (Ruttan, 2006; Varynen, 1992). Moreover, any evaluation would depend on a number of fluctuating variables, such as the level of crowding out, the spillover effects resulting from technological changes, the openness of the international trading order, along with the subsequent length of continued military expenditure. Thus I have opted to not include the presence of 'economic slack' as a formal variable in the abstracted and generalized 'military expenditure impetus to mode of development shifts theory.' In my view, the interactions between state directed / market-based technological development on the one hand, and the short-term corrosive effects of crowding out on the other, are not specifiable enough at this juncture to warrant it.[333]

Nevertheless, what I believe has been made clear through this work is that during the British Industrial and American Informational Mode of Development Shifts long-term large-scale military expenditure played a similar role in coaxing

[333] Also, in the interests of parsimony, it seems prudent to exclude speculative arguments involving crowding out from the formalized and generalized 'military expenditure impetus to mode of development shifts theory.' As previously explicated, the voluminous literature addressing crowding out is highly complex, entirely unsettled, and overly polemical.

out radically new technological capacities that lay hidden in both economies.[334] Owing to the radical novelty of these new capacities, along with the inherently expensive costs of applying them to production, war, and the intensive life and death struggles it entails for individuals and states, capitalized on these latent capabilities prior to peaceful civilian economic production. Thus, as discussed in chapter one, war became rather industrial in nature before the 18th century British economy did (at least in regards to the importance of a cast iron infrastructure); and analogously, war became entirely informational in nature before the 20th century American economy did. As has been averred throughout, it is quite unlikely that the radical new facilities embodied in the critical infrastructural mode of development shift technologies in each era would have emerged in finished forms capable of interacting to generate productivity gains in new and unforeseen ways within a condensed timeframe absent the military expenditure impetus. Additionally, I believe it has also been sufficiently demonstrated that the vicissitudes of military expenditure fomented intermittent cycles of synchronized technological diffusion flowing out of defense-related industries and into the larger commercial economy in each respective nation, thus providing a further coordinating mechanism.

Intriguingly, the processes through which military expenditure propelled radical technical change in 18th century Britain were more gradual and less direct,

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[334] For example, advanced casting techniques and coke-smelting in the British Case and quantum physics and solid-state research in the American Case. The scientific processes that gave rise to these hidden capacities largely fall outside the purview of this dissertation (there are of course large literatures which discuss the history of scientific progress).

moreover 18th century technologies were far less complex; and yet, America's Information Technologies Revolution seems, somehow, less momentous than Britain's initial Industrial Revolution. Whether this is an effect of temporal distance, or an effect of our generalized accustomedness to technological change is difficult to say. Perhaps it is a bit of both. Prior to the British Industrial Revolution no one realized that sustained technical change resulting in multiplicative economic growth could occur. Over the next 200 years unremitting industrial change (sometimes slower, sometimes faster) habituated successive generations to technological development. Thus in the 21st century the task has become one of differentiating industrial change from informational change; i.e. differentiating a mode of development shift from other types of technical change. This is unquestionably a more complicated affair. It is my hope that this work will contribute to establishing the latter 20th century as a period of technological transformation as exceptional and momentous as the initial Industrial Revolution in Britain. I believe it does so by demonstrating that similar extra-market impetuses and mechanisms played a crucial role in causing market economies to transition to new productivity paradigms and regimes of accumulation in both cases.

Perhaps the above begs a particularly salient question: why was there a 200 year interval in-between each mode of development shift; an interval wherein technical change continued, but within the same basic productivity paradigm already established? The answer of course goes back to the conjunctional causal variables delineated in the generalized 'military expenditure impetus to mode of

development shifts theory.' For instance, what phase of the 19th and early 20th centuries is marked by a multiple decade great power rivalry wherein a leading nation expended approximately 10% of GNP per annum on capital intensive warfare? The reader shall be hard pressed to think of one. The WWI era does come to mind, but here is where conjunction comes in. The US, for example, during WWI did not procure weapons via a market-based contracting system; the advanced weapons of the day, such as airplanes, were constructed in state owned and operated facilities (Beaumont, 1977). Meanwhile, Britain and her European allies and rivals were not at all insulated from attack. Most importantly, defense expenditure was not sustained at a high level in the decades following WWI, as both America and Britain demilitarized. As previously stated, all the many conjunctional independent variables, causal mechanisms, and associated corollaries and caveats in the 'military expenditure impetus to mode of development shifts theory' make it a process of extremely rare occurrence, but when it does crystallize the transformative effects have proven amazingly profound.

Which brings us to the two cases formally incorporated into the dissertation in which such a crystallization did not occur. The case of 18th century France clearly demonstrates that the relationship between military expenditure and technological evolution is entirely mediated through institutional economic structure. Outside of long-term large-scale military expenditure Old Regime France contained none of the causal variables included in the dissertation's overarching general theory, and accordingly, a mode of development shift did not

materialize. Postwar Japan, on the other hand, presents a more difficult case. For military expenditure in latter 20th century Japan bordered on nil, and yet, Japanese firms excelled in select IT sectors, for a time out-competing US firms. As has been shown, this was a partial consequence of the open international trading order coupled with poor public deficit finance policies in the US during the 1970s and accumulating crowding out effects in the American economy during the 1980s. More remarkably, the Japanese case demonstrates that absent advanced weapons expenditure, Japan failed to develop the institutions (such as VC markets) and capital capacities (such as specialized firms and an engineering corps adept at radical innovation) necessary to maintaining leadership in rapidly and unpredictably evolving IT sectors; thus suggesting that military expenditure was indeed indispensable to the mechanisms enabling indigenous origination and subsequent successful commercial diffusion of information technologies in the US.

In closing, allow me to indulge in a qualification. The idea of hailing military expenditure as a dynamic transformative force does not sit well with this author. Few, I imagine, will be enamored with the interpretation of technological history put forth in the above chapters; and I do sympathize. However, over the course of studying the two existent mode of development shifts, and the processes that have fomented each, I have come to realize that the causal theory that I have identified as analogously pertaining to both in fact emphasizes markets before military expenditure. Indeed, what is truly hailed in this work is the power of embedded autonomous states to harness the far greater power of distributed and

well capitalized markets, especially when the goal is clear, and the national polity is democratic and supportive. In isolating the military expenditure impetus to mode of development shifts, by way of a lengthy comparative historical analysis, I believe I have demonstrated how the mechanisms enabling pervasive radical rapid discontinuous technological transformation in the infrastructural bases of production might one day be entirely disassociated from war, and yet continue. For there are numerous non-defense-related crises currently confronting humanity which may soon require a revolutionary modification of global productivity paradigms. Should such crises motivate states in developed nations to expend, say, 5%-15% of their GDPs in a long-term large-scale effort to switch the rails of the global economy, then the 'military expenditure impetus to mode of development shifts theory' could provide a blueprint. I have no doubt that the powerful embedded autonomous mechanisms of change elucidated above, if underpinned by liberal political economic institutions and sound fiscal practices, would be capable of provoking intensive and profound economic transmogrification over a condensed period of time, absent the caustic effects of war, should today's informational nations ever feel the need to activate them.

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