Essays in International Macrodynamics

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Abstract

Essays in International Macrodynamics

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The first essay, entitled "Sectoral Adjustment Costs and Real Exchange Rate Dynamics in a Two-Sector Dependent Economy," investigates dynamics of real exchange rates in a two-sector model with both capital accumulation and capital reallocation. Instead of choosing one of the extreme assumptions regarding production structure (gradual capital accumulation with instantaneous reallocation versus no reallocation), we allow the movement of capital across sectors but with costs. By appropriately parameterizing this cost, we find that the standard Heckscher-Ohlin and the sector-specific capital models emerge as two polar cases. We also get persistence of the deviation of the real exchange rate, with the persistence, and possible overshooting, of the real exchange rate increasing with the magnitude of the intersectoral adjustment costs, consistent with the evidence.

The second essay, entitled "Sectoral Adjustment Costs and The Rate of Convergence in a Two-Sector Endogenous Growth Model" investigates the speed of convergence in a Lucas type two-sector model with sectoral adjustment costs. In two-sector endogenous growth models of Lucas vintage all variables converge to their respective long-run equilibrium at the same constant rate. By introducing sectoral adjustment costs we obtain stable dynamic adjustment paths as two-dimensional manifolds. So, convergence speeds vary over time and among variables. Also, the time path of the rate of convergence depends on the size of the sectoral adjustment costs. As

different countries have different sectoral adjustment costs, the cross-country variations in convergence profile can be addressed using this framework.

The third essay, entitled "How Big Is the Border Effect in Developing Countries? A Case Study of Bangladesh and India" investigates the nature and extent of the failure of the Law of One Price in developing countries. Disaggregated price data from two developing countries, Bangladesh and India, are used to test the proposition that the variation of the prices in equidistant cities located in two countries is systematically larger than that for the cities in the same country. For Bangladesh and India, the extent of failure of LOP in the short-run is found to be very significant.

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To My Parents

Anwara Begum

and

Md. Karam Ali

CHAPTER 1

Sectoral Adjustment Costs and Real Exchange Rate Dynamics in a Two-Sector Dependent Economy

1.1 Introduction

One of the realities facing an open economy is that international trading activities have differential effects on different parts of the economy. Those sectors specializing in exporting, importing, and closely related activities are obviously highly sensitive to international trading conditions, while other sectors, such as domestic service industries, operate more or less independently of the international environment. The differential impacts of international conditions on these various sectors were a central issue in the debate over the Dutch disease and the discovery of oil in northern Europe, as well as in assessing the effects of mineral discoveries in Australia. In each case, the discovery of the resource led to a change in the country's terms of trade and this in turn had effects on both the country's traditional export sectors and its import-competing sectors, as well as the internal nontraded sector.

The two-sector dependent economy model presents a convenient approach to studying these issues. By distinguishing between traded and nontraded goods, it provides a general equilibrium framework for analyzing the behavior of the real exchange rate, which plays such a critical role in the adjustment process. The two-sector model has a long history during which it has become something of a workhorse model in international macroeconomics. The earliest applications, associated with the Australian school (e.g. Salter, 1959, Swan 1960, Corden, 1960, McDougall, 1965) were purely static, focusing on the demand-side determinants of the real exchange rate.[1] Subsequent applications have introduced capital accumulation, thereby enabling one to analyze the determination of the real exchange rate as part of a dynamic process in conjunction with the accumulation of capital and foreign assets.[2]

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[1] About the same time the contributions by Balassa (1964) and Samuelson (1964) used a similar framework, but focused more on the supply-side effects (productivity differentials) to explain the behavior of real exchange rates.

[2] This literature is comprehensively reviewed by Turnovsky (1997, chapter 4).

A critical aspect of the dynamic dependent economy model concerns the structure of production. In this respect, the literature usually adopts one of two polar assumptions. Most prevalent is to introduce accumulating capital into the standard Heckscher-Ohlin technology. This approach assumes that, while aggregate capital is accumulated only gradually, it can be allocated instantaneously, along with labor, across the two sectors; see Obstfeld (1989), Turnovsky (1991), van Wincoop (1993) Brock and Turnovsky (1994), Turnovsky and Sen (1995), Brock (1996). In other words, while it is costly to convert new output to capital, it is costless to transform one form of existing capital to another. Although this assumption is analytically convenient, it is clearly unrealistic. To transform one form of existing capital to another involves demolition and is likely to be more, rather than less, costly than converting some uncommitted new output to capital. Remodeling and retrofitting is typically more costly than building from scratch.

These models also yield strong, though not necessarily plausible, implications for the real exchange rate, making its behavior highly sensitive to the relative sectoral capital intensities. In the event that the traded sector is more capital intensive, the real exchange rate is devoid of any transitional dynamics. Instead, it responds instantaneously and fully to supply shocks, and there is no response at all to demand shocks. In the case where the sectoral capital intensities are reversed, the corresponding adjustments now involve transitional dynamics though the speed of adjustment tends to be unrealistically fast. In either case, instantaneous adjustment in the former case and overly rapid convergence in the latter, is inconsistent with the observed persistence of deviations of the real exchange rate from its equilibrium purchasing power parity conditions; see Froot and Rogoff (1995) Edwards and Savastano (1999), and Cheung and Lai (2000).

At the other extreme, fewer models employ the assumption that capital is completely immobile across sectors, being specific to the sector in which it is located. Rather, changes in capital occur through new capital accumulation in the sector in which the return to capital is higher and through the depreciation of capital in the other sector.

These models are known as sector-specific capital models; see Ryder (1969), Jones (1971), Neary (1978), Eaton (1987), and Murphy (1988).

But the absence of *any* sectoral reallocation of capital is also too extreme. For example, resources used to produce traded output can usually be retrofitted to produce nontraded goods, though at some cost, should the relative profitability of these two activities change. Indeed, the retrofitting of capital and its recycling using scarce resources has been a common phenomenon in both developed and developing countries during periods of structural adjustments. While examining the impact of railroads on American economic growth, Fogel (1964) observed that during the initial period of expansion of the railroads, British imports of iron rails had been the most important source of tract for U.S. rails. However, later, scrap iron from worn out rails came to make up a large part of crude iron used for new rails. In the East European transition economies many former defense-related industries now produce farm equipment and machinery, household appliances, and medical equipment. For example in the former Czechoslovakia, ZTS Martin (a former tank producing firm) now produces tractors and construction machinery. In order to facilitate these conversions, governments have provided generous financial support to these industries.[3] Likewise, the end of the cold war has also induced countries like Great Britain, Germany, and France to convert many of their defense industries to non-defense related industries.[4] And a similar transition occurred in the United States directly after the Second World War. The common theme throughout these episodes is that they require resources for the reconfiguration of capital (adjustment costs).

Attempts to analyze the intermediate case of partial sectoral mobility of capital are sparse, the first such effort being by Mussa (1978). He introduces a third "retrofit" sector that remodels capital taken from the sector with lower return to capital, and sells it to the sector yielding the higher return to capital. This retrofitting of capital requires

[3] For example, in the former Czechoslovakia the amount of financial support for conversion projects were equivalent to around $US 40 million in 1989 and around $50 million in 1991; see Kiss (1997).

labor. In Mussa's model, capital is sector-specific in the short run, while it is perfectly mobile in the long run. Gavin (1990,1992) has used this setup using an intertemporal optimizing approach, characteristic of more contemporary models in international macroeconomics. But he focuses exclusively on the reallocation of existing capital without considering the accumulation of new capital. In reality, both new capital accumulation and the reallocation of existing capital take place simultaneously.

To understand the dynamics of real exchange rates, and their interaction with accumulating capital, it is important to develop a model in which both capital accumulation and capital reallocation proceed simultaneously, but gradually[5]. This is the objective of the present paper. Instead of introducing a retrofit sector we assume that the movement of capital across sectors involves convex intersectoral adjustment costs, of the conventional type due to Hayashi (1982), and routinely introduced into aggregate models of capital accumulation in small open economies; see Turnovsky (1997). This approach is similar to that taken by Grossman (1983) in the standard static Heckscher-Ohlin framework. The introduction of such adjustment costs slows the return to equilibrium below what it would be in the absence of adjustment costs, yielding a more plausible convergence speed for the real exchange rate, irrespective of the degree of sectoral capital intensity.

Once one introduces capital its tradability needs to be addressed. Brock and Turnovsky (1994) introduced both forms of capital and concluded that as long as the economy utilizes some nontraded capital in production, the fundamental structural dynamic characteristics of the model remain intact, with or without the inclusion of traded investment in the model. Accordingly, since the simultaneous treatment of aggregate capital accumulation and intersectoral adjustment costs raises the complexity of the dynamics, we shall assume that capital is produced only in the nontraded sector. Moreover, since the output of this sector is constrained by the economy's own internal

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[4] Details are provided by Kaldor and Schmeder (1997).

[5] Unlike Neary (1978) and Mussa (1978) models, capital is mobile even in the short-run.

resources, we can abstract from adjustment costs associated with aggregate capital formation, focusing instead on the adjustment costs of sectoral capital movements.

The essence of these adjustment costs is that to transfer X units of capital from the nontraded sector to the traded sector, the decline in nontraded sector capital must exceed the amount X. We consider this amount of lost capital as the intersectoral adjustment cost.[6] Since X can take both positive and negative values, the capital transfer may occur in either direction. These adjustment costs proxy the resources and time involved in reconfiguring capital in response to changing trading conditions. By appropriately parameterizing the adjustment costs, we find that the standard Heckscher-Ohlin and the sector-specific technologies emerge as two polar cases.

The higher order dynamic system enriches the transitional dynamics of the real exchange rate. However, while it is possible to give a general characterization (i.e. establish that it has a well-defined saddle point structure), further analysis requires the extensive use of numerical simulations. For plausible parameterizations of the model we can show that the introduction of realistic sectoral adjustment costs accomplishes two important objectives. First, in the case where the traded sector is more capital intensive, when the basic two-sector model leads to instantaneous jumps in the real exchange rate, the real exchange rate is now subject to transitional dynamics. Second, in the case where the nontraded sector is more capital intensive, the speed of convergence of the real exchange rate is now reduced. In either case we get persistence of the deviation of the real exchange rate from its equilibrium, with the persistence increasing with the magnitude of the intersectoral adjustment costs, consistent with the evidence.[7] In turn, this sluggishness in the real exchange rate creates imbalances in the current account that may persist for quite a long time.

[6] Grossman (1983) has a similar index of capital mobility measured by the percentage loss in efficiency that is incurred in transferring the marginal unit of capital.

[7] This is in contrast to generating persistence of the real exchange rate by means of sticky prices; (e.g., see Obstfeld and Rogoff (1995)). In a recent paper, Huffman and Wynne(1999) have introduced *intra*sectoral adjustment costs to explain sectoral business cycles and observe that the introduction of *intra*sectoral costs helps explain some puzzling empirical regularities. In their model they argue that when new capital is formed, costs of adjustment for a good to be converted

The remainder of the paper is structured as follows. Section 1.2 sets out the basic analytical framework and derives the macroeconomic equilibrium. In Section 1.3 we examine some of the long-run responses to both demand and supply shocks. The former originate from fiscal policy shocks like changes in government expenditures, while supply shocks emanate from productivity changes in the two sectors. In section 1.4 we calibrate the economy and in section 1.5 we simulate numerically the transitional dynamics of the economy in response to the various demand and supply shocks. Section 1.6 addresses the implications of our results for the convergence of the real exchange rate, while Section 1.7 contains some concluding comments.

1.2 The Model

1.2.1 Economic Structure

We consider a small open economy inhabited by a single representative agent who is endowed with a fixed supply of labor (normalized to be one unit), which he sells at the competitive wage. The agent produces a traded good T (taken to be the numeraire) using a quantity of capital K_T and labor L_T by means of a neoclassical production function $F(K_T, L_T)$. That is, both capital and labor have positive, but diminishing, marginal physical products, and production is subject to constant returns to scale. He also produces a nontraded good N using a quantity of capital, K_N, and labor, L_N, by means of another production function, $H(K_N, L_N)$, which has similar neoclassical properties. The agent allocates his labor between these two production processes and consumes both the traded and nontraded good.

We assume that the traded good is used only for consumption (either private or public), while the nontraded good may be either consumed or accumulated as a capital

into capital are different for different sectors. In our model, we do not allow *intra*sectoral adjustment costs. Rather, we allow capital conversion and introduce adjustment cost in this process.

good, to which it may be converted without incurring any adjustment costs.[8] This assumption is made because, in order to focus on the intersectoral capital transfer costs, we try to keep other adjustment processes as simple as possible. With capital being nontraded, the absence of adjustment costs is consistent with a finite rate of aggregate capital accumulation, although this would not be so if capital were traded; see Turnovsky (1997, Chapter 4).

The agent also accumulates net foreign bonds, B, that pay a given world interest rate r. Equation (1a) describes the agent's instantaneous budget constraint,

$$\dot{B} = \tau + F(K_T, L_T) - C_T + \sigma\left[H(K_N, L_N) - C_N - I\right] - T_L + rB \tag{1a}$$

where C_T and C_N are the agent's consumption of traded goods and nontraded goods, respectively; σ is the relative price of nontraded goods to traded goods; I denotes new investment, τ denotes transfer from abroad in the form of traded goods, and T_L denotes lump-sum taxes.

We further assume that the capital stock does not depreciate and that it cannot move freely across sectors. Only nontraded new output can be converted into capital, and once it becomes capital good in the nontraded sector, it takes extra resources to transform it into capital suitable for use in the traded sector. Accordingly, capital accumulation in this economy is described by:

$$\dot{K}_T = X \tag{1b}$$

$$\dot{K}_N = I - X\left(1 + \frac{hX}{2K_N}\right) \tag{1c}$$

where X is the amount of capital transferred from the nontraded to the traded sector, and

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[8] The assumption that all capital is nontraded is not as restrictive as may at first appear. Brock and Turnovsky (1994) consider a model which includes traded as well as nontraded capital and find that the latter plays a much more fundamental role in determining the equilibrium dynamics.

$$I = H(K_N, L_N) - C_N - G_N \tag{1d}$$

identifies the amount of nontraded output available for investment as being the amount of nontraded output remaining after both private consumption, C_N, and government purchases, G_N, have been met. In order to provide X units of capital to the traded sector, the amount of capital in the nontraded sector must be reduced by more than X. This excess amount, $hX^2/2K_N > 0$ represents the intersectoral adjustment costs.

This specification is analogous to the standard specifications of aggregate adjustment costs based on Hayashi (1982), and preserves the conventional properties. The convexity in X implies that increasing the rate at which capital is transferred from the nontraded to the traded sector requires giving up increasing amounts of capital in the nontraded sector. The coefficient $h > 0$ parameterizes the degree of the sectoral adjustment costs. This specification of adjustment costs in relative terms, per unit of nontraded capital, K_N, is standard, and since this normalization renders the adjustment cost parameter, h, unit-free, is convenient for conducting the numerical simulations.

Three other points should be noted. First, the direction of the sectoral flows, $X \gtrless 0$, depend upon the relative return to capital in the two sectors. Thus, if the returns to capital in the nontraded sector is higher, not only the new capital formation (conversion of nontraded output into capital) will take place there, but also a flow of capital back from the traded to the nontraded sector will occur. Denoting that (positive) flow by $Y = -X$, the resulting capital it generates in the nontraded sector is only $Y((1 - hY/2K_N)$. Second, summing (1b) and (1c) yields that the total rate of capital accumulation in the economy, $\dot{K}$, is

$$\dot{K} \equiv \dot{K}_T + \dot{K}_N = I - \frac{hX^2}{2K_N} \tag{1e}$$

where the last term in (1e) denotes the loss in capital due to sectoral movements, whatever their direction. In the absence of sectoral adjustment costs, (1e) reduces to the standard aggregate capital accumulation relationship $\dot{K} = I$. Finally, as formulated (1c) permits negative aggregate investment. The usual interpretation of this is that the agent is permitted to consume his capital stock or sell it in the market for new output.

Labor is perfectly mobile across sectors and the labor market always clears.[9] Thus the following equation must hold all the time

$$L_T + L_N = 1 \tag{1f}$$

The agent's decisions are to choose his consumption levels C_T, C_N, labor allocation L_T, L_N, the rate of investment I, the capital allocation decisions K_T and K_N, and his rate of accumulation of traded bonds to maximize the following intertemporal utility function

$$\int_0^\infty U(C_T, C_N)e^{-\beta t}dt \tag{2}$$

subject to the constraints (1a) – (1f), and given initial stocks $K_T(0) = K_{T,0}$, $K_N(0)=K_{N,0}$, and $B(0)=B_0$. The instantaneous utility function is assumed to be concave and the two consumption goods are assumed to be normal goods. The agent's rate of time preference ,β, is taken to be constant.

Writing the Hamiltonian as

$$Z \equiv U\left(C_T, C_N\right)e^{-\beta t} + \lambda e^{-\beta t}\left[\tau + F\left(K_T, L_T\right) - C_T - T_L + \sigma\left(H\left(K_N, L_N\right) - C_N - I\right) + rB - \dot{B}\right]$$

$$+q_1\lambda e^{-\beta t}\left[X - \dot{K}_T\right] + q_2\lambda e^{-\beta t}\left[I - X\left(1 + \frac{hX}{2K_N}\right) - \dot{K}_N\right] + ve^{-\beta t}\left[1 - L_T - L_N\right] \tag{3}$$

where λ is the shadow value of wealth in the form of internationally traded bonds, and q_1, q_2 may be interpreted as the market prices of the traded and nontraded capital

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[9] The assumption that labor can move costlessly across sectors, while less objectionable than perfect sectoral capital mobility is also restrictive, since in reality this will involve labor retraining costs; see Dixit and Rob (1994). The presence of sunk costs in their model generates hysteresis in the movement of labor across sectors.

respectively.[10] The optimality conditions are thus:

$$U_T(C_T,C_N)=\lambda \tag{4a}$$

$$U_N(C_T,C_N)=\lambda\sigma \tag{4b}$$

$$F_L(K_T,L_T)=\sigma H_L(K_N,L_N) \tag{4c}$$

$$\frac{X}{K_N}=\frac{(q_1-q_2)}{q_2 h} \tag{4d}$$

$$\sigma=q_2 \tag{4e}$$

$$\beta-\frac{\dot{\lambda}}{\lambda}=r \tag{4f}$$

$$\frac{F_K}{q_1}+\frac{\dot{q}_1}{q_1}=r \tag{4g}$$

$$H_K+\frac{hX^2}{2K_N^2}+\frac{\dot{q}_2}{q_2}=r \tag{4h}$$

together with the transversality conditions

$$\lim_{t\to\infty}\lambda Be^{-\beta t}=\lim_{t\to\infty}q_1\lambda K_T e^{-\beta t}=\lim_{t\to\infty}q_2\lambda K_N e^{-\beta t}=0 \tag{4i}$$

Equations (4a) to (4e) are static efficiency conditions. Equations (4a) and (4b) equate the marginal utilities of the two consumption goods to the shadow price of wealth, appropriately measured in terms of the numeraire. Equation (4c) equates the marginal physical product of labor in the two sectors and reflects the assumed perfect sectoral mobility of labor. Equation (4d) determines the rate at which capital is being transferred between the two sectors. Capital flows from the sector where it is less valued to the

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[10] By writing the Lagrange multipliers as $q_1\lambda$, $q_2\lambda$ renders q_1, q_2 unit-free (like the Tobin q)

sector where it is more valued, at a rate that is inversely related to the size of the adjustment cost parameter, h. The transfers cease when the shadow values of capital are equalized. Since nontraded output can be either converted into capital or consumed, in equilibrium the agent should be indifferent between these two uses of new output. This yields the equality of the marginal utility of consumption of nontraded goods, $\lambda\sigma$, and the shadow value of capital, $q_2\lambda$, in the nontraded sector and reduces to equation (4e).

The remaining three conditions are intertemporal efficiency conditions. Equation (4f) equates the rate of return on consumption to the rate of return on traded bonds. In order to obtain a well-defined steady-state value in which marginal utility, and therefore consumption remain finite, we require $\beta = r$ which implies that $\dot{\lambda} = 0$ for all t, so that the marginal utility λ remains constant over all time, i.e., $\lambda = \bar{\lambda}$[11]. Equations (4g) and (4h) equate the rates of return on traded and nontraded capital to the rate of return on traded bonds. Both include the "payout rate" (the appropriately valued marginal physical product) plus the rate of capital gain. In addition, since increasing the stock of nontraded capital reduces the adjustment costs, this comprises a third component of the rate of return to nontraded capital. Note that in the absence of sectoral adjustment costs, $h = 0$, implying $q_1 = q_2 = \sigma$. Substituting these conditions into (4g) and (4h), the latter reduce to the standard static efficiency condition $F_K = \sigma H_K$.

The government in this economy is passive. It simply raises lump-sum taxes to finance its expenditures on the traded and nontraded good, G_T and G_N, respectively, in accordance with $T_L = G_T + \sigma G_N$. For simplicity, we assume that government spending yields no utility, so that it represents a pure drain on the economy.

[11] This assumption is standard in deriving intertemporal models of small open economies, although it is not particularly appealing. Its consequences for the equilibrium dynamics are discussed by Turnovsky (1997) in some detail.

1.2.2 Macroeconomic Equilibrium

The macroeconomic equilibrium is obtained as follows. First, we solve equations (4a) and (4b) for traded and nontraded consumption C_T and C_N in the form[12]

$$C_T = C_T(\bar{\lambda}, \sigma) \qquad \partial C_T/\partial \bar{\lambda} < 0;\ \partial C_T/\partial \sigma \gtrless 0 \tag{5a}$$

$$C_N = C_N(\bar{\lambda}, \sigma) \qquad \partial C_N/\partial \bar{\lambda} < 0;\ \partial C_N/\partial \sigma < 0 \tag{5b}$$

From the labor market efficiency condition (4c) and (1f) we may derive

$$L_T = L_T(K_T, K_N, \sigma) \qquad \partial L_T/\partial K_T > 0;\ \partial L_T/\partial K_N < 0;\ \partial L_T/\partial \sigma < 0 \tag{5c}$$

$$L_N = L_N(K_T, K_N, \sigma) \qquad \partial L_N/\partial K_T < 0;\ \partial L_N/\partial K_N > 0;\ \partial L_N/\partial \sigma > 0 \tag{5d}$$

An increase in the marginal utility of wealth leads to a reduction in consumption. An increase in the relative price of the nontraded good also leads to a decline in its consumption, while the effect on traded consumption depends upon the complementarity or substitutability of the two goods in consumption. It also attracts labor to the nontraded sector from the traded sector. An increase in the stock of traded capital raises the productivity of labor in that sector, attracting labor from the nontraded sector, while an increase in the stock of nontraded capital has the reverse effect.

Utilizing (5a) – (5d), the macroeconomic equilibrium can be summarized by the following autonomous system in the four variables, K_T, K_N, σ, X

$$\dot{K}_T = X \tag{6a}$$

$$\dot{K}_N = H\left(K_N L_N(K_T, K_N, \sigma)\right) - C_N(\bar{\lambda}, \sigma) - X\left(1 + \frac{hX}{2K_N}\right) - G_N \tag{6b}$$

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[12] The condition that the consumption of either good decreases in the marginal utility of wealth is a consequence of the assumption of normality.

$$\dot{\sigma} = \sigma\left(r - H_K\left(K_N L_N(K_T, K_N, \sigma)\right) - \frac{h}{2}\frac{X^2}{K_N^2} \right) \tag{6c}$$

$$\dot{X} = \left(\frac{H\left(K_N, L_N(K_T, K_N, \sigma)\right) - C_N(\bar{\lambda}, \sigma) - G_N}{K_N} + H_K\left(K_N, L_N(K_T, K_N, \sigma)\right) \right) X$$

$$- \frac{X^2}{2K_N} - \frac{K_N}{h\sigma}\left(F_K\left(K_T, L_T(K_T, K_N, \sigma)\right) - \sigma H_K\left(K_N, L_N(K_T, K_N, \sigma)\right)\right) \tag{6d}$$

together with the current account condition

$$\dot{B} = \tau + F\left(K_T, L_T(K_T, K_N, \sigma)\right) - C_T(\bar{\lambda}, \sigma) + rB - G_T \tag{6e}$$

Equations (6a) and (6b) repeat (1b) and (1c) describing the rates of accumulation of the two kinds of capital.[13] Equation (6c) describes the rate of change of the real exchange rate. This equation is obtained by taking the time derivative of equation (4e) and combining with (4h). Equation (6d) represents the dynamics of the amount of the transfer flow of capital from nontraded sector to the traded sector. This is obtained by taking time derivative of (4d) and combining with (4g) and (4h). The rate of accumulation of traded bonds is shown in equation (6e). The excess of the domestic production of the traded good over domestic consumption of that good (by both consumer and government), together with foreign transfers and the interest earned on the outstanding stock of foreign bonds, determine the current account and the rate of accumulation of the traded bond.

1.2.3 Equilibrium Dynamics

Linearizing (6a) – (6d) around the steady state (denoted by tildes), the dynamics of K_T, K_N, σ, and X can be approximated by

[13] When $h = 0$, the dynamics reduces to a second order system in $K \equiv K_T + K_N$ and σ; see Turnovsky (1997).

$$\begin{pmatrix} \dot{K}_T \\ \dot{K}_N \\ \dot{\sigma} \\ \dot{X} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 1 \\ a_{21} & a_{22} & a_{23} & -1 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & H_K \end{pmatrix} \begin{pmatrix} K_T - \tilde{K}_T \\ K_N - \tilde{K}_N \\ \sigma - \tilde{\sigma} \\ X - \tilde{X} \end{pmatrix} \tag{7}$$

where

$$a_{21} = H_L \frac{\partial L_N}{\partial K_T}; a_{22} = H_K + H_L \frac{\partial L_N}{\partial K_N}; a_{23} = H_L \frac{\partial L_N}{\partial \sigma} - \frac{\partial C_N}{\partial \sigma};$$

$$a_{31} = -\sigma H_{KL} \frac{\partial L_N}{\partial K_T}; a_{32} = -\sigma\left(H_{KK} + H_{KL} \frac{\partial L_N}{\partial K_N} \right); a_{33} = -\sigma H_{KL} \frac{\partial L_N}{\partial \sigma};$$

$$a_{41} = -\frac{K_N}{h}\left(\frac{1}{\sigma}\left[F_{KK} + F_{KL} \frac{\partial L_T}{\partial K_T} \right] - H_{KL} \frac{\partial L_N}{\partial K_T} \right);$$

$$a_{42} = -\frac{K_N}{h}\left(\frac{1}{\sigma} F_{KL} \frac{\partial L_T}{\partial K_N} - \left[H_{KK} + H_{KL} \frac{\partial L_N}{\partial K_N} \right] \right); \; a_{43} = -\frac{K_N}{h}\left(-\frac{F_K}{\sigma^2} + \frac{F_{KL}}{\sigma} \frac{\partial L_T}{\partial \sigma} - H_{KL} \frac{\partial L_N}{\partial \sigma} \right);$$

Equation (7) describes a fourth order linear dynamic system, and by examining its characteristic equation we can establish that there are two positive and two negative eigenvalues, implying that the equilibrium is a saddlepoint. [14] We assume that the two capital stocks, K_T and K_N, are constrained to move sluggishly, while the relative price, σ, and the rate of intersectoral capital transfer, X, are free to jump instantaneously, so that the equilibrium yields a unique stable saddlepath.

We denote the stable eigenvalues by μ_1 and μ_2, with $\mu_2 < \mu_1 < 0$, so that the (linearized) stable solutions may be written in the form:

$$K_T - \tilde{K}_T = D_1 e^{\mu_1 t} + D_2 e^{\mu_2 t} \tag{8a}$$

$$K_N - \tilde{K}_N = D_1 v_{21} e^{\mu_1 t} + D_2 v_{22} e^{\mu_2 t} \tag{8b}$$

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[14]The characteristic equation for the linearized fourth-order system is of the form: $\mu^4 + e_1\mu^3 + e_2\mu^2 + e_3\mu + e_4 = 0$, where e_i are functions of the elements a_{ij} of the matrix of the coefficients. By direct evaluation, we can establish $e_1 < 0, e_3 > 0, e_4 > 0$, which by Descartes rule of signs implies the existence of two positive roots.

$$\sigma-\tilde{\sigma}=D_1 v_{31}e^{\mu_1 t}+D_2 v_{32}e^{\mu_2 t} \tag{8c}$$

$$X-\tilde{X}=D_1 v_{41}e^{\mu_1 t}+D_2 v_{42}e^{\mu_2 t} \tag{8d}$$

where the vector $\begin{pmatrix}1 & v_{2i} & v_{3i} & v_{4i}\end{pmatrix}'$ i = 1, 2 (and the prime denotes vector transpose) is the normalized eigenvector associated with the stable eigenvalue, μ_i, and the constants D_1 and D_2, obtained by considering (8a) and (8b) at $t = 0$, are given by

$$D_1=\left[(\tilde{K}_N-K_{N,0})-v_{22}(\tilde{K}_T-K_{T,0})\right]/(v_{22}-v_{21});$$
$$D_2=\left[-(\tilde{K}_N-K_{N,0})+v_{21}(\tilde{K}_T-K_{T,0})\right]/(v_{22}-v_{21})$$

These depend upon the changes in the steady-state capital stocks and thus the specific shocks.

An important issue concerns the rate of convergence of $\sigma(t)$, the rate at which the real exchange rate adjusts to its new steady state, following some shock. We shall define this as

$$\kappa(t)\equiv\frac{\dot{\sigma}(t)}{\sigma(t)-\tilde{\sigma}}=\left(\frac{D_1 v_{31}e^{\mu_1 t}}{D_1 v_{31}e^{\mu_1 t}+D_2 v_{32}e^{\mu_2 t}}\right)\mu_1+\left(\frac{D_2 v_{32}e^{\mu_2 t}}{D_1 v_{31}e^{\mu_1 t}+D_2 v_{32}e^{\mu_2 t}}\right)\mu_2 \tag{9}$$

which is a time-varying weighted average of the two eigenvalues. Initially,

$$\kappa(0)=\left(\frac{D_1 v_{31}}{D_1 v_{31}+D_2 v_{32}}\right)\mu_1+\left(\frac{D_2 v_{32}}{D_1 v_{31}+D_2 v_{32}}\right)\mu_2$$

and asymptotically, $\kappa(t)\rightarrow\tilde{\kappa}\equiv\mu_1$. In our numerical simulations we shall study how $\kappa(0),\tilde{\kappa}$ depend upon the adjustment cost, h.

1.2.4.1 Current Account Dynamics

To derive the (linearized) current account dynamics we return to (6e) and adopt the procedure discussed by Turnovsky (1997). Specifically, we expand this equation around its steady state and substitute the linear solutions (8a), (8b), and (8c). Thus the solution for $B(t)$ takes the form

$$B(t)=\tilde{B}+\frac{\Omega_1}{\mu_1-r}e^{\mu_1 t}+\frac{\Omega_2}{\mu_2-r}e^{\mu_2 t}+(B_0-\tilde{B}-\frac{\Omega_1}{\mu_1-r}-\frac{\Omega_2}{\mu_2-r})e^{rt} \tag{10}$$

where

$$\Omega_i=D_i\left(F_K+F_L\left(\frac{\partial L_T}{\partial K_T}+v_{2i}\frac{\partial L_T}{\partial K_N}+v_{3i}\frac{\partial L_T}{\partial \sigma}\right)-v_{3i}\frac{\partial C_T}{\partial \sigma}\right),\ i=1,2$$

Imposing the transversality condition $\lim_{t\to\infty}\lambda B(t)e^{-rt}=0$ (since $r=\beta$), this will be true if and only if the international solvency condition

$$B_0-\tilde{B}-\frac{\Omega_1}{\mu_1-r}-\frac{\Omega_2}{\mu_2-r}=0 \tag{11a}$$

holds. Substituting (11a) into (10) implies the following accumulation equation for traded bonds

$$B(t)=\tilde{B}+\frac{\Omega_1}{\mu_1-r}e^{\mu_1 t}+\frac{\Omega_2}{\mu_2-r}e^{\mu_2 t}. \tag{11b}$$

The expressions Ω_1 and Ω_2 describe the instantaneous effects of an increase in the traded and nontraded capital stocks, respectively on the current account. To complete the solution, we substitute the values of D_1 and D_2 (depending upon the specific shock) into (11a) and (11b).

1.2.5 Steady State

The economy reaches steady state when $\dot{K}_T=\dot{K}_N=\dot{\sigma}=\dot{X}=\dot{B}=0$, implying further that in steady-state, $X=0$. Imposing these conditions yields the steady-state relationships

$$\frac{F_K(\tilde{K}_T, L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma}))}{\tilde{\sigma}} = r \tag{6d'}$$

$$H_K(\tilde{K}_N, L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = r \tag{6c'}$$

$$F(\tilde{K}_T, L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = C_T(\bar{\lambda}, \tilde{\sigma}) + G_T - \tau - r\tilde{B} \tag{6e'}$$

$$H(\tilde{K}_N, L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = C_N(\bar{\lambda}, \tilde{\sigma}) + G_N \tag{6b'}$$

From (6d') and (6c') we see that in steady state, the marginal product of capital in both sectors are equal to the exogenously given world interest rate and accordingly all intersectoral transfers of capital cease. Equation (6e') shows that in the long-run current account balance must be equal to 0 while equation (6b') is the market clearing condition for nontraded goods.

Since labor is perfectly mobile across sectors, the marginal product of labor will always be equal in both sectors, and in particular in steady state, implying:

$$F_L(\tilde{K}_T, L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) = \tilde{\sigma} H_L(\tilde{K}_N, L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma})) \tag{4c'}$$

Labor market equilibrium condition implies

$$L_T(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma}) + L_N(\tilde{K}_T, \tilde{K}_N, \tilde{\sigma}) = 1 \tag{1f'}$$

The equilibrium is similar in structure to that of the Turnovsky-Sen (1995) model in which capital is freely mobile intersectorally. Specifically, given the homogeneity of the production functions, (6c') determines the capital-labor ratio, $\tilde{k}_N \equiv \tilde{K}_N / \tilde{L}_N$, in the non traded sector, while (6d') and (4c') jointly determine the relative price, $\tilde{\sigma}$, and the capital-labor ratio, $\tilde{k}_T \equiv \tilde{K}_T / \tilde{L}_T$ in the traded sector. Having obtained these three quantities, the goods market conditions, (6e'), (6b'), the labor market condition, (1f') and the international solvency condition (11a), then jointly determine $\tilde{K}_T, \tilde{K}_N, \tilde{B}$, and $\bar{\lambda}$.

Once all these quantities are known, the sectoral employment, $\tilde{L}_T, \tilde{L}_N$, and consumption. $\tilde{C}_T, \tilde{C}_N$, immediately follow. Note that since the sectoral adjustment cost, h, impinge on the long-run equilibrium only through the international solvency condition (11a), which reflects the economy's transitional adjustment path, it has no impact on either the sectoral capital-labor ratios or the relative price; it does, however, affect the levels of the capital stocks.

1.3 Long-run Responses

Because of the complexity of the model most of our analysis is conducted numerically. To aid our understanding of the simulations it is useful to note the steady-state responses and since the steady state is similar to that of the model with perfectly mobile capital, our comments shall be brief.

1.3.1 Demand Shocks

The model includes three demand shocks (G_T, G_N and τ). But since the transfer from abroad operates precisely like a negative government expenditure shock on the traded good, we can focus on just the two forms of government expenditure shocks. No form of demand shock has any long-run effect on the relative price, σ, or on the sectoral capital intensities, all of which are determined by production conditions alone; see equations (6c'), (6d'), and (4c'). Similarly, the sectoral capital-output ratios remain unchanged. An increase in G_T, say, raises the demand for traded goods. With the sectoral capital intensities remaining fixed, the additional output necessary to maintain equilibrium is produced by attracting labor from the nontraded sector, so that $\tilde{L}_T$ rises and $\tilde{L}_N$ declines. This raises the productivity of capital in the traded sector and reduces it in the nontraded sector, encouraging a corresponding long-run intersectoral movement in capital. The steady-state level of traded output rises, while that of nontraded output falls. Since $\tilde{K}_T$ rises and $\tilde{K}_N$ falls the net effect on the aggregate stock of capital, $\tilde{K} = \tilde{K}_T + \tilde{K}_N$ depends upon the relative capital intensities, $\tilde{k}_N - \tilde{k}_T$, of the two sectors. With the balanced government budget, the increase in G_T implies a reduction in private wealth and an increase in its constant shadow value. This leads to a reduction in the private consumption of both goods, with the reduction in C_N matching the reduction in the output of the nontraded good. A parallel argument applies with respect to an increase in government expenditure on the nontraded good, G_N.[15]

1.3.2 Supply Shocks

The supply shocks take the form of multiplicative shifts in the production functions of the two sectors. Consider first the production function in the traded goods sector, expressed as $\phi F(K_T, L_T)$, with a proportional shift being parameterized by $d\phi > 0$. Such a shift, as well as increasing the level of output, increases the marginal product of both factors proportionately. It is therefore a representation of a Hicks-neutral technological improvement. Since the steady-state capital intensity in the nontraded sector, $\tilde{k}_N$, is determined by conditions in that sector alone, it is independent of the shift $d\phi$. There is therefore no change in $\tilde{k}_N$. It follows from the equilibrium conditions (6c'), (6d') and (4c') that a proportional shift such as this leads to proportional adjustments in the capital-labor ratio in both sectors. In this case, $\tilde{k}_T$ remains unchanged as well. On the production side, all that happens is that the relative price of the nontraded good rises, in order to maintain equality among rates of return; i.e.

$$\frac{d\tilde{k}_T}{d\phi} = \frac{d\tilde{k}_N}{d\phi} = 0; \quad \frac{d\tilde{\sigma}}{d\phi} > 0 \tag{12a}$$

The productivity increase in the traded sector reduces the capital-output ratio in that sector, while that in the nontraded sector remains unchanged.

From the steady-state relationships summarized in Section 2.5 one can determine the remaining long-run responses. In contrast to the demand shocks, the rise in the

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[15] The effects on the equilibrium stock of bonds are ambiguous, depending upon Ω_1, Ω_2 and are not reported.

relative price $\tilde{\sigma}$ introduces further effects, which offset the direct effects of the productivity shift $d\phi$. The qualitative responses to the direct and relative price effects are summarized in the first two columns of Table 1.1.B.

One immediate effect of an increase in productivity in the traded sector is to increase the flow of output from the resources available to the economy. The economy's wealth increases, leading to a decrease in the shadow value of wealth, λ. In the absence of any change in the relative price, this wealth effect will increase the consumption of both traded and nontraded goods. With the productivity of labor, and the capital-labor ratio in the nontraded sector remaining fixed, this additional output is obtained by causing labor to shift from the traded to the nontraded sector. But the concurrent rise in the relative price $\tilde{\sigma}$ has an offsetting effect. It tends to reduce the demand for the nontraded good, and therefore the equilibrium output of the nontraded sector. The net effect upon the output of that sector, and upon the allocation of labor which determines it, depends upon whether or not the direct effect dominates the relative price effect.

The long -run responses to a productivity shock in the nontraded sector are reported in the final 3 columns of Table 1.1.B. In contrast to a shock in the traded sector, a shift in the production function $\psi H(K_N, L_N)$, $d\psi > 0$, raises the marginal product of capital in the nontraded sector above the world interest rate. This leads to an increase in the capital intensity in that sector, $\tilde{k}_N$, and given the proportionality of the shock, in the traded sector $\tilde{k}_T$, as well. This in turn causes a decline in the marginal product $F_K(K_T, L_T)$ and requires a decrease in the relative price $\tilde{\sigma}$, in order for the arbitrage condition (6d') to be maintained:

$$\frac{d\tilde{k}_T}{d\psi} > 0; \quad \frac{d\tilde{k}_N}{d\psi} > 0; \quad \frac{d\tilde{\sigma}}{d\psi} < 0 \tag{12b}$$

The increase in the sectoral capital labor ratio in the traded sector raises the capital-output ratio in that sector. In the nontraded sector there are two offsetting effects.

While the higher capital-labor ratio has a similar effect, the higher productivity has an offsetting effect and the net effect depends upon the elasticity of substitution between capital and labor in that sector.

The productivity shock in the nontraded sector impacts on the remainder of the steady state in three ways, through: (i) the direct effect, (ii) the relative price effect, and in addition (iii) adjustments stemming from changes in the sectoral capital intensities. The direct effects are essentially analogous to those associated with the productivity shock in the traded sector. The only substantive difference is that it attracts labor to the traded sector. The responses of the equilibrium stocks of capital and traded bonds to this effect follow as before. The relative price effects are directly opposite to those arising from an analogous shock in the traded sector. However, the impacts resulting from the induced changes in the sectoral capital intensities are not straightforward. Different responses may result and these cannot be determined without imposing further restrictions.

1.4 Calibration

In order to conduct the numerical analysis we adopt the following explicit utility and production functions:

Utility Function: $$U = \frac{1}{\gamma}(C_T^{\theta} C_N^{1-\theta})^{\gamma} \qquad 0 < \theta < 1; \; -\infty < \gamma < 1 \tag{13a}$$

Production Functions: $$H(K_N, L_N) \equiv \psi K_N^{\delta} L_N^{1-\delta}; F(K_T, L_T) \equiv \phi K_T^{\alpha} L_T^{1-\alpha}; 0 < \alpha < 1, \; 0 < \delta < 1 \tag{13b}$$

where $1/(1-\gamma)$ is the intertemporal elasticity of substitution, θ parameterizes the relative importance of traded and traded goods in the overall consumption bundle, and the exponents α, δ parameterize the respective degrees of capital intensity in the two sectors.

Since the behavior of the economy depends upon the relative sectoral capital intensities, we identify two benchmark equilibria, one for each case. The corresponding structural parameters are reported in Table 1.2. In base case 1, the steady-state capital-labor ratio in the traded sector is greater than that of the nontraded sector, while in base case 2 the sectoral capital intensities are reversed. In order to maximize comparability between these two cases, these changes are brought about solely by changes in the production elasticities, α, δ.

In both cases we assume $\gamma = -1.5$, so that the intertemporal elasticity of substitution is 0.4. The share of the traded good in the consumption portfolio is $\theta = 0.75$, while the world interest rate is fixed at 6%.[16] The choice of adjustment cost parameter $h = 10$ is within the standard range 10-15; Auerbach and Kotlikoff (1987), and Ortigueira and Santos (1997). One of the issues is to determine the sensitivity of the dynamic adjustment to h and in our simulations below we shall let h vary between 0, the standard costless sectoral-adjustment model, to 100, when sectoral capital adjustment is extremely costly, and the model approximates the specific-factors model.

The only differences are in the productivity elasticities. In the first case $\alpha = 0.35, \delta = 0.25$, the capital intensity of the traded sector exceeds that of the nontraded sector; in the second case, $\alpha = 0.25, \delta = 0.35$, the relative sectoral intensities are reversed. We assume $G_T = 0.6, G_N = 0.15$, and $\tau = 0$, while the productivity parameters, ϕ, ψ are set at 1.5 and 1 respectively. [17] These parameters imply the plausible steady-state equilibrium quantities and ratios reported as benchmark cases in Table 1.3.

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[16]The choice of $\gamma = -1.5$ is consistent with recent empirical evidence by Ogaki and Reinhart (1998). The choice of θ is justified as follows. Backus, et al (1994) report empirical evidence to suggest that approximately 75% of consumption consists of domestic goods. If we assume that approximately 2/3 of these goods are traded, this implies that approximately 75% of consumption consists of traded goods (of both domestic and foreign origin).

[17]The numerical computation of the equilibrium solution is actually quite complex due to the fact that because of the intertemporal solvency condition (11a), the steady-state equilibrium and the eigenvalues describing the transitional dynamics about that equilibrium, are simultaneously determined. This renders the system highly nonlinear and we have solved it using a recursive procedure.

In Part A of the table, the relative sectoral capital-labor ratio $k_T/k_N \equiv (K_T/L_T)/(K_N/L_N) =$ 1.57, with 70.3% of labor allocated to the production of traded output, and the balance of 29.7% to the production of the nontraded good. The corresponding sectoral capital-output ratios in the traded and nontraded sectors are 3.136 and 4.167 respectively, yielding an overall capital-output ratio of 3.412.[18] Just over 75% of traded output is consumed by the private sector and 25% by the government. The corresponding allocation of nontraded output is 69% and 31%. This implies an overall share of government consumption of around 26.5%. The long-run relative price of non-traded to traded output is 1.86.

In Part B, where the nontraded sector is relatively capital intensive, the relative sectoral capital-labor ratio is 0.62, with 78.2% of labor allocated to the production of traded output, and the balance of 21.8% to the production of the nontraded good. The corresponding sectoral capital-output ratios in the traded and nontraded sectors are 3.56 and 5.83 respectively, yielding an overall capital-output ratio of 4.11. Just under 71% of traded output is consumed by the private sector and 29% by the government. The corresponding allocation of nontraded output is 73% and 27%. This implies an overall share of government consumption of around 28.6%. The long-run relative price of non-traded to traded output is 1.17.[19]

1.5. Numerical Analysis of Transitional Paths

Rows 2-5 in Tables 1.3.A and 1.3.B describe the long-run effects of changes in government expenditures (G_T, G_N) and productivity shocks (ϕ, ψ) in the cases where the traded sector is capital intensive $(\alpha > \delta)$, and where the nontraded sector is capital intensive $(\delta > \alpha)$, respectively. The resulting dynamic adjustments of the sectoral capital stocks, K_T, K_N, the real exchange rate, σ, and the sectoral allocation of labor, L_T, are illustrated as Panels (i) – (iii) in Figs. 1.1 –1.4.[20] The time paths are highly sensitive to

[18] We define the overall capital-output ratio by $K/Y = (K_T + \sigma K_N)/(Y_T + \sigma Y_N)$.
[19] These figures imply that 73.6% and 75.7% of total output in the respective steady states are traded.
[20] We have also derived the time path for traded bonds, but these are not illustrated.

the adjustment costs h, and the contrast between $h=0$ and $h>0$ are quite striking. The responses of L_T and σ, expressed in elasticity form, are reported in Table 1.4.[21]

1.5.1 Government Expenditure on Traded Good

Case I: $\alpha>\delta$. Row 2 in Table 1.3.A describes the long-run effects of an increase in G_T from 0.60 to 0.80 in the case where the sectoral capital intensity of the traded sector exceeds that of the nontraded sector.[22] The expansion in G_T attracts resources from the nontraded to the traded sector, reducing the level of output in the former, and raising it in the latter. As a consequence, G_T/Y_T rises from 0.247 to 0.322, while G_N/Y_N rises, but by less, from 0.314 to 0.332. Being a demand shock, the long-run relative price, $\tilde{\sigma}$, the sectoral capital-labor ratios, K_i/L_i, and the sectoral capital-output ratios, K_i/Y_i all remain unchanged. The fraction of labor employed in the traded sector increases from 0.703 to 0.719, with the output changing in the same proportion. The aggregate capital-output ratio, changes, however, due to the change in the output mix.

The transitional paths are illustrated in Fig. 1.1.A for the following values of the adjustment cost parameter: $h=0$, costless sectoral adjustment; $h=10$, the benchmark case; $h=20$; and $h=100$, when the model approximates the specific factors model. In all cases the capital stocks start at the point P in Panel (i), though the terminal points depend upon h.[23] The speeds along the four paths differ significantly. If $h=0$, then after 10 periods $K_T=7.793$ and its adjustment is virtually complete; if $h=100$, then after 10 periods $K_T=7.623$ and its accumulation has just begun.

In the absence of adjustment costs, the relative price, $\sigma(t)$, remains unchanged throughout the transition at $\sigma=1.86$; see Turnovsky and Sen (1995). In particular, $\sigma(0)$

[21]We can easily compute the elasticities for L_N as well.

[22] This increase in G_T represents an increase from 24.7% to 32.9% of initial traded output. Because the dynamics employ linear approximations, we restrain the size of the shocks.

[23] This is because of the differential effects on the accumulation of traded bonds. However, these differences turn out to be small, so that in fact the terminal points are actually quite close to the point Q.

does not change on impact and as a consequence, the initial labor allocations, $L_T(0)$ (and $L_N(0)$) remain at their pre-shock equilibrium values as well. Over time, as capital moves toward the traded sector, $L_T(t)$ gradually increases from 0.703 to its new equilibrium allocation, 0.719. The transition path for the capital stocks, PAQ, is obtained as follows. Noting $K_T(t) = k_T(\tilde{\sigma})L_T(t)$, $K_N(t) = k_N(\tilde{\sigma})L_N(t)$, and that $\dot{L}_T(t) = -\dot{L}_N(t)$, we immediately see that $dK_N(t)/dK_T(t) = -k_N(\tilde{\sigma})/k_T(\tilde{\sigma}) < 0$, which is constant over time. The adjustment path PAQ is thus linear.

The benchmark adjustment costs $h = 10$ are illustrated by the solid line in all three panels. In contrast to perfectly mobile capital, the increase in government expenditure on the traded good immediately lowers the relative price of nontraded output which drops by about 1.5%. This is to offset the extra return to nontraded capital in the form of lower adjustment costs; see (4h). The initial reduction in $\sigma(0)$ increases marginally with the adjustment costs, as can be seen in Panel (ii). Over time, as the resources are attracted to the traded sector, the relative price of nontraded output rises and $\sigma(t)$ is gradually restored back to its long-run equilibrium value.

With the sectoral capital stocks fixed instantaneously, the fall in the initial relative price causes an immediate shift of labor from the nontraded to the traded sector, illustrated in Panel (iii). For the benchmark case $h = 10$, $L_T(0)$ increases from its initial equilibrium level of 0.703 to 0.725 and with higher adjustment costs it is even somewhat larger. Notice that for the adjustment costs illustrated, this overshoots the long-run response.

Starting from point P in Panel (i), as the economy transforms capital from the nontraded sector to the traded sector along the locus PB, it obtains less traded capital in exchange for nontraded capital than if capital could be transformed costlessly. This is because of the capital lost in the adjustment process. The convexity of the PB locus (viewed from the Southwest) is due to the following. With the capital stocks fixed instantaneously, the shift in labor from the nontraded to the traded sector at time 0, causes an initial decline in nontraded output. At the same time, the reduction in the relative price of the nontraded good stemming from the higher G_T raises the consumption of that good, although this may be offset, at least in part, by the negative wealth effect, resulting from the higher taxes necessary to finance the higher government expenditure. On balance there is a net reduction in the excess supply of the nontraded good, so that starting from an initial equilibrium where $I = 0$, I becomes negative. Thus during the initial phase of the dynamics, the stock of nontraded capital is reduced at a rapid rate. This is in part to satisfy the additional consumption needs, with reduced new output, and in part to satisfy the investment needs in the traded sector. Thus initially, $(dK_N/dK_T)_{h=10}$ is relatively steep. As the economy evolves, both $\sigma(t)$ and $L_N(t)$ increase, the net effect of which is to reduce $H - C_N$, while the reduction in $K_N(t)$ tends to reduce nontraded output. On balance, the first two effects dominate so that I increases, and in fact during the transition can be shown to become positive. As this occurs, some of the increase in K_T is provided out of new investment so that the rate of decline in $K_N(t)$ is mitigated, and the slope of the locus flattens out.

As the adjustment cost h increases, the $K_T - K_N$ locus shifts out, as more resources are required to transform the capital from one type to another. The adjustment speed also slows. In the limit as $h \to \infty$, the transitional path becomes vertical, directly below P, reflecting the impossibility of transforming nontraded to traded capital. The two types of capital are sector-specific.

Case II: $\delta > \alpha$. This is summarized in Row 2 in Table 1.3.B. As in Case 1, the expansion in G_T attracts resources from the nontraded to the traded sector, reducing the level of output in the former and raising it in the latter. As a consequence, G_T/Y_T now rises from 0.293 to 0.382, while G_N/Y_N rises by less from 0.266 to 0.289. The long-run relative price, $\tilde{\sigma}$, remains unchanged at 1.17, while long-run employment in the traded sector increases from 0.782 to 0.799, with the output changing in the same proportion.

The transitional dynamics illustrated in Fig. 1.1.B show several interesting differences from Case I. First, while the time paths for σ in the presence of adjustment costs are essentially unchanged, there is an initial decline in the real exchange rate in the absence of adjustment costs. This contrast from the previous case is discussed by Turnovsky and Sen (1995) and is the result of the fact that σ is playing the dual role of an asset price and a current output price. Second, since in the absence of adjustment costs the two capital stocks can be moved costlessly between the two sectors, the initial slight reduction in σ causes an immediate increase in K_T coupled with an offsetting reduction in K_N, with the overall capital stock $K = K_T + K_N$ remaining fixed. This is represented by the move from P to A in Panel (i), which occurs instantaneously. This shift in capital toward the traded sector leads to an immediate migration of labor to that sector, with $L_T(0)$ jumping up to 0.804. This exceeds the short-run move of labor toward the traded sector in the presence of adjustment costs, when the sectoral capital stocks are fixed instantaneously, and the response is solely due to the (larger) declines in σ.

Returning to Panel (i), the adjustment in the sectoral capital stocks in the absence of adjustment costs consists of an initial jump along the 45 degree line from P to A, at which point both capital stocks have overshot their respective long-run targets. The large increase in σ that has occurs at that time attracts resources to the nontraded sector and the time paths for capital are gradually reversed along the locus AQ. By contrast, with adjustment costs, K_T, K_N approach their respective steady states monotonically, with the curvature of the adjustment paths reflecting the magnitude of the adjustment costs as in Case I.

1.5.2 Government Expenditure on Nontraded Good

This case is a mirror image of the effect of an increase in government expenditure on the traded good. In this case, the increase in G_N attracts resources toward the nontraded sector and the dynamic ajustment and eventual long-run responses can be analyzed as in Section 5.1. Table 4 brings out one interesting difference in the adjustments following the two forms of government expenditure. In the case $\alpha > \delta$ an increase in G_N generates larger short-run responses in labor and the relative price, than does an equal percentage increase in G_T. If the capital intensities are reversed, this relative sensitivity in responses is also reversed.

1.5.3 Productivity Increase in Traded Sector

The long-run responses are reported in Rows 4 of Table 1.3.A and 1.3.B. In both cases, the increase in productivity of the traded sector leads to a substantial change in the relative price, σ; in fact the long-run elasticity of the relative price with respect to ϕ = -1; see Table 1.4. The results in Table 1.3 enable us to resolve some of the ambiguities associated with the theoretical responses reported in Table 1.1, at least for these plausible benchmark parameters.

Thus we see that the direct expansionary effect of a positive productivity shock in the traded sector prevails, so that output of the traded sector rises. The increase in traded output reduces the relative price proportionately, causing labor and capital to move from the traded to the nontraded sector. The extent to which traded output rises relative to nontraded output depends upon the sectoral capital intensities, and in both cases the increase in traded output is substantially larger (approximately 30-31% vs. 4-5%). With the size of government remaining unchanged, the share of both outputs devoted to private consumption rises.

The transitional paths are illustrated in Figs 1.3.A and 1.3.B. Following the initial jumps, these paths are similar to those following an increase in G_N. One further point worth noting arises in the case where the traded sector is more capital intensive. In the absence of adjustment costs, $(h = 0)$, there is no initial jump in the sectoral allocation of labor, L_T. Neither is there any initial sectoral reallocation of the capital stocks (which could occur). The reason is that the productivity shock is accommodated by a proportionate change in the relative price, leaving the short-run allocation conditions unchanged. Over time, the economy responds to the increase in σ by gradually moving resources from the traded to the nontraded sector.

In the presence of adjustment costs, $\sigma(0)$ overshoots its long-run response, by an amount that varies inversely with the adjustment costs. With capital stocks fixed instantaneously, this leads to an initial over-adjustment in employment toward the traded sector, which is then reversed over time. Thus we obtain the contrasting transitional paths for employment depending upon whether or not there are adjustment costs, analogous to those obtained for government expenditure. But one difference is that despite the qualitative similarity of the dynamics to that following government consumption expenditure (cf. Figs. 1.2 and 1.3), relatively more of the transitional adjustment is borne by the relative price than by employment; see Table 1.4. As a result, given the scale, we cannot conveniently illustrate the initial jump.

1.5.4 Productivity Increase in Nontraded Sector

The long-run responses to this shock are reported in Rows 5 of Tables 1.3.A and 1.3.B. Again, the productivity shock raises the long-run output of both sectors. Interesting, in the case $\alpha > \delta$ it raises the output of the traded sector relatively more than it does that of the nontraded sector (17.7% vs. 15.3%), although if $\delta > \alpha$, the relative effects are reversed (13.3% vs. 20.8%). As a result, the relative price σ undergoes a larger decline in the latter case (see Table 1.4). On the other hand, in the short run the higher productivity in the nontraded sector has a sharp negative impact on $\sigma(0)$ and on $L_T(0)$ causing traded output to decline.

The dynamics are illustrated in Figs 1.4.A and 1.4.B. The higher productivity in the nontraded sector increases the marginal productivity of both capital and labor in that sector. In the absence of adjustment costs, the capital stocks can be reallocated instantaneously, along with labor, so that in the short run both factors move from the traded to the nontraded sector. This leads to an increase in nontraded output, and a decrease in traded output, leading to a reduction in the relative price σ. This reduction in σ then attracts resources back toward the traded sector, so that over time K_T and L_T gradually increase. The adjustment paths for capital are approximately the same, irrespective of sectoral capital intensities.[24]

In the presence of adjustment costs, the capital stocks K_T, K_N are fixed instantaneously. The increase in ψ leads to a smaller initial reduction in L_T and therefore a smaller reduction in σ. For equilibrium among asset returns to hold, σ must continue to fall ($\dot{\sigma} < 0$) and this attracts resources to the traded sector. During the initial transitional phase the higher productivity of the nontraded sector attracts capital to that sector, so that initially there is positive capital accumulation in both sectors, This is accomplished through sufficiently positive net investment. However, over time, as labor moves away from the nontraded sector, the productivity of capital in that sector declines, so that K_N eventually gradually declines. As a consequence, output of the nontraded sector eventually declines and the relative price σ begins to increase, converging to its new long-run equilibrium.

1.6 Convergence of Real Exchange Rate

An important empirical issue concerns the tendency for the deviations of the real exchange rate from its long-run PPP equilibrium condition to persist. The empirical evidence suggests that persistence away from this equilibrium is an important phenomenon, with the average half-life of the deviation being 3-5 years.[25] One of the key problems with the conventional two-sector model with freely mobile capital is that it implies one of two things. First, if the traded sector is more capital intensive than the nontraded sector, the real exchange rate is always in steady-state equilibrium.

[24] One sharp contrast in the case of the productivity shock in the nontraded sector is the dramatic initial decline in labor in the traded sector in the absence of adjustment costs. This is because of the large instantaneous shift in capital from the traded to the nontraded sector.

Alternatively, if the capital intensities are reversed, the real exchange rate may deviate from its long-run equilibrium. But if so, the deviations are small and are quickly eliminated. This can be immediately seen by looking at the time paths for σ in Figs. 1.1-1.4 for the case where $h = 0$.

These figures also illustrate how in the presence of sectoral adjustment costs the real exchange rate deviates from its long-run equilibrium for substantial periods of time. Further analysis of this persistence is provided in Table 1.5, which reports the short-run and asymptotic rates of convergence for the real exchange rate, using equation (9) in response to the different shocks.[26] The results are quite illuminating.

Consider first the case where $\alpha > \delta$. In the absence of sectoral adjustment costs the real exchange rate remains unchanged in response to the two forms of government expenditure shocks. On the other hand it jumps instantaneously to its new steady state following a productivity shock in the traded sector, so that there is no further adjustment in that case. In the case of the productivity shock in the nontraded sector it jumps short of the steady state and thereafter converges at the very rapid uniform rate of 39% per annum, thus eliminating the deviation almost immediately.

The introduction of adjustment costs changes that dramatically. For the benchmark case where $h = 10$ we find that σ converges initially at around 11% for the first three shocks, but slows to around 2% asymptotically.[27] In response to the productivity shock in the nontraded sector the initial rate of convergence is higher, but this slows to 1.8% asymptotically. As h increases, the asymptotic speed of convergence is reduced and for $h = 100$ it is only around 0.2%.[28]

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[25] See e.g. Edwards and Savastano (1999), and Cheung and Lai (2000).
[26] The figures reported there are the rates of convergence, following initial jumps.
[27] This implies a half-life of a little greater than 5 years, generally consistent with the empirical evidence.
[28] The very rapid initial rate of convergence of the real exchange rate in response to the productivity shock in the nontraded sector is a consequence of the overshooting that occurs in that case. It is evident from the definition of the

The same general pattern is seen in the case $\delta > \alpha$, where the nontraded sector is more capital intensive. But there are some interesting differences. In the benchmark case, $h = 10$, the asymptotic speed of convergence is somewhat faster, being over 3% per annum, but in the short-run it is somewhat slower than when $\alpha > \delta$. This presumably reflects the fact that part of the adjustment in the present case is brought about by a larger initial jump.

1.7 Conclusion

The prevalent assumption adopted by two-sector models that existing capital can be reallocated instantaneously and costlessly across sectors is implausible. In this paper have developed a two-sector model in which capital movement across the sectors requires adjustment costs, which we express in the form of capital lost in the transformation process. Intersectoral adjustment costs are introduced in a sufficiently tractable way that allows us to take into account both capital reallocation and capital accumulation simultaneously. With very low adjustment costs the equilibrium dynamics are qualitatively similar to those obtained in the standard Heckscher-Ohlin technology where perfect factor mobility across sectors prevails. At the other extreme, with extremely higher intersectoral adjustment costs, the model converges to the specific-factor model. Thus our framework embodies these two standard models as polar extremes.

The introduction of sectoral adjustment costs has important consequences for the dynamics of capital accumulation, and in particular for real exchange rate dynamics. First, the dependence of the behavior of the exchange rate upon sectoral capital intensities in the absence of adjustment costs no longer applies. Irrespective of these intensities, persistent deviation of the real exchange rate from its equilibrium values obtains without the need to assume price rigidity, as for example considered by Obstfeld and Rogoff

speed of convergence provided in (9) that $\kappa(t)$ becomes infinite at the point where $\sigma(t)$ crosses its equilibrium at the point of overshooting.

(1995). Plausible values of the adjustment cost parameters can easily reconcile the degree of real exchange rate persistence with existing empirical evidence.

The framework we have developed in this paper has applications in other related areas. One obvious example is in the dynamics of transition economies, and the role played by the state in facilitating the restructuring. More generally, the approach has important implications in other applications of two-sector models, virtually all of which assume that existing capital is perfectly mobile across sectors. The two-sector Lucas (1988) endogenous growth model is one example, which has a similar structure to the model analyzed here; see Bond, Wang, and Yip (1996).

Table 1.1

A. Demand Shocks

Variables	G_T	G_N
$\bar{k}_T$	0	0
$\bar{k}_N$	0	0
$\tilde{\sigma}$	0	0
$K_T/\bar{Y}_T$	0	0
$K_N/\bar{Y}_N$	0	0
$\tilde{L}_T$	+	-
$\tilde{L}_N$	-	+
$\tilde{K}_T$	+	-
$\tilde{K}_N$	-	+
$\tilde{Y}_T$	+	-
$\tilde{Y}_N$	-	+
$\bar{\lambda}$	+	+
$\tilde{C}_T$	-	-
$\tilde{C}_N$	-	-

B. Supply Shocks

Variables	Traded Sector ϕ		Nontraded Sector ψ		
	Direct Effect	Relative Price Effect	Direct Effect	Relative Price Effect	Sectoral capital Intensity Effect
$\bar{k}_T$	0	na	+	na	na
$\bar{k}_N$	0	na	+	na	na
$\tilde{\sigma}$	+	na	-	na	na
$K_T/\bar{Y}_T$	+	na	+	na	na
$K_N/\bar{Y}_N$	-	na	sgn(1-η)	na	na
$\tilde{L}_T$	-	+	+	-	?
$\tilde{L}_N$	+	-	?	+	?
$\tilde{K}_T$	-	+	+	-	?
$\tilde{K}_N$	+	-	-	+	?
$\tilde{Y}_T$	-	+	+	-	?
$\tilde{Y}_N$	+	-	?	+	?
$\bar{\lambda}$	-	?	-	?	?
$\tilde{C}_T$	+	?	-	?	?
$\tilde{C}_N$	+	-	-	+	?

na denotes not applicable

η denotes the elasticity of substitution between capital and labor in the production of nontraded output.

Table: 1.2
Base Parameter Values

Base parameter values when traded sector is more capital intensive									
Preference parameters			Production parameters			Govt. Expend.		Productivity	
γ	θ	r	h	α	δ	G_T	G_N	ϕ	ψ
-1.5	0.75	0.06	10	0.35	0.25	0.6	0.15	1.5	1
Base parameter values when nontraded sector is more capital intensive									
Preference parameters			Production parameters			Govt. Expend.		Productivity	
γ	θ	r	h	α	δ	G_T	G_N	ϕ	ψ
-1.5	0.75	0.06	10	0.25	0.35	0.6	0.15	1.5	1

Table 1.3

A. Steady-State Responses to Permanent Changes $\alpha = 0.35, \delta = 0.25$ (traded sector is more capital intensive): $h = 10$

	K_T/L_T	K_N/L_N	K_T/Y_T	K_N/Y_N	K/Y	$\sigma(0)$ $\tilde{\sigma}$	$L_T(0)$ $\tilde{L}_T$	Y_T	Y_N	C_T/Y_T	C_N/Y_N	G_T/Y_T	G_N/Y_N	μ_1 μ_2
Benchmark ***G_T=0.6, G_N=0.15*** ***ϕ=1.5, ψ=1***	**10.83**	**6.705**	**3.136**	**4.167**	**3.412**	**1.860** **1.860**	**0.703** **0.703**	**2.428**	**0.478**	**0.753**	**0.686**	**0.247**	**0.314**	**-0.0190** **-0.1446**
G_T=0.8, G_N=0.15 *ϕ=1.5, ψ=1*	10.83	6.705	3.136	4.167	3.396	1.808 1.860	0.725 0.720	2.487	0.450	0.674	0.667	0.322	0.333	-0.0179 -0.1428
G_T=0.6, G_N=0.20 *ϕ=1.5, ψ=1*	10.83	6.705	3.136	4.167	3.435	1.926 1.860	0.674 0.680	2.347	0.516	0.751	0.612	0.256	0.388	-0.0210 -0.1365
G_T=0.6, G_N=0.15 *ϕ=2, ψ=1*	10.83	6.705	2.352	4.167	2.860	2.527 2.479	0.688 0.691	3.180	0.498	0.814	0.699	0.189	0.301	-0.0200 -0.1390
G_T=0.6, G_N=0.15 *ϕ=1.5, ψ=1.25*	14.58	9.028	3.806	4.167	3.888	1.594 1.532	0.669 0.746	2.857	0.551	0.646	0.728	0.210	0.272	-0.0160 -0.1469

Table 1.3 (Cont'd)

B. Steady-State Responses to Permanent Changes $\alpha = 0.25, \delta = 0.35$ (nontraded sector is more capital intensive): $h = 10$

	K_T/L_T	K_N/L_N	K_T/Y_T	K_N/Y_N	K/Y	$\sigma(0)$ $\tilde{\sigma}$	$L_T(0)$ $\tilde{L}_T$	Y_T	Y_N	C_T/Y_T	C_N/Y_N	G_T/Y_T	G_N/Y_N	μ_1 μ_2
Benchmark ***G_T=0.6, G_N=0.15*** ***ϕ=1.5, ψ=1***	**9.334**	**15.08**	**3.560**	**5.833**	**4.111**	**1.170** **1.170**	**0.782** **0.782**	**2.051**	**0.563**	**0.707**	**0.734**	**0.293**	**0.266**	**-0.0335** **-0.0910**
G_T=0.8, G_N=0.15 *ϕ=1.5, ψ=1*	9.334	15.08	3.560	5.833	4.071	1.117 1.170	0.804 0.799	2.095	0.520	0.620	0.711	0.382	0.289	-0.0306 -0.0931
G_T=0.6, G_N=0.20 *ϕ=1.5, ψ=1*	9.334	15.08	3.560	5.833	4.150	1.211 1.170	0.763 0.767	2.012	0.601	0.700	0.667	0.298	0.333	-0.0364 -0.0884
G_T=0.6, G_N=0.15 *ϕ=2, ψ=1*	9.334	15.08	2.670	5.833	3.483	1.607 1.561	0.766 0.769	2.690	0.596	0.776	0.748	0.223	0.252	-0.0358 -0.0892
G_T=0.6, G_N=0.15 *ϕ=1.5, ψ=1.25*	13.16	21.25	4.605	5.833	4.862	1.009 0.905	0.752 0.813	2.324	0.680	0.619	0.779	0.258	0.221	-0.0280 -0.0952

Table 1.4: Short-run responses to permanent changes

A. Traded sector more capital intensive ($\alpha = 0.35, \delta = 0.25$)

	$G_T = 0.8, G_N = 0.15$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.20$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 2, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 1.5, \psi = 1.25$	
Short-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$
h=0	0	0	0	0	0	1.000	-3.408	-0.700
h=10	0.092	-0.089	-0.123	0.112	-0.065	1.081	-0.194	-0.572
h=20	0.102	-0.099	-0.138	0.126	-0.072	1.090	-0.137	-0.620
h=100	0.114	-0.111	-0.156	0.142	-0.081	1.101	-0.067	-0.678
Long-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$
h=10	0.072	0	-0.101	0	-0.054	1.000	0.241	-0.703

B. Nontraded sector more capital intensive ($\alpha = 0.25, \delta = 0.35$)

	$G_T = 0.8, G_N = 0.15$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.20$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 2, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 1.5, \psi = 1.25$	
Short-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$	$L_T(0)$	$\sigma(0)$
h=0	0.122	-0.005	-0.108	0.005	-0.093	1.006	-2.221	-0.740
h=10	0.085	-0.136	-0.073	0.105	-0.061	1.119	-0.155	-0.552
h=20	0.096	-0.154	-0.083	0.119	-0.069	1.134	-0.122	-0.596
h=100	0.109	-0.176	-0.096	0.137	-0.080	1.154	-0.070	-0.663
Long-run								
	Elasticity wrt G_T		Elasticity wrt G_N		Elasticity wrt ϕ		Elasticity wrt ψ	
	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$	$\tilde{L}_T$	$\tilde{\sigma}$
h=10	0.064	0	-0.057	0	-0.049	1.000	0.160	-0.908

Table 1.5: Speed of Convergence and Adjustment Costs

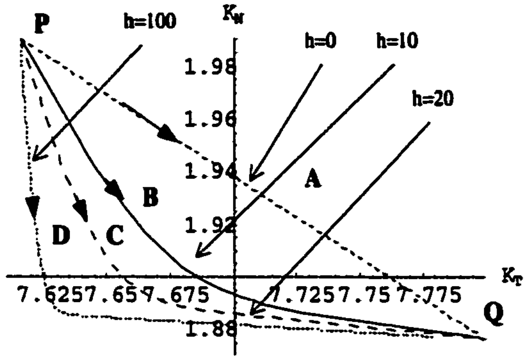
A. Traded sector more capital intensive ($\alpha = 0.35, \delta = 0.25$)

	$G_T = 0.8, G_N = 0.15$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.20$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 2, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 1.5, \psi = 1.25$	
	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$
$h = 0$	-------		----------		----------		0.3900	0.3900
$h = 10$	0.1166	0.0179	0.1084	0.0210	0.1106	0.0200	0.4913	0.0160
$h = 20$	0.1166	0.0098	0.1084	0.0115	0.1106	0.0110	0.7043	0.0087
$h = 100$	0.1166	0.0022	0.1084	0.0026	0.1106	0.0024	2.0525	0.0019

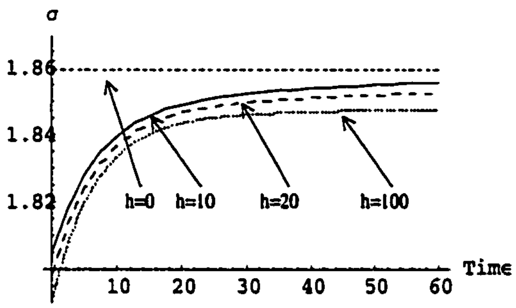
B. Nontraded sector more capital intensive ($\alpha = 0.25, \delta = 0.35$)

	$G_T = 0.8, G_N = 0.15$ $\phi = 1.5, \psi = 1$		$G_T = 0.8, G_N = 0.20$ $\phi = 1.5, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 2, \psi = 1$		$G_T = 0.6, G_N = 0.15$ $\phi = 1.5, \psi = 1.25$	
	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$	$\kappa(0)$	$\tilde{\kappa}$
$h = 0$	0.3900	0.3900	0.3900	0.3900	0.3900	0.3900	0.3900	0.3900
$h = 10$	0.0944	0.0306	0.0916	0.0364	0.0918	0.0358	0.1699	0.0280
$h = 20$	0.0944	0.0165	0.0916	0.0194	0.0918	0.0191	0.1804	0.0152
$h = 100$	0.0944	0.0037	0.0916	0.0044	0.0918	0.0044	0.2038	0.0034

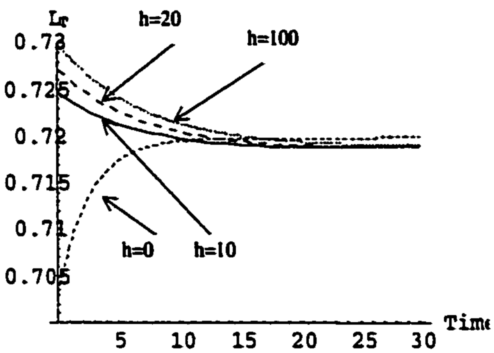
A. *Traded Good More Capital Intensive*



(i) Capital Adjustments



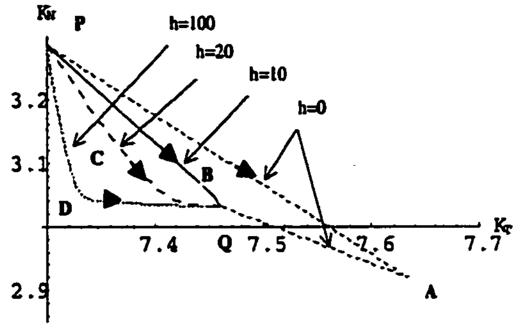
(ii) Real Exchange Rate



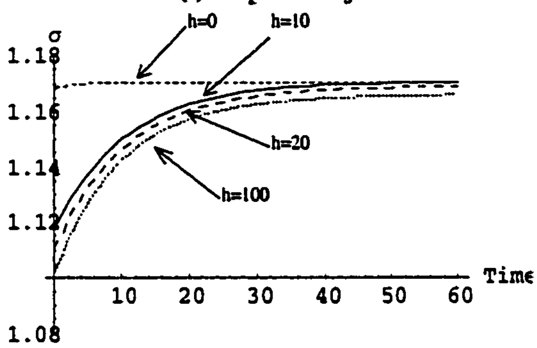
(iii) Labor in Traded Sector

Figure: 1.1: Adjustmetn Paths When G_T Increase From 0.6 to 0.8

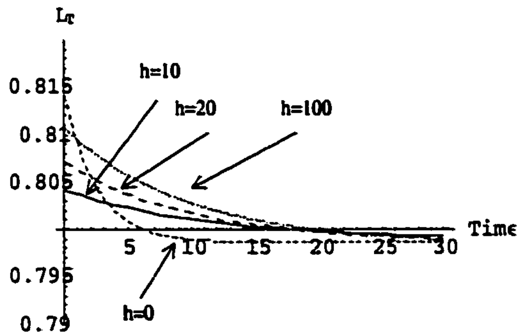
B. *Nontraded Good More Capital Intensive*



(i) Capital Adjustments

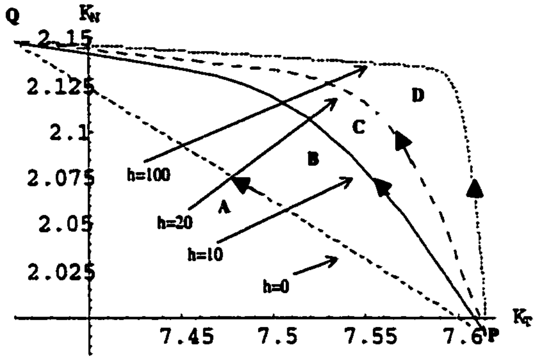


(ii) Real Exchange Rate

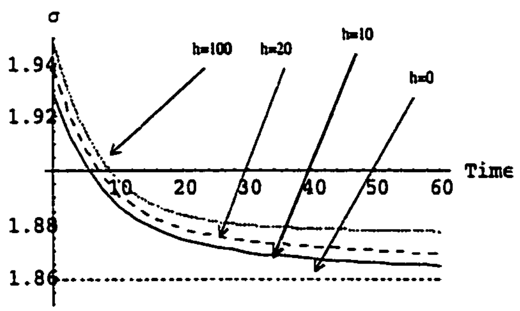


(iii) Labor in Traded Sector

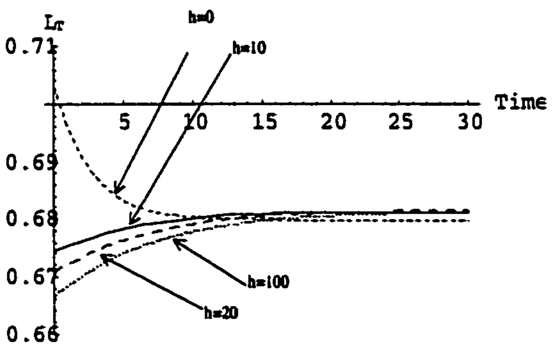
A. Traded Good More Capital Intensive



(i) Capital Adjustments

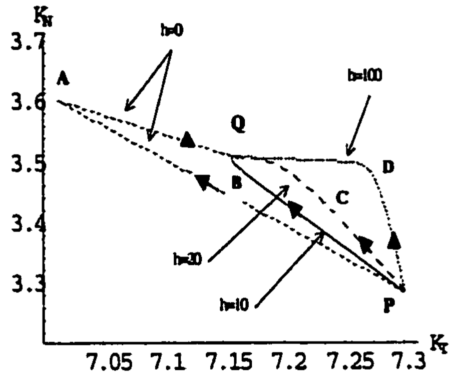


(ii) Real Exchange Rate

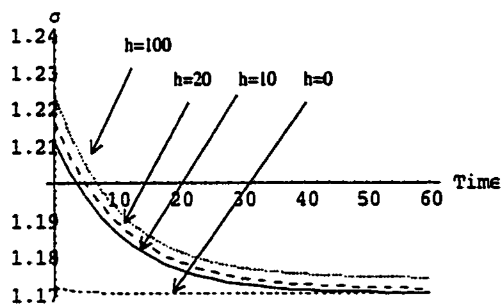


(iii) Labor in Traded Sector

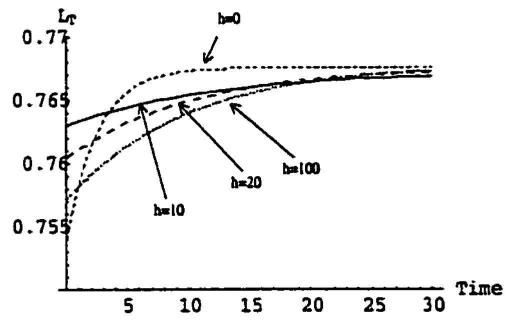
B. Nontraded Good More Capital Intensive



(i) Capital Adjustments



(ii) Real Exchange Rate



(iii) Labor in Traded Sector

Figure: 1.2: Adjustment Paths When G_N Increases From 0.15 to 0.2

A. *Traded Good More Capital Intensive*

B. *Nontraded Good More Capital Intensive*

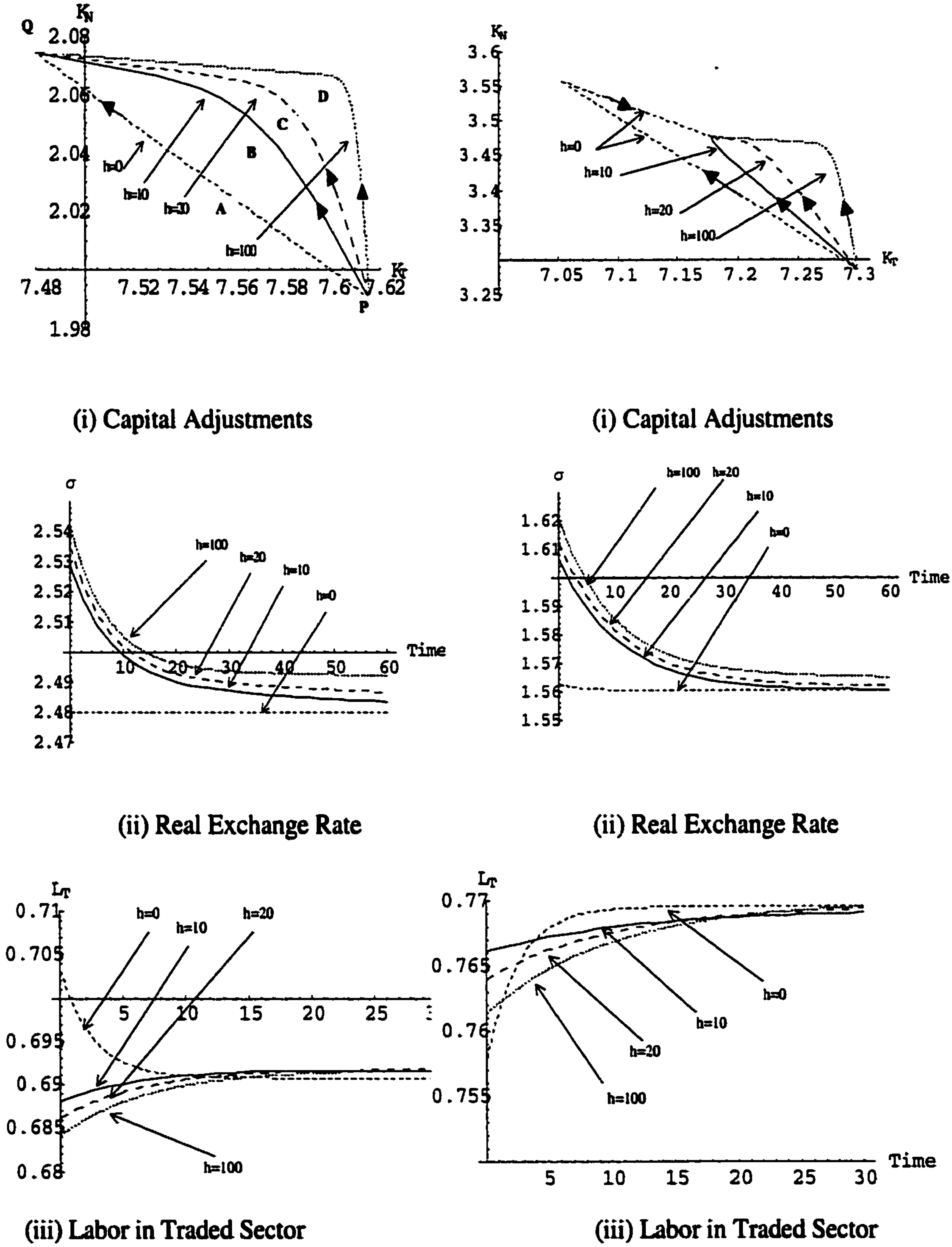
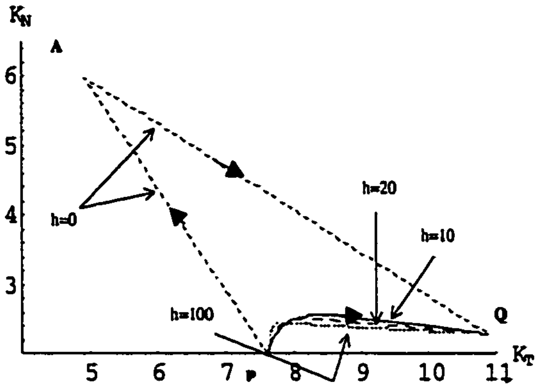
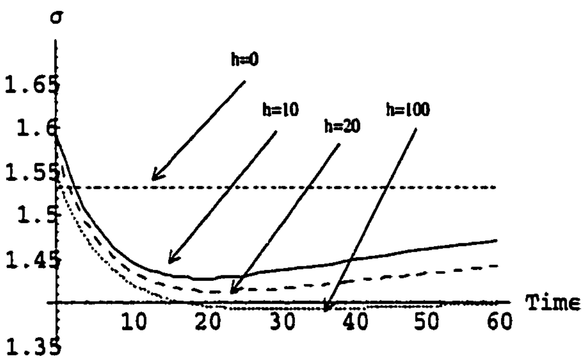


Figure: 1.3: Adjustment Paths When ϕ Increases From 1.5 to 2

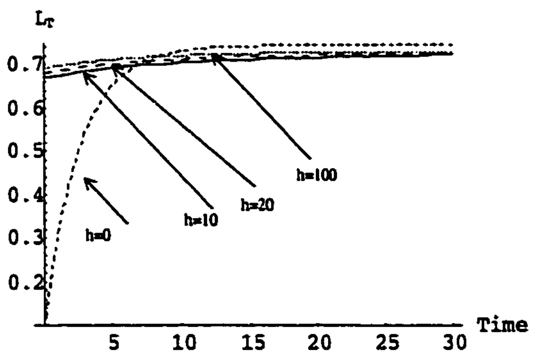
A. *Traded Good More Capital Intensive*



(i) Capital Adjustments

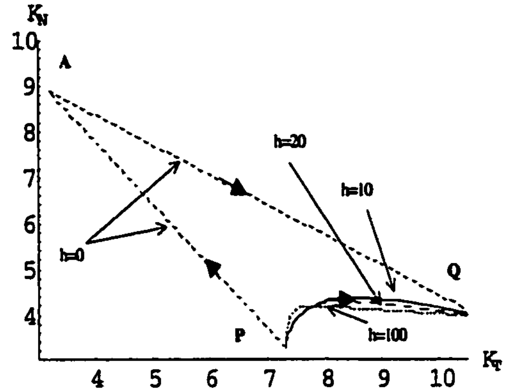


(ii) Real Exchange Rate

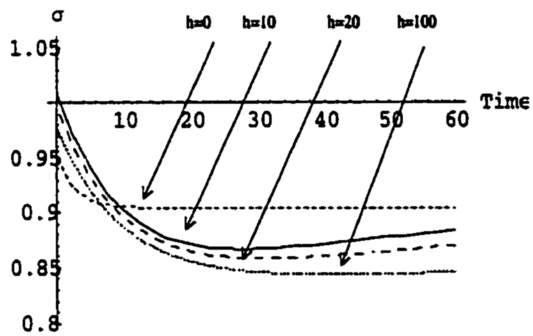


(iii) Labor in Traded Sector

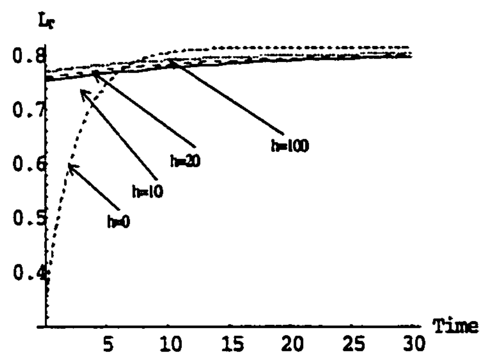
B. *Nontraded Good More Capital Intensive*



(i) Capital Adjustments



(ii) Real Exchange Rate



(iii) Labor in Traded Sector

Figure:1.4: Adjustment Paths When ψ Increases From 1 to 1.25

CHAPTER 2

Sectoral Adjustment Costs and The Rate of Convergence in a Two-Sector Endogenous Growth Model

2.1 Introduction and Motivation

Economic growth is viewed as an endogenous outcome of a general equilibrium model in the endogenous growth framework. In order to achieve this internally generated growth, some restrictions related to homogeneity, like production must generally take place subject to constant returns to scale, must be imposed[1]. One way to circumvent this is to take a broader view of capital where capital includes human capital such as AK model; for a survey see Barro and Salai-i-Martin (1995). As physical capital and human capital are produced by different technologies, Lucas (1988) has proposed a two-sector model where we have an exclusive human capital production sector along the lines of Uzawa (1965). The production of human capital is now the source of long-run per capita growth in these models. The capital goods are produced along with the consumption goods in the final output sector. Human capital sector uses both physical and human capital. The agent has to decide at every instant (i) how to allocate his physical and human capital in two sectors, (ii) how much to consume, and (ii) the rate of accumulation of physical capital and human capital.

The growth model with a human capital sector has been extended in various directions, but empirical performance of these models are less than satisfactory; see a survey by Durlauf and Quah (1999). Calibrations of Lucas model generate a rate of convergence of 7% or more while empirical estimates for the rate of convergence are around 2%; Mankiw, Romer, and Weil (1992) and Barro and Sala-i-Martin (1995). In a recent paper Ortigueira and Santos (1997), by introducing adjustment cost in physical

[1] These restrictions are of a knife-edge character and have been criticized; Solow (1994)

capital accumulation, have found empirically validated rate of convergence[2] with a reasonable adjustment cost parameter. But in all these exercises, all state variables have same rate of convergence and the rates of convergence do not have a time path[3]. Bernard and Jones (1996) have shown that the conventional one metric rate of convergence is inadequate as different sectors in OECD countries show different convergence profiles. In order to take into account these features, Eicher and Turnovsky (1999) have put forward a two-sector nonscale model where different variables have different convergence profile and the rate of convergence is time varying. They have shown that scale adjusted capital and technology have different convergence rates.

As capital accumulation gains prominence in these models, sectoral reallocation of captial has been kept very simple. Both human capital and physical capital have been assumed to be *costlessly* and *instantaneously* mobile across the two sectors. Though this assumption is analytically convenient, it is unrealistic. The reconfiguration of existing capital is neither costless nor instantaneous. A factory building cannot be used for school without any reconfiguration (adjustment costs). A farmer cannot work in a bank without training. In order to make one unit of capital from one sector suitable for the other sector, be it physical capital or human capital, a resource consuming retrofitting or retraining is required. These retrofitting or retraining cost (sectoral adjustment costs) has important intertemporal implications.

As a motivating example, consider the conversions of defense industries in Europe after the end of cold war. The project "KONVER" had been designed to convert defense-related industries into consumer goods industries in European Union with generous fiscal support[4]. In the EU, the conversion is considered as structural change and conversion support is seen as an investment in a regional economy; Jorn Brommelhorster (1997).

[2] The empirical consensus of 2% rate of convergence is under strain with new studies with different techniques. By taking into account the fixed effects in panel-data approach, Islam (1995) has found the rate of convergence to be 4.7% for non-oil countries and 9.7 for OECD countries. Caselli, Esquivel, and Lefort (1996) have suggested a convergence rate of 10% after conditioning out individual heterogeneities.

[3] This is due to the presence of a one-dimensional stable manifold where the negative eigenvalue determines the rate of convergence.

Similar transformations also have been taking place in East European countries and even in USA. In former Czechoslovakia, ZTS Martin (a former tank producing firm) now produces agricultural machineries. The Congress of the United States has once earmarked $400 million in the national budget for conversion of Russian defense industries (Nunn-Lugar Act.); see Wall-Palms (1995).

Mussa (1978), Gavin (1990, 1992) are among others who have tried to incorporate this sectoral adjustment cost by introducing a third "Retrofit Sector" in a two-sector dependent economy framework. Recently in a paper Morshed and Turnovsky (2000) have proposed a simple way to incorporate this sectoral adjustment cost by assuming a net loss in capital in the donor sector. For example, to transform X unit of capital from one sector, the loss of capital in the donor sector is more than the amount X. This excess amount is the sectoral adjustment cost. This has opened up the opportunity to incorporate the costly sectoral movement of capital without introducing a third "Retrofit Sector". Both capital reallocation and capital accumulation can be now treated simultaneously with ease.

The time variations of the rate of convergence in Bernard and Jones (1996) and cross-country variations in the rate of convergence as found in Durlauf and Quah (1999) question the relevance of the one dimensional stable manifold in growth models. Eicher and Turnovsky (1999) have proposed a model with time varying rate of convergence but the cross-country variations can not be analyzed without assuming differences in production structure and/or preference parameters. Lucas (1993) has shown that apparently similar countries may end up with different growth profile.

In order to incorporate cross-country variations in convergence profile, we have introduced sectoral adjustment costs in a two-sector Lucas endogenous growth model. In order to keep the economy simple we have assumed no adjustment cost in the accumulation of new capital. This yields the stable dynamic adjustment path as a two-

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[4] For KONVER II project the EU have allocated 744.3 million Ecu for the years 1994-1999.

dimensional manifold and thus the rate of convergence in *not identical* and *not constant*. This is in contrast with both the one sector neoclassical model and two sector endogenous growth models in which the stable adjustment path is a one dimensional manifold; Bond, Wang and Yip (1996) and Ortigueira and Santos (1997). The time variations of the rate of convergence are consistent with Bernard and Jones (1996) findings where different sectors have different convergence time profile. Moreover, the time path of the rate of convergence depends on the size of the sectoral adjustment costs. This flexibility of the time path of the rate of convergence allows us to incorporate cross-country variations in the convergence profile[5] in an endogenous growth framework.

We have calculated the rate of convergence of the final output per unit of human capital. It is a function of physical capital per unit of human capital and the share of human capital in final good production. So the rate of growth of final output per unit of human capital is a linear function of the rate of growth of the physical capital per unit of human capital and the rate of growth of the fraction of the human capital in final good sector. Our calibration experiment generates a time profile of the rate of convergence that is sensitive to the size of the sectoral adjustment costs. With a very low sectoral adjustment costs, for an increase in the rate of time preference, the rate of convergence initially turns out to be very high and asymptotically it comes down to about 8%, which is comparable to other calibration exercises. But as the size of the sectoral adjustment costs increases, the initial rate of convergence becomes smaller. Eventually, for a sufficiently high sectoral adjustment cost, the initial rate of convergence starts below the asymptotic rate.

This paper contributes in the convergence literature in two ways. First, the Bernard and Jones (1995) criticism can be easily sorted out in a two-sector endogenous Lucas growth model as the derived rate of convergence is time varying and the rates of convergence are different for different state variables. Second, By allowing different convergence paths for the same shock with different sectoral adjustment costs, this model can capture the cross-country variations in convergence profile.

This paper is organized as follows. A two-sector Lucas type endogenous growth model with sectoral adjustment costs is developed in section 2.2. In order to shed light on the dynamics of the model, we have calibrated the model that is reported in section 2.3. The long run responses due to preference shocks and productivity shocks are analyzed in section 2.4 while the numerical analysis of transitional path is discussed in section 2.5. Time profiles of rate of convergence are discussed in section 2.6. Instead of the sectoral adjustment costs in physical capital transfer across sectors, we have also introduced it in human capital transfer. A brief description of that experiment is presented in section 2.7. At the end some concluding remarks are made.

2.2 The model

We have a slightly modified version of two-sector endogenous growth model. A single, infinitely lived representative agent accumulates two types of capital, physical capital K and human capital H, for rental at the competitively determined rental rate. There is no depreciation of capital and the accumulation of new capital does not require adjustment costs. There is no government and it is a closed economy.

Agent produces a final output X using both types of capital by means of the following production function:

$$X = aK_X^{\alpha}H_X^{1-\alpha}; 0<\alpha<1 \qquad (1)$$

where K_X and H_X denote allocation of physical capital and human capital in producing final goods respectively. The final good can be used either for consumption C or added to the physical capital stock in the final goods sector with no adjustment cost.

[5] Durlauf and Quah (1999) have shown that different group of countries show different convergence dynamics. They have proposed "club convergence" meaning countries with similar structural characteristics and similar initial conditions converge to similar levels of per capita income.

The agent produces human capital using the following linearly homogenous production function.

$$Y=\dot{H}=bK_Y^{\delta}H_Y^{1-\delta};0<\delta<1 \tag{2}$$

where K_Y is the amount of physical capital used in production of human capital and H_Y is the amount of human capital used in the production of human capital.

Capital accumulations have been taking place for both physical capital (both in final good sector and human capital sector) and human capital. We assume that the new physical capital will be accumulated only in the final good producing sector and the human capital production sector will get additional physical capital by dismantling the existing physical capital in final good producing sector. This sectoral movement of capital requires adjustment costs. The physical capital accumulation equations are:

$$\dot{K}_Y=T \tag{3}$$

$$\dot{K}_X=aK_X^{\alpha}H_X^{1-\alpha}-C-T(1+\tfrac{hT}{2K_X}) \tag{4}$$

T is the amount of physical capital accumulated in production of human capital and C is the consumption of final good. In order to get T amount of new capital in human capital production, the amount of physical capital lost in the final good sector is greater than T. This excess amount, $\frac{hT^2}{2K_X}>0$ represents the sectoral adjustment cost. This specification is analogous to the standard specifications of aggregate adjustment costs based on Hayashi (1982), and preserves the conventional properties. The coefficient $h>0$ parameterizes the degree of the sectoral adjustment costs. This specification of adjustment costs in relative terms, per unit of physical capital in final good sector, K_X, is standard, and since this normalization renders the adjustment cost parameter, h, unit-free, is convenient for conducting the numerical simulations. T is also allowed to assume negative values meaning factor movement can take place in both directions.

At each moment of time amount of human capital will be reallocated in two production processes X and Y.

$H = H_X + H_Y;$ (5)

Since we have introduced sectoral adjustment cost for physical capital reallocation, we have $\dot{K}_X + \dot{K}_Y \neq X - C$. This inequality will turn into equality if we assume no sectoral adjustment costs, $h = 0$.

The agent maximizes the following utility function $U = \int_0^\infty \frac{1}{\gamma} C^\gamma e^{-\beta t} dt$ subject to equations (2)-(5), and the initial stocks of capitals K_{X0}, K_{Y0}, and H_0.

The Lagrangean expression to this optimization problem is

$$L = \frac{1}{\gamma} C^\gamma e^{-\beta t} dt + \lambda_1 e^{-\beta t}[aK_X^\alpha H_X^{1-\alpha} - C - T(1 + \frac{hT}{2K_X}) - \dot{K}_X] + \lambda_2 e^{-\beta t}[T - \dot{K}_Y] + \lambda_3 e^{-\beta t}[bK_Y^\delta H_Y^{1-\delta} - \dot{H}]$$
$$+ V_1 e^{-\beta t}[H - H_X - H_Y]$$

(6)

The optimality conditions are thus:

$$C^{\gamma-1} = \lambda_1 \quad (6.1)$$

$$\frac{T}{K_X} = \frac{\lambda_2 - \lambda_1}{\lambda_1 h} \quad (6.2)$$

$$\lambda_1 (1-\alpha) a K_X^\alpha H_X^{-\alpha} = \lambda_3 (1-\delta) b K_Y^\delta H_Y^{-\delta} \quad (6.3)$$

$$a\alpha K_X^{\alpha-1} H_X^{1-\alpha} + \frac{hT^2}{2K_X^2} = \beta - \frac{\dot{\lambda}_1}{\lambda_1} \quad (6.4)$$

$$\frac{\lambda_3}{\lambda_2} b\delta K_Y^{\delta-1} H_Y^{1-\delta} = \beta - \frac{\dot{\lambda}_2}{\lambda_2} \quad (6.5)$$

$$\frac{\lambda_1}{\lambda_3}(1-\alpha)aK_X^{\alpha}H_X^{-\alpha} = (1-\delta)bK_Y^{\delta}H_Y^{-\delta} = \beta - \frac{\dot{\lambda}_3}{\lambda_3} \qquad (6.6)$$

together with the transversality conditions

$$\underset{t\to\infty}{Lt}\,\lambda_1 K_X e^{-\beta t} = \underset{t\to\infty}{Lt}\,\lambda_2 K_y e^{-\beta t} = \underset{t\to\infty}{Lt}\,\lambda_3 H e^{-\beta t} = 0 \qquad (7)$$

Where λ_1, λ_2, and λ_3 are the shadow value of physical capital in the production of final good, shadow value of physical capital in the production of human capital, and the shadow value of human capital respectively.

Condition (6.1) states that the marginal utility of consumption of final good is equal to the shadow value of physical capital in the production of final good. This is standard result as the final output can either be consumed or be accumulated as physical capital in the final good sector with no adjustment costs. Since the physical capital in final good sector and physical capital in human capital sector are different, effectively we have assumed three different types of capital. The returns to human capital in both production processes are equal when valued with appropriate shadow prices (equation (6.3)). Equation (6.2) gives the rate of transfer of capital across sectors. If the shadow prices of physical capital in both sectors are equal, i.e., λ_1 and λ_2 are equal, there would be no transfer of capital across sectors. Moreover, the rate of transfer is negatively related to the adjustment cost parameter h. When the movement of capital across sectors is very expensive, a very high h, we expect little or no reconfiguration of capital. But a smaller h increases the rate of transfer.

Equations (6.4), (6.5), and (6.6) are intertemporal efficiency conditions. Since the human capital sector gets additional capital from transfer of capital from the final good sector, the return from consumption in this case is equal to return from physical capital in human capital sector plus an additional item to take into account the sectoral adjustment costs; see equation (6.4).

Determination of Equilibrium

We have derived the following overall consumption growth by taking the time derivative of equation (6.1) and using the equation (6.4):

$$\frac{\dot{C}}{C}=\frac{\beta-a\alpha K_X^{\alpha-1}H_X^{1-\alpha}-\frac{hT^2}{2K_Y^2}}{\gamma-1} \tag{8}$$

This result implies that the rate of growth of consumption depends on the rates of return to capital in sector producing final good. Since the rate of returns is time dependent, the total consumption growth would be time dependent as well. Moreover, the consumption growth rate depends on the size of the sectoral adjustment costs. If we assume h is equal to 0, then this yields same result we obtain in two-sector endogenous growth model; for details see Turnovsky (2000).

We will show how macroeconomic equilibrium can be represented by five differential equation in q_1, q_2, k_X, k_Y, and c, where these are defined as follows: $\frac{\lambda_1}{\lambda_3}=q_1$, $\frac{\lambda_2}{\lambda_3}=q_2$, $\frac{K_X}{H}=k_X$, $\frac{K_Y}{H}=k_Y$, $\frac{C}{H}=c$. As we will see that the steady state equilibrium will have a characteristics $\dot{q}_1=\dot{q}_2=\dot{k}_X=\dot{k}_Y=\dot{c}=0$, so that all types of capital and consumption will grow at the same rate while relative shadow prices will remain constant.

We also define share of human capital in the production of final good u so that $\frac{H_X}{H}=u$, and $\frac{H_Y}{H}=1-u$. Solving equation (6.3) we get $u=f(q_1,k_X,k_Y)$.

Now we can write the dynamic equations using these newly defined variables.

$$\frac{\dot{q}_1}{q_1}=(1-\delta)b(\frac{k_Y}{1-u})^{\delta}-a\alpha(\frac{k_X}{u})^{\alpha-1}-\tfrac{h}{2}(\frac{q_2-q_1}{q_1h})^2 \tag{9.1}$$

$$\frac{\dot{q}_2}{q_2}=(1-\delta)b(\frac{k_Y}{1-u})^{\delta}-\frac{b\delta}{q_2}(\frac{k_Y}{1-u})^{\delta-1} \tag{9.2}$$

$$\frac{\dot{k}_X}{k_X} = a(\frac{k_X}{u})^{\alpha-1} - \frac{c}{k_X} - \frac{q_2 - q_1}{q_1 h} - \tfrac{h}{2}(\frac{q_2 - q_1}{q_1 h})^2 - b(\frac{k_Y}{1-u})^{\delta-1} k_Y \tag{9.3}$$

$$\frac{\dot{k}_Y}{k_Y} = (\frac{q_2 - q_1}{q_1 h})\frac{k_X}{k_Y} - b(\frac{k_Y}{1-u})^{\delta-1} k_Y \tag{9.4}$$

and

$$\frac{\dot{c}}{c} = \frac{1}{\gamma - 1}(\beta - a\alpha(\frac{k_X}{u})^{\alpha-1} - \tfrac{h}{2}(\frac{q_2 - q_1}{q_1 h})^2) - b(\frac{k_Y}{1-u})^{\delta-1} k_Y \tag{9.5}$$

Steady State

Steady-state equilibrium is achieved when $\dot{q}_1 = \dot{q}_2 = \dot{k}_X = \dot{k}_Y = \dot{c} = 0$. So the system of equations we get is as follows:

$$(1-\delta)b(\frac{\tilde{k}_Y}{1-\tilde{u}})^{\delta} - a\alpha(\frac{\tilde{k}_X}{\tilde{u}})^{\alpha-1} - \tfrac{h}{2}(\frac{\tilde{q}_2 - \tilde{q}_1}{\tilde{q}_1 h})^2 = 0 \tag{10.1}$$

$$(1-\delta)b(\frac{\tilde{k}_Y}{1-\tilde{u}})^{\delta}\tilde{q}_2 - b\delta(\frac{\tilde{k}_Y}{1-\tilde{u}})^{\delta-1} = 0 \tag{10.2}$$

$$a(\frac{\tilde{k}_X}{\tilde{u}})^{\alpha-1}\tilde{k}_X - \tilde{c} - \frac{\tilde{q}_2 - \tilde{q}_1}{\tilde{q}_1 h}\tilde{k}_X - \tfrac{h}{2}(\frac{\tilde{q}_2 - \tilde{q}_1}{\tilde{q}_1 h})^2\tilde{k}_X - b(\frac{\tilde{k}_Y}{1-\tilde{u}})^{\delta-1}\tilde{k}_Y\tilde{k}_X = 0 \tag{10.3}$$

$$(\frac{\tilde{q}_2 - \tilde{q}_1}{\tilde{q}_1 h})\tilde{k}_X - b(\frac{\tilde{k}_Y}{1-\tilde{u}})^{\delta-1}\tilde{k}_Y^2 = 0 \tag{10.4}$$

and

$$\frac{1}{\gamma - 1}(\beta - a\alpha(\frac{\tilde{k}_X}{\tilde{u}})^{\alpha-1} - \tfrac{h}{2}(\frac{\tilde{q}_2 - \tilde{q}_1}{\tilde{q}_1 h})^2) - b(\frac{\tilde{k}_Y}{1-\tilde{u}})^{\delta-1}\tilde{k}_Y = 0 \tag{10.5}$$

Here $\tilde{u} = f(\tilde{q}_1, \tilde{k}_X, \tilde{k}_Y)$. So it is a system of 5 equations and 5 unknowns- $\tilde{q}_1, \tilde{q}_2, \tilde{k}_X, \tilde{k}_Y$, and $\tilde{c}$. From equations (10.1), (10.2), (10.4), and (10.5) we derive steady state values of $\tilde{q}_1, \tilde{q}_2, \tilde{k}_X, \tilde{k}_Y$, and then we plug these steady-state values in equation (10.3) to get $\tilde{c}$.

Equilibrium Dynamics

Linearizing equations (9.1)-(9.5) around the steady state (denoted by tildes), the dynamics of q_1, q_2, k_X, k_Y, and c can be approximated by

$$\begin{pmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{k}_X \\ \dot{k}_Y \\ \dot{c} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & -1 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 0 \end{pmatrix} \begin{pmatrix} q_1 - \tilde{q}_1 \\ q_2 - \tilde{q}_2 \\ k_X - \tilde{k}_X \\ k_Y - \tilde{k}_Y \\ c - \tilde{c} \end{pmatrix} \tag{11}$$

Where $a_{11} = q_1(1-\delta)b\frac{\partial \xi^\delta}{\partial q_1} - q_1 a\alpha \frac{\partial \omega^{\alpha-1}}{\partial q_1} + \frac{q_2}{q_1 h}(\frac{q_2}{q_1} - 1)$; $a_{21} = (\frac{q_1 - q_2}{q_1 h})$;

$a_{13} = q_1(1-\delta)b\frac{\partial \xi^\delta}{\partial k_X} - q_1 a\alpha \frac{\partial \omega^{\alpha-1}}{\partial k_X}$; $a_{14} = q_1(1-\delta)b\frac{\partial \xi^\delta}{\partial k_Y} - q_1 a\alpha \frac{\partial \omega^{\alpha-1}}{\partial k_Y}$;

$a_{21} = q_2(1-\delta)b\frac{\partial \xi^\delta}{\partial q_1} - b\delta \frac{\partial \xi^{\delta-1}}{\partial q_1}$; $\quad a_{22} = (1-\delta)b\xi^\delta$; $\quad a_{23} = q_2(1-\delta)b\frac{\partial \xi^\delta}{\partial k_X} - b\delta\frac{\partial \xi^{\delta-1}}{\partial k_X}$;

$a_{24} = q_2(1-\delta)b\frac{\partial \xi^\delta}{\partial k_Y} - b\delta \frac{\partial \xi^{\delta-1}}{\partial k_Y}$; $a_{31} = ak_X \frac{\partial \omega^{\alpha-1}}{\partial q_1} + \frac{q_2^2 k_X}{q_1^3 h} - bk_X k_Y \frac{\partial \xi^{\delta-1}}{\partial q_1}$; $\quad a_{32} = -\frac{q_2 k_X}{q_1^2 h}$;

$a_{33} = ak_X \frac{\partial \omega^{\alpha-1}}{\partial k_X} - bk_X k_Y \frac{\partial \xi^{\delta-1}}{\partial k_X} + \frac{c}{k_X}$; $a_{34} = ak_X \frac{\partial \omega^{\alpha-1}}{\partial k_Y} - bk_X \xi^{\delta-1} - bk_X k_Y \frac{\partial \xi^{\delta-1}}{\partial k_Y}$;

$a_{41} = -\frac{q_2 k_X}{q_1^2 h} - bk_Y^2 \frac{\partial \xi^{\delta-1}}{\partial q_1}$; $a_{42} = \frac{k_X}{q_1 h}$; $a_{43} = \frac{q_2 - q_1}{q_1 h} - bk_Y^2 \frac{\partial \xi^{\delta-1}}{\partial k_X}$; $a_{44} = -bk_Y^2 \frac{\partial \xi^{\delta-1}}{\partial k_Y} - 2b\xi^{\delta-1}k_Y$

; $a_{51} = \frac{c}{\gamma - 1}(-a\alpha \frac{\partial \omega^{\alpha-1}}{\partial q_1} - \frac{1}{2h}\frac{\partial}{\partial q_1}(\frac{q_2}{q_1} - 1)^2) - bck_Y \frac{\partial \xi^{\delta-1}}{\partial q_1}$; $a_{52} = -\frac{c}{\gamma - 1}(\frac{1}{q_1 h}(\frac{q_2}{q_1} - 1))$;

$a_{53} = \frac{c}{\gamma - 1}(-a\alpha \frac{\partial \omega^{\alpha-1}}{\partial k_X}) - bck_Y \frac{\partial \xi^{\delta-1}}{\partial k_X}$; and $a_{54} = \frac{c}{\gamma - 1}(-a\alpha \frac{\partial \omega^{\alpha-1}}{\partial k_Y}) - bck_Y \frac{\partial \xi^{\delta-1}}{\partial k_Y} - bc\xi^{\delta-1}$

Here $\xi = \frac{k_Y}{1-u}$ and $\omega = \frac{k_X}{u}$.

Equation (11) describes a fifth order linear dynamic system. Analytically it is virtually impossible to determine the signs of determinants and eigenvalues. So we will adopt numerical methods to analyze equilibrium dynamics. For all adjustment cost parameters we have found two negative eigenvalues and three positive eigenvalues (all real). Since we have three jump-variables q_1, q_2, and c and two sluggish variables k_X *and* k_Y. So the equilibrium yields a unique stable saddlepath.

We denote the stable eigenvalues by μ_1 and μ_2, with $\mu_2<\mu_1<0$, so that the linearized stable solutions takes the following forms:

$$q_1-\tilde{q}_1=A_1e^{\mu_1 t}+A_2e^{\mu_2 t} \tag{12a}$$

$$q_2-\tilde{q}_2=A_1v_{21}e^{\mu_1 t}+A_2v_{22}e^{\mu_2 t} \tag{12b}$$

$$k_X-\tilde{k}_X=A_1v_{31}e^{\mu_1 t}+A_2v_{32}e^{\mu_2 t} \tag{12c}$$

$$k_Y-\tilde{k}_Y=A_1v_{41}e^{\mu_1 t}+A_2v_{42}e^{\mu_2 t} \tag{12d}$$

$$c-\tilde{c}=A_1v_{51}e^{\mu_1 t}+A_2v_{52}e^{\mu_2 t} \tag{12e}$$

where the vector $(1, v_{2i}, v_{3i}, v_{4i}, v_{5i})'$ i =1,2 (and the prime denotes vector transpose) is the normalized eigenvector associated with stable eigenvalue μ_i, and the constant A_1 and A_2 are obtained by considering equation (12c) and (12d) at $t = 0$. These constants depend on the changes in the steady-state capitals and thus the specific shocks.

In order to calculate the rate of convergence of $x=\frac{X}{H}$, the rate at which the final output per unit of human capital adjusts to its new steady-state following some shock, we have taken the intensive form of the final output production function.

$$x=a\left(\frac{K_X}{H}\right)^{\alpha}\left(\frac{H_X}{H}\right)^{1-\alpha} \tag{13}$$

i.e., $x=ak_X{}^{\alpha}u^{1-\alpha}$, where $u=f(q_1,k_X,k_Y)$. So the rate of convergence is defined as

$$\chi(t)=-\frac{\dot{x}}{x-\tilde{x}}=-\frac{\left(\alpha\frac{\dot{k}_X}{k_X}+(1-\alpha)\left(\frac{\partial u}{\partial k_X}\dot{k}_X+\frac{\partial u}{\partial k_Y}\dot{k}_Y+\frac{\partial u}{\partial q_1}\dot{q}_1\right)\right)*x}{x-\tilde{x}} \tag{14}$$

We then differentiate equations (12a), (12c), and (12d) with respect to time and using these equations, we can derive the rate of convergence which is a function of time. We will study the properties of this rate of convergence using numerical methods.

2.3 Calibration

Since this is a very highly non-linear system, we will use calibration to shed light on the characteristics of transitional dynamics in this growth model. We have chosen the following base parameters to generate benchmark long run equilibrium; see table 2.1.

Table 2.1

Benchmark Parameters

Preference parameters		Production parameters			Productivity parameters	
γ	β	α	δ	"h"	a	"b"
-1.5	0.04	0.7	0.1	10	0.4	0.15

We have assumed $\gamma = -1.5$, so that the intertemporal elasticity of substitution is 0.4[6]. The rate of time preference is assumed to be 4%. The share of physical capital in final good sector is assumed to be 70% while the share of physical capital in the production of human capital[7] is 10%. These are taken to keep overall capital output ratio between 3 and 5. The sectoral adjustment cost parameter, *h*, is assumed to be 10, is within the standard range 10-15; Auerbach and Kotlikoff (1987), and Ortigueira and Santos (1997). We will allow *h* to take values between 0 to 40 to determine the sensitivity of the dynamic adjustment to *h*. Total productivity measures are so chosen to get a reasonable equilibrium. These parameters yield a plausible steady state equilibrium quantities and ratios reported as benchmark cases in table 2.2.

Benchmark capital output ratio in final good sector is 5.43 while it is 4.39 in human capital sector. About 80% of the final output is consumed and the remaining is

[6] The choice of $\gamma = -1.5$ consistent with recent empirical evidence by Ogaki and Reinhart (1998).

[7] In Lucas (1988) model, human capital was produced only using human capital.

invested in the final good sector. It may be mentioned here that we have assumed no depreciation, no government, and no adjustment cost in accumulation of new capital in final good sector. Steady-state shadow prices for physical capital in two sectors shown in column 7 in table 2.2, implies that in order to maintain a steady state growth rate, the human capital sector needs a tiny flow of physical capital from the final good sector. As we know that $y = \frac{\dot{H}}{H}$, i.e., y gives us the growth rates of human capital as well as the steady state growth rate. The benchmark steady state growth rate is 3.55%.

2.4 Long-run Responses

Our model is highly non-linear and so most of the analyses have been done numerically. We have analyzed three different shocks namely, (i) increase in rate of time preference, (ii) increase in aggregate productivity in the final good sector, and (iii) increase in aggregate productivity in the human capital sector.

An increase in the rate of time preference increases the long-run physical capital in the final good sector while the same declines in human capital sector. By discounting the future at a higher rate, the agent will increase consumption and it is reflected in the increase in the consumption output ratio from 0.80 to 0.83 when $h=10$. Also, as expected, the long-run growth rate declines from 3.55% to 3.2%. The larger negative eigenvalue turns out to be –0.087 meaning the asymptotic rate of convergence would be 8.7% when the sectoral adjustment cost parameter is 10. The asymptotic rate of convergence is 8.5% when $h=0$, which is within the reasonable estimates in a calibrated Lucas Model; see Eicher and Turnovsky(1999).

An increase in the (Hicks-neutral) productivity of final good sector increases physical capital per unit of human capital in final good sector significantly. This shock increases the long-run physical capital in human capital sector as well; see table 2.2 for $h=10$. The increase in productivity of final good increases the amount of final good available at each instant and thus the amount available for the accumulation of physical capital increases and thereby the shadow value of physical capital declines. Surely, this is welfare improving as the consumption increases significantly but the consumption output ratio remains same. As the new physical capital accumulation in the final good sector requires no adjustment costs, the return from consumption and the return from accumulation should be same and so the main impact rests on the shadow value of capital while keeping the consumption output ratio same. Nonetheless, the long-run growth rate increases from 3.55% to 3.85%.

An increase in (Hicks-neutral) productivity of human capital sector reduces the physical capital in both the sectors significantly. As all our stationary variables are normalized by the size of human capital and as expected, we have ended up with lower physical capital in both sectors but the capital output ratio declines significantly. The shadow value of physical capital normalized by the shadow value of human capital increases significantly as the abundance of human capital reduces its shadow value. Long-run steady-state growth rate increases from 3.55% to 4.8% as human capital plays a crucial role in these models and the productivity of human capital sector increases here.

2.5 Numerical Analysis of Transitional Paths

As transition is an integral part of the growth process, we would characterize the transitional paths of the sluggish variables, k_X, k_Y, q_1, q_2, and the dynamic paths of the share of human capital in the final good sector. We have shown transitional path of capital and share of human capital with five different sectoral adjustment costs parameters; shown in figure 2.1,2.2, and 2.3. The time paths are highly sensitive to the adjustment costs, h.

2.5.1 Shock 1: An Increase in the Rate of Time Preference; *β from 0.04 to 0.05.*

The transitional paths are illustrated in figure 2.1 for the following values of adjustment cost parameter: $h=0$, costless sectoral adjustment; $h=10$, the benchmark case;

h=20; h=30; and h=40. The starting points and terminal points of capital stocks depend on the size of the sectoral adjustment cost as can be deduced from equations (10.1)-(10.5). The speeds along the paths differ significantly.

Since the agent now discounts the future at a higher rate, he will put more emphasis on present consumption. So, the final output will be increased and proportionately lower amount will be available for capital accumulation and thus the growth rate will be lower. With zero sectoral adjustment cost, an increase in consumption demand results in a transfer of the physical capital from human capital sector to the final good sector to meet the excess demand for physical capital in final good sector. As the production function in final good sector is a Cobb-Douglas one, it requires more human capital as well. This human capital will be realized at the expense of human capital in human capital production. As a result, we observe a sharp rise in the share of human capital in final good sector; see figure 2.1, panel (iv). Initially the relative shadow prices jumps for both $q1$ and $q2$. So the relative return in physical capital increases in both sector and so the accumulation of physical capital in both sectors starts and so reduces the difference in returns. The relative shadow prices of capital $q1$ and $q2$ start to decline.

With sectoral adjustment costs, the transfer of physical capital from the human capital sector is constrained as the part of the shock is absorbed by the extra term in the left-hand side of arbitrage equation (6.4). So the jump in relative shadow prices of capital is much lower and so is the drop in k_Y. Since loss in physical capital is more with a sectoral adjustment costs, the relative shadow price $q2$ continues to rise and then with accumulation of physical capital in both sectors it starts coming down to its long run steady-state value. As $q2$ rises, the physical capital accumulation in human capital sector declines. As a result of the overshooting of the relative shadow price, we have observed an initial decumulation followed by an accumulation of k_Y.

2.5.2 Shock 2: Increase in the productivity in the final good sector; *"a" from 0.4 to 0.5.*

We have assumed a *Hicks-neutral* productivity increase in the final good sector. This increase in productivity increases wealth and thereby consumption as consumption is a normal good; see figure 2.2. To meet this excess demand of final good, production will be increased. An improvement in the aggregate productivity in final good sector raises marginal productivity of both physical capital and human capital in final good sector. As human capital is costlessly transferable across sectors, to maintain equality of marginal product of human capital in both sectors, H_Y declines that means H_X jumps up instantaneously; see figure 2.2, panel (iv). With a Cobb-Douglas production function, this implies an accumulation of physical capital in final good sector. The immediate source is the reconfiguration of the physical capital in the human capital sector. The relative shadow price declines immediately. Since the excess of final good over consumption is accumulated as physical capital, the relative shadow prices declines further. So favorable shadow price of human capital results in accumulation of it. As human capital production requires physical capital, k_Y starts rising.

With sectoral adjustment costs, in accordance with the arbitrage condition (6.4), the increase in H_X is lower than that with no sectoral adjustment costs. So the accumulation of physical capital will be lower and so would be the reduction of k_Y. Eventually, the relative shadow price will start falling and so physical capital will be accumulated in both sectors.

2.5.3 Shock 3: Increase in the productivity in the human capital sector; *"b" from 0.15 to 0.2.*

For an increase in the productivity in the human capital sector (*Hicks neutral*), the production of human capital increases. This yields a higher growth rate in the long run. The adjustment paths are shown in figure 2.3. An increase in the productivity in the human capital sector increases both marginal products of human capital and physical capital in that sector. In order to maintain the equality of returns to human capital in both sectors (equation (6.3)), a jump in H_Y is warranted. So given H fixed at each point in time, $\frac{H_X}{H}$ drops sharply; figure 2.3, panel (iv). So k_Y jumps to point A. At the same time this renders a sharp decline in q1 and q2.

As the productivity in human capital sector increases, more human capital with same amount of input will increase the availability of human capital and so the shadow value of human capital will decline. This will raise q1 and q2. In order to maintain equations (6.5) and (6.6), k_X and k_Y must decline. As the production functions are of Cobb-Douglas type, this requires a jump in share in human capital in human capital production, u. As expected, the share of human capital in final goods production function (1-u) declines to 6% when there is no sectoral adjustment cost. With sectoral adjustment costs, arbitrage conditions (equations (6.4), (6.5), and (6.6)) imply a smaller increase in H_X *is* sufficient for the adjustment.

2.6 Convergence Rates

In growth literature, there is no consensus about the rate of convergence. Mankiw, Romer, and Weil (1992) and Barro and Sala-i-Martin (1995) have shown that that there is strong empirical evidence in favor of some catching up for poor countries; for a recent survey see Durlauf and Quah (1999). But the estimates of the rate of convergence has a big spread ranging from a mild 2% (Barro and Salai-i-Martin) to a high of 9.7% (for OECD countries; Islam (1995)). Lucas (1988) has proposed a one-dimensional stable manifold with the same rate of convergence for all variables[8]. Ortiguera and Santos (1997), by introducing an adjustment cost in investment, have found that the rate of convergence is negatively related to the adjustment costs. But the rate of convergence remains constant and unique for all variables. Eicher and Turnovsky (1997) in a two-sector nonscale model have shown that with the stable manifold a two-dimensional locus, the speed of convergence is now no longer constant and not same for all state variables. They have obtained a fourth order dynamic system with two negative eigenvalues. In a more realistic setting of sectoral adjustment costs, we have obtained a fifth order dynamic system with two negative real eigenvalues. This yields a time varying rate of convergence and it is different for different variables in a Lucas endogenous growth model. The time path also depends on the size of the sectoral adjustment costs even though the asymptotic rates of convergence are not very different.

The rate of convergence of final output per unit of human capital defined in equation (14). Our model yields two (real) negative eigenvalue with the larger one equals –0.086. This means the asymptotic rate of convergence would be 8.6% when there is no sectoral adjustment costs. The introduction of the sectoral adjustment costs does not change the asymptotic rate of convergence much but it changes the dynamic path of the rate of convergence; see figure 2.4. It should be noted that the sectoral adjustment costs are needed only to convert physical capital in one sector into physical capital in other sector. As all variables are normalized by the amount of human capital, the constraints on capital transformation (sectoral adjustment costs) does not influence long run rate of convergence much.

An increase in the rate of time preference increases the present consumption of final good and so there will be an increase in production of final good immediately and so the amount of capital in final good sector will come from the human capital sector. As the physical capital accumulation involves sectoral adjustment costs, an increase in 1 unit of physical capital in final good sector will reduce the amount of physical capital in human capital sector by more than one unit. So there will be a large decline in the physical capital in human capital sector. But the production of final good requires human capital as well. To produce human capital the agent needs both physical capital and human capital. As soon as the production of final good becomes highly constrained for the lack

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[8] Calibration of Lucas model yields convergence rates from 7% to 10%.

of human capital, the physical capital in final goods sector is being converted for human capital sector.

For zero sectoral adjustment costs, the initial rate of convergence is very high and gradually it comes down to long run rate. But an introduction of sectoral adjustment costs brings down the initial rate of convergence and for a sufficiently high sectoral adjustment costs the initial rate of convergence can be lower than the long run rate. As the jumps and drops are extreme for models with no sectoral adjustment costs, the initial rate of convergence is higher. With a very high adjustment cost parameter, the jumps in the share of human capital are smaller.

2.7 Sectoral Adjustment Costs in Human Capital

We have also examined the alternative case where physical capital reallocation is costless while human capital reallocation requires sectoral adjustment costs. So the human capital accumulation equations are

$$\dot{H}_X = R \tag{15}$$

$$\dot{H}_Y = bK_Y^{\delta} H_X^{1-\delta} - R(1 + \tfrac{hR}{2H_Y}) \tag{16}$$

and the physical capital accumulation equation is

$$\dot{K} = aK_X^{\alpha} H_X^{1-\alpha} - C \tag{17}$$

where R is the amount of human capital to be converted.

The results from this modified model are similar to those in the model with sectoral adjustment costs in physical capital and the size of the sectoral adjustment costs lowers the initial level of rate of convergence as before.

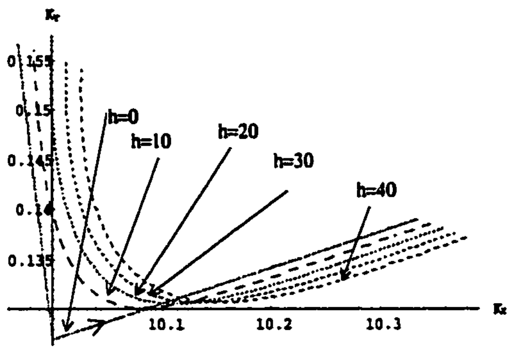
2.8 Conclusions

Bernard and Jones (1996) have challenged the conventional one dimensional, unique, and constant rates of convergence in endogenous growth models. Eicher and Turnovsky (1997), in a nonscale growth model, have put forward a model that yields a two dimensional stable manifold with a time varying rate of convergence. In this paper we have derived time varying rates of convergence in a two-sector Lucas model by introducing sectoral adjustment costs. By incorporating the sectoral adjustment costs we have obtained a two dimensional stable manifold with two negative (real) eigenvalues. These eigenvalues, which depend on the size of the adjustment cost parameter, determine the rate of convergence. With a large enough sectoral adjustment costs, the immediate rate of convergence may be lower than the long run rate of convergence. Cross-country variations of the rate of convergence as shown in Durlauf and Quah (1999) can be modeled using this framework as countries may differ in the size of the sectoral adjustment costs. In this sense, this model is more general that of Eicher and Turnovsky (1999).

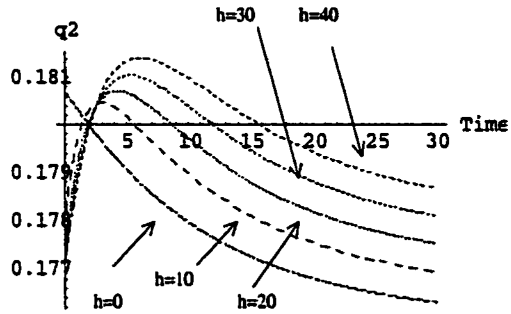
Table 2.2

Steady-state Responses to Permanent Changes in β, a, and b when $h = 10$

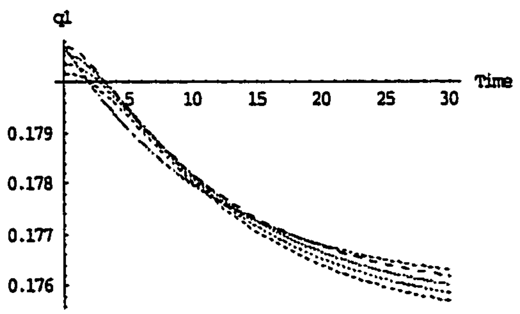
	k_X	k_Y	k_x/x	k_y/y	c/x	q_1 q_2	x	y	μ_1 μ_2
Bench mark β=0.04, γ=-1.5, a=0.4, b=0.15	9.98	0.16	5.43	4.39	0.80	0.176 0.177	1.84	0.035	-
β=0.05, γ=-1.5, a=0.4, b=0.15	10.35	0.14	5.43	4.39	0.83	0.176 0.177	1.91	0.032	-0.0867 -0.6735
β=0.04, γ=-1.5, a=0.5, b=0.15	17.30	0.28	5.14	7.25	0.80	0.101 0.101	3.37	0.038	-0.0918 -0.6491
β=0.04, γ=-1.5, a=0.4, b=0.20	4.73	0.08	4.38	1.72	0.79	0.360 0.363	1.08	0.048	-0.1079 -0.6802



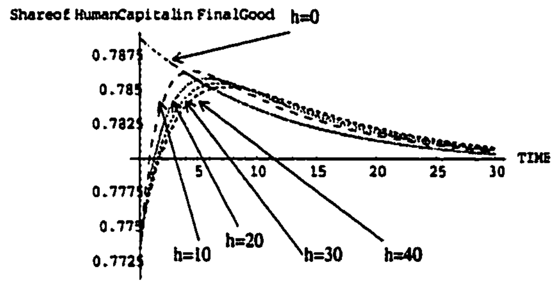
(i) Capital Adjustment Path



(iii) Relative Shadow Price (*q2*)

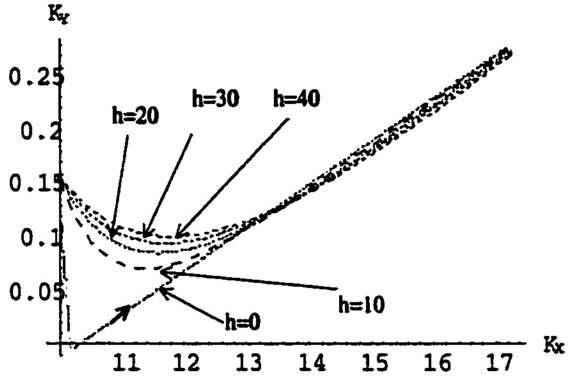


(ii) Relative Shadow Price (*q1*)

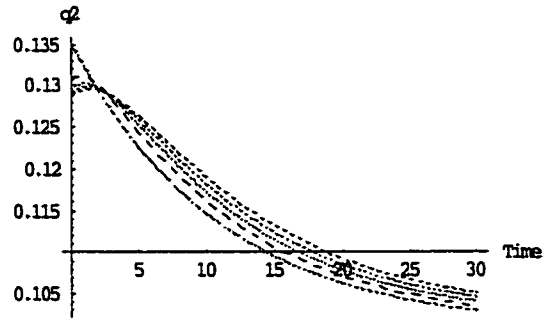


(iv) Time Path of Share of Human capital in Final Good Production

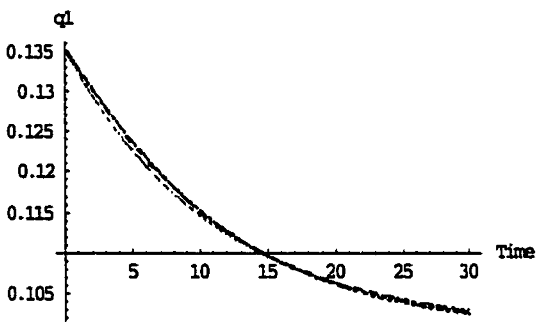
Figure 2.1: Sectoral Adjustment Costs and the Dynamic Adjustments When the Rate of Time Preference Increases from 0.04 to 0.05



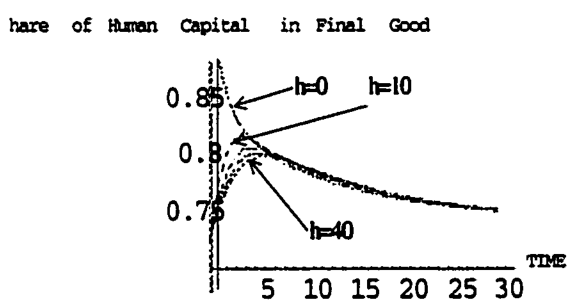
(i) Capital Adjustment Path



(iii) Relative Shadow Price of Capital (*q2*)

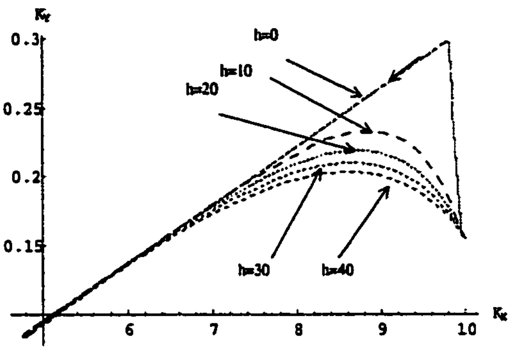


(ii) Relative Shadow Price of capital (*q1*)

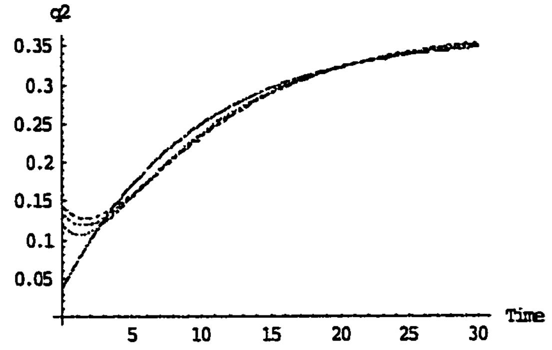


(iv) Time Path of Share of Human capital in Final Good Production

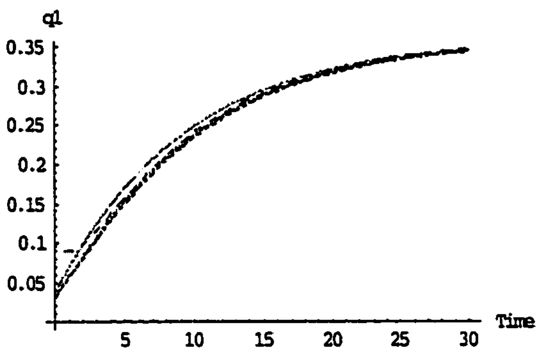
Figure 2.2: Sectoral Adjustment Costs and the Dynamic Adjustments When Productivity in the Final Good Sector Increases from 0.4 to 0.5



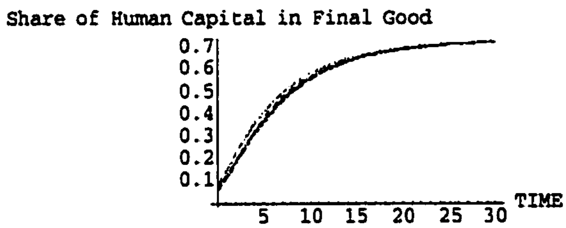
(i) Capital Adjustment Path



(iii) Relative Shadow Price of Capital (*q2*)

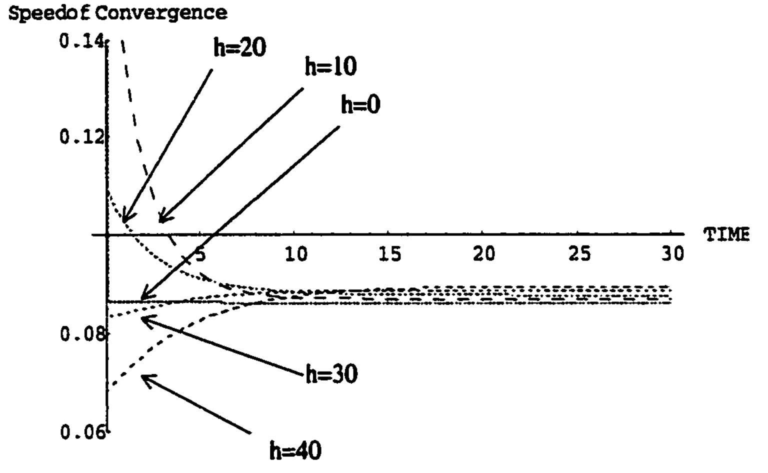


(ii) Relative Shadow Price of capital (*q1*)

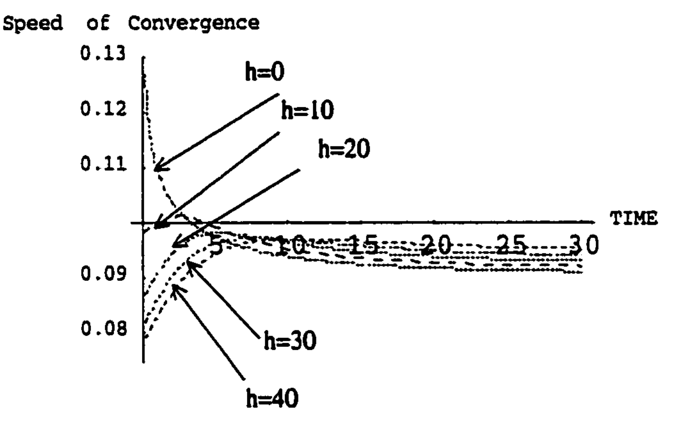


(iv) Time Path of Share of Human capital in Final Good Production

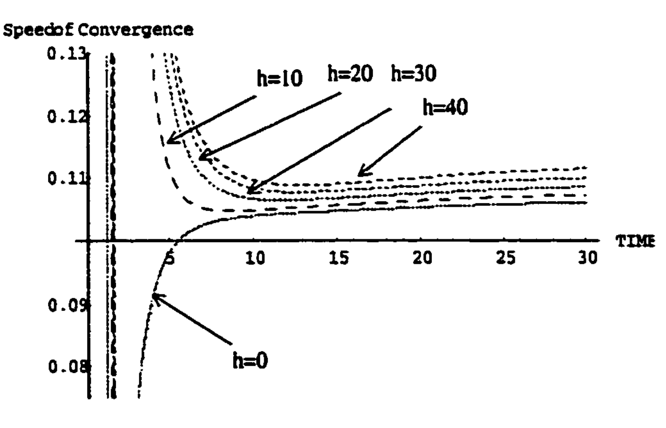
Figure 2.3: Sectoral Adjustment Costs and the Dynamic Adjustments When Productivity in the Human Capital Sector Increases from 0.15 to 0.20



(i) Increase in rate of Time Preferences



(ii) Increase in aggregate productivity in final good sector



(iii) Increase in aggregate productivity in the human capital sector

Figure 2.4: Rate of Convergence of Output Per Unit of Human Capital

CHAPTER 3

How Big Is the Border Effect in Developing Countries? A Case Study of Bangladesh and India

3.1 Introduction

Theoretically, one version of the Law of One Price (LOP) implies that the differences in prices of same commodity at different locations should be equal to the transportation costs. Very few attempts have been made to test this claim. Isard (1977) was first to test this claim using US–German export transaction data and found that LOP does not hold. Jain (1980), Krugman (1987), Knetter (1993), and Engel and Rogers (1996) also prove that LOP fails miserably in the short-run.

In a recent study, Engel and Rogers (1996) (hereafter ER(1996)) have used disaggregated time series price data of cities in the USA and Canada to test whether LOP holds in the short-run. They have examined the importance of distance between cities and the presence of a national border by looking at the difference in the volatility[1] of prices at locations within the country and the volatility of prices at locations across the border. They observe that the volatility of prices is much higher at locations across the border even if it is controlled for distance. The differences in volatility of prices are so large that they have opined that distance between locations, trade restrictions etc. cannot fully explain the degrees of failure of LOP.

A good number of economists propose that we should not expect equality of prices at different locations because producers set different prices for different locations. This is known as the pricing to market (PTM) literature. Dornbusch (1987), Krugman (1987), Dixit (1989), Feenstra (1989), Froot and Klemperer (1989), and Knetter (1989,1993) are examples of this research program. There are at least two arguments in favor of PTM. One, profit-maximizing monopolists may accept different mark-ups at different locations, and those mark-ups may vary due to fluctuations in the nominal exchange rates. Two, in the retail price of consumer goods, prices of nontraded services are embodied and also nontraded services may be highly integrated on a national basis. Segmentation of markets due to presence of border is assumed to be an important factor for the PTM.

ER (1996) postulate two other possible reasons for border to be an important determinant of price dispersion in cities across countries. Productivity shocks may be felt in the same way at different locations within the country but not at locations across the borders. The other reason is that the price of a consumer good may be sticky in terms of the currency of the country where the good is sold. Engel (1999), Devereaux and Engel (1998), and others have advanced this idea in a general equilibrium setup.

In most of the empirical studies, data from developed countries have been used to test LOP. There are at least three reasons for this. First, we can get a long time series data only for developed countries. Second, data from developed countries are more reliable. Third, the goods market no arbitrage condition seems more plausible for developed countries as information dissemination is not very costly. Due to a lack of reliable, and a long time series data, a few attempts have been made to test LOP in developing countries. Bahmani-Oskooee (1993), Ron and Boyd (1995) and others have conducted studies with panel data on a number of developing countries. While Lyon (1991) has tested PPP for Peru, Baghestani (1997) has tested PPP for India in presence of black market for foreign exchange, and Hossain (1997) has calculated real exchange rates for Bangladesh. These all are done with aggregated data.

As a matter of fact no attempt is made to test LOP using disaggregated data for developing countries. As aggregated data are hard to come-by, the disaggregated price data for different locations in developing countries are virtually non-existent. But it is interesting to examine whether what is found for *developed* countries holds for *developing* countries or not. This paper is an attempt to close this gap. Here we have

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[1] Standard deviation is the measure of volatility

gathered disaggregated time series price data at a number of locations in Bangladesh and India. Since these are developing countries, we will be able to test LOP in developing countries.

If LOP holds, the volatility of the price of a good at different locations in the same country should be close to the volatility of the prices at locations in different countries. The volatility estimates of the price at different locations within the countries, and across those two countries have been compared. It is shown that the volatility of the price of a good at locations in different countries (one location in Bangladesh and another in India) is significantly higher than the volatility of the price of the same good at different locations in the same country. This means that crossing the border adds significant amount of volatility in the consumer price in *developing* countries as it is found in *developed* countries. In addition to this, the magnitude of the difference in volatility has shown a time dimension. The differences in volatility of prices *across* vs *within* country were greater in the 70s compared to those in the 80s.

This paper contributes in the border effect literature in three ways. First, while all the studies in this literature have used disaggregated price data from *developed* countries, this paper deals exclusively with disaggregated price data from *developing* countries. It is found that the border effect on price variability is very large even in developing countries. Second, this paper also shows that the border effect is comparatively smaller in the second period of the sample. So time variations of border effect need to be addressed in border effect literature. Third, effects of some of the variables deemed as the factors responsible for border effect are appraised. It has been found that the existing explanations seem inadequate to explain the very large border effect.

This paper is structured as follows: section 3.2 contains a brief discussion on LOP and the border effect, section 3.3 contains the methodology and description of data, and in section

3.4, the results are reported. We have examined the possible explanations for large border effect in section 3.5 and at the end some concluding remarks have been made.

3.2 The Law of One Price and the Border Effect

The Law of One Price in the international context implies that the following must hold for any good i:

$$p_t(i) = p_t^*(i) + s_t$$

where $p_t(i)$ is the log of the time-t domestic currency price of good i, $p_t^*(i)$ is the log of the time-t foreign currency price of the good i, and s_t is the log of time-t domestic currency price of foreign exchange. This law embodies the idea that in the absence of transactions costs, free trade in goods will ensure identical price for identical goods across countries. If there is a difference in price between two locations, people will be able to make profit by buying goods from a location where price is low and sell it at a location where price is high. As a result the demand will increase at the location where price is low, and supply will increase at the locations where price is high. Eventually the prices will be equalized. In literature it is known as goods market no arbitrage condition.

There are many reasons for which we expect prices will be different at different locations within a country and also a lot of additional factors come into effect when the locations are in different countries. A good in a certain location and the same good in another location are not the same economic objects. Location of a good is one of the essential traits in the definition of a good[2]. The transportation cost (distance) may account a part of the variation in prices at different locations within a country. In the international trade, along with the distance, tariffs, quantitative restrictions, exchange rate uncertainty, and other barriers to trade are supposed to account the variations of prices at different locations across countries.

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[2] See Debreu (1959).

In order to identify the border effect, we have calculated of price variations at different locations. To reduce a significant amount of noise embodied in the prices, we have used the relative price as our point of departure. The standard deviation of the log of relative price is our metric of price variability. This metric has a few advantages. Since we use a relative price measure, the location specific variations are taken into account for locations within a country while, in addition to this, the effects of general trade barriers are taken into account for locations across countries. The following example will clarify this.

Let $P_{F,Dhaka}$ be the price of food in Dhaka, Bangladesh and $P_{F,Rajshahi}$ be price of food in Rajshahi, Bangladesh at a particular date. Let us also assume that these two places have some special differences. So we expect that the following equation may hold.

$$P_{F,Dhaka} = P_{F,Rajshahi}(1+\tau)$$

where τ measures the difference in attributes in two locations and the transportation costs.

As we expect a very little change in the attributes in two different places over a short period of time, we may expect τ to be very stable. So once we take the relative price i.e. $\frac{P_{F,Dhaka}}{P_{F,Rajshahi}}$, we expect a stable ratio.

Similarly, if we define $P_{F,Delhi}$ to be price of food in Delhi, India, then we expect the following equation may hold.

$$P_{F,Dhaka} = P_{F,Delhi}(1+\psi)$$

where ψ incorporates location specific effect, the effect of distance, and the international trade related effects on prices. Again, if there is little variation in the international trade policy, exchange rate etc. in these two countries over a short period of time we expect ψ to be a stable parameter. In these circumstances, the relative price estimate i.e. $\frac{P_{F,Dhaka}}{P_{F,Delhi}}$ should be a stable one.

Now if we compare the variations of τ with the variations of ψ, we expect that the variations of ψ would not be higher if the international trade and exchange rate policies of these countries are stable. Even for policy-stable countries like USA and Canada ER (1996) have found that the variations of ψ is greater than the variations of τ. They have defined these excess variations in ψ as the border effect. They have estimated this for Canada and USA and have found a very large variability of prices for cities across the border. In later papers Engel and Rogers (2000, 2001) have tried to identify factors responsible for large border effects.

We expect that the volatility of relative prices at different locations should be the same when distance between locations is taken into account. The presence of a border will add more volatility to consumer prices. How much variability in prices is added to when there is border (i.e. how much does the border matter) is examined in this paper. Standard regression analysis has been conducted to assess the contributions of distance and other variables in generating volatility in consumer prices. Furthermore, the border effect has been also computed to examine the time dimensionality of it.

Recently, we have observed a significant rise in number of studies dealing with disaggregated price data; Parsley and Wei (2000), Haskel and Wolf (2001). Virtually in every case, economists have used data from developed countries. City specific data are very hard to come by for developing countries. In this paper, disaggregated price data for 23 cities[3] of Bangladesh and India over 21 years have been used to test LOP. In addition to assessing the effect of border for the whole period, we have estimated border effect for two sub-periods. We have observed that the size of the border effect declines in the later part of the sample.

3.3. Methodology and Data

Standard deviation of the relative price is our measure of the price variability. The relative prices in this paper have been calculated in the following way. Let $p^i_{j,k}$ be the log of the price of good i in location j relative to the price of good i in location k. All prices are converted into Bangladeshi *Taka* (Bangladeshi Currency) by using period average *Taka-Rupee* (*Rupee* is Indian Currency) exchange rates. For each category of goods, there are observations for 253 city pairs. For each city pair, one volatility measure is calculated by computing standard deviation of $p^i_{j,k}$. The great circle distance between the cities in kilometers is the distance variable[4]. First, we compare average price variability in the cities within each country and cities across borders and then we have used linear regression technique to assess the importance of border and distance.

A simple regression equation has been estimated to explain the volatility of $p^i_{j,k}$.

$$V(P^i_{j,k}) = \beta^i_1 r_{j,k} + \beta^i_2 B_{j,k} + \sum_{m=1}^{n} \gamma^i_m D_m + u_{j,k} \qquad (1)$$

where $V(p^i_{j,k})$ is the volatility of $p^i_{j,k}$, $r^i_{j,k}$ is the log of the distance between locations, and B is the country dummy variable. D's are the dummy variables for each city.

The creation of dummy variables deserves explanation. The country dummy variable $B_{j,k}$ denotes whether location j and k are in different countries or not. For example, for relative price between Dhaka and Chittagong (two cities in Bangladesh), the value of this dummy is 0. If the cities are located in different countries the dummy variable assumes the value of 1. Also, city dummies (D_m) for each city have been used in our regression analysis. For the city pair (j,k) the dummy variable for city j and city k assumes a value of 1. There are at a number of reasons in favor of inclusion of the city dummies: there may be idiosyncratic error in some cities that make their prices more

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[3] **4 Bangladeshi cities and 19 Indian cities are included in this study. These are selected depending upon the availability of long time series data.**
[4] **For methodology in detail, see Engel and Rogers (1996).**

volatile on average, measurement error may exist, and that volatility in one city may be high for some reasons not modeled here (ER (1996)).

We have estimated the equations with alternative specifications where volatility is the quadratic function of distance, not logarithmic. This means a squared distance term has been added into our regression equations. This allows us to test our assumption about concave distance relationship. We find that for food and CPI, distance function turns out to be a quadratic function when full sample is taken into account. We have also estimated the regression equation where all the variables are deflated by the log of distance. This is done to capture the idea that the standard deviation of the regression errors may have been proportional to the log of distance between cities. This means the following equation has been estimated as well.

$$V(P^i_{j,k})/r_{j,k} = \beta^i_1 + \beta^i_2(B_{j,k}/r_{j,k}) + \sum_{m=1}^{n} \gamma^i_m (D_m/r_{j,k}) + u_{j,k} \tag{2}$$

variables of this equation are same as they are in equation 1.

In another set of regressions we have used the correlation of log of prices of same goods at different locations as the dependent variable in equation 1. This is another measure of price variability. Following Engel and Rogers (2000), let us assume that the nominal prices share a common nominal shock and independent idiosyncratic shocks.

$$\Delta \ln p_{i,t} = u_{i,t} + v_t$$
$$\Delta \ln p_{j,t} = u_{j,t} + v_t$$

So correlation can be written as $(1+\frac{Var(u_i)}{Var(v)})^{-\frac{1}{2}} * (1+\frac{Var(u_j)}{Var(v)})^{-\frac{1}{2}}$. It scales the variance of the idiosyncratic shocks by the variance of the common nominal shocks. And so, the correlation declines when the idiosyncratic shocks are larger relative to common shocks. So the estimating equation is

$$Corr(p_i, p_j) = \beta^i_1 + \beta^i_2 r_{j,k} + \beta^i_3 B_{j,k} + \sum_{m=1}^{n} \gamma^i_m D_m + v_{j,k} \tag{3}$$

where the right-side variables are same as they are for equation 1. We expect the signs of coefficients of distance and country dummy to be negative.

Another way to identify the failure of LOP is to compare variability of the price of some good "i" relative to another good j, within the same location and the variability of the prices of some good "i" relative to the same good in different locations. If we find that the variability of the price of the good "i" in one location relative to the price of the same good in a different location is higher than the variability in relative prices of different goods in same locations, we may safely conclude that there are significant deviations in LOP. We have found that the variability in relative prices of different commodities at the same location is much smaller than the variability in relative prices of same good at different locations. This strengthens our contention that LOP does not hold in the short run.

In order to separate the border effect from the effect of exchange rate volatility, Engel and Rogers (2000) have suggested a measure of cross border relative price that does not involve the exchange rate. Accordingly, we have expressed all goods prices in a particular location relative to the overall price index of that location. For example, we take food price in Calcutta relative to the overall CPI of Calcutta. We then compare this relative price to a similar price in a different location, such as the food price in Dhaka relative to CPI of Dhaka. These are nominal exchange rate free measures. If the sticky-price cum volatile nominal exchange rate explanation accounted for all of the border effect, the border coefficient should not be significant in a regressions (using equation 1) with relative price constructed in this way. We observe border dummy is still highly significant in all those regressions.

Another possible explanation put forward is that the border effect originates from the structure of labor market. Labor market may be more homogenous within countries. As we know that the variability of relative price between two countries depends on the variability of the relative price of non-traded services, which can be approximated with relative wages between locations. So, we include the standard deviation of the relative wage in our regression equation 1. We expect that by inclusion of this right hand side variable, the explanatory power of the country dummy should decline. Since we are able to gather location specific wage data for only 4 Bangladeshi cities and 8 Indian cities[5], the results reported in table 9 are for these 12 cities over the period 1976-1995.

Time series annual disaggregated consumer price data for 4 cities in Bangladesh and 19 cities in India over 1974-1995 have been collected. Data of consumer price index[6] disaggregated into two categories for all the cities have been used. These categories are *Food* and *Clothing, Bedding and Footwear* (hereafter clothing). Data sources are reported in the appendix 1.

All the calculations are done for full sample period and for two sub-periods (1974-84 and 1985-95). In 1985, the South Asian Association for Regional Cooperation (SAARC) was established with a mandate of more regional cooperation including a promise to create SAPTA (South Asian Preferential Trading Agreement). So we have two sub samples and the dividing date is 1985. The results of these two sub periods will help us in assessing the changes in the consumer price variability under the new institutional setup.

[5] The cities are: Dhaka, Chittagong, Rajshahi, Khulna, Ahmedabad, Bangalore, Bombay, Nagpur, Sholapur, Madras, Kanpur, and Delhi.

[6] Consumer Price Index of middle income families in four Bangladeshi cities: Dhaka, Chittagong, Rajshahi and Khulna (base year 1974=100 although data reported like 1973-74 =100; we took the later year as the effective year for our calculation i.e. CPI for 1974 is equal to 100) and consumer price index for industrial workers of twenty-one Indian cities: Hyderabad, Jamshedpur, Ahmedabad, Srinagar,

3.4. Results

A. Preliminary Results

In this paper, the importance of a border between two neighboring countries in south Asia - Bangladesh and India has been examined. Prior to 1947 these countries were parts of the British Empire. The area comprising Bangladesh and West Bengal (a province of India) was known as Bengal from time immemorial. The economic activities of the people in this region are similar. The economies of two countries have been agriculture-based. Bangladesh has borders in three directions with India. Of about 4246 km of border (this excludes the Bay of Bengal), Bangladesh shares 4053 km with India. Although there are some trade restrictions between these two countries, India still is the top trading partner of Bangladesh. In 1994/95, the import of Bangladesh from India was about 12 percent of its total imports, while its export was about 1.3 percent of its total exports (Hossain et. al. 1997). Moreover, there is a big unofficial market between these two countries.

In calculating relative price, yearly data of the prices of goods have been used. This yearly aggregation essentially takes away certain amount of seasonal variations in prices. I have used *food*, and *clothing* prices and these are aggregated prices to a considerable extent. So variations in individual food item or individual clothing item are already neutralized during the aggregation.

Selected summary statistics are reported in tables 3.1. The average standard deviations for pairs of cities that (i) are both in Bangladesh, (ii) both in India, and (iii) one in each country for all the categories including CPI are reported. Average price variability for the full sample is reported in table 3.1.A, while the same for period 1975-84 is reported in table 3.1.B, and in table 3.1.C, the average price variability in later period (1985-95) is reported.

Bangalore, Bhopal, Bombay, Nagpur, Sholapur, Amritsar, Jaipur, Madras,Kanpur, Asansol, Calcutta, Howrah, Jalpaiguri, Raniganj and Delhi (base year 1960=100) have been used.

Table 3.1 reveals that the volatility of prices in locations in each country is smaller than that for the cross-country locations. The cross-country average price volatility is almost three times higher than the volatility in locations in each country. So it has been found that the border has exerted substantial amount of forces against LOP. The border issue becomes solidified when we look at the price volatility of individual goods. For food, the cross-country price volatility is three/four times than those of the cities located in each country. Cross-country clothing price volatility is almost 3 times that in the locations in India. Cross-country clothing price volatility is almost 4 times that in the locations in Bangladesh.

The average price variability declined significantly in all categories in the second half of the sample in locations in Bangladesh (compare table 3.1.B and table 3.1.C) while food price variability in Indian cities declined in the second half while the clothing price variability increased significantly. The CPI variability increases in India in the second half of the sample period. Across country food and clothing price variability declined significantly in the second sub-period while aggregate CPI variability increased a little in the second half of the sample.

We have also compared the variability of the price of the good i relative to another good j in the same location with the variability of the relative price of same good in different locations. This is reported in table 3.9. It is observed that the variability of the relative price of same good at different locations is higher than the variability of the relative price of different goods in the same location. For example, in Dhaka, the average variability of food price over cloth price is only 0.034 while the variability of relative food prices across locations is 0.163 and variability of relative cloth prices across locations is 0.225. These results further show that LOP fails miserably in the short run.

B. Regression Results

The regression results of equation (1) for food, clothing, and CPI have been reported in table 3.3. Log of distance and country dummy are used as regressors. In table 3.3.A, regression results for full sample are reported while in table 3.3.B and 3.3.C regression results of two sub-periods are reported. This table reveals that for food, the log of distance variable is significant at 1% error probability level while for clothing it is not significant. The pattern remains same for sub-samples.

But the border dummy variable is found to be highly significant (at 1% level) for both the categories. Border variable is highly significant always for the CPI. But the log of distance variable is highly significant under full sample and also for the first half. For the second sub-sample the log of distance yields a negative sign but it is not statistically significant. For all these regressions adjusted R-Squares are very high. So the results reported in this table indicate that border is very significant in explaining the relative price variability.

Different specifications are used to test the robustness of the finding that the border matters in the variability of prices. The findings of a quadratic distance function in the model i.e. distance and distance squared are added as regressors along with country and city dummies are reported in table 3.4. In table 3.4.A, results for the full sample are reported and in 3.4.B and 3.4.C, results from two sub-samples are reported. Country dummy turned out to be highly significant and positive in all cases. Under full sample, distance coefficient turns out to be positive and the distance-squared coefficients are with negative sign for all categories as expected. The coefficients for clothing are not significant. So increase in distance increases the variability at a decreasing rate for food and CPI.

It is possible that the variance of the error term might be greater, the more distant the cities are. The regression results when the left- and right-hand side variables are all deflated by the log of distance (equation 2) is reported in table 3.5. The implicit assumption is that the standard deviation of the regression error is proportional to the log of distance between cities. The deflated country dummy (border dummy) is positive and highly significant, as expected, for all the categories and for all sample periods.

Another convex specification of the distance variable has been attempted, in which the testing hypothesis is that after a certain critical distance (arbitrarily chosen by trial and error method to be 1600 km), additional distance does not contribute at all to volatility. A new dummy variable, 0 if the city pairs are less than 1600 km and 1 if the city pairs are greater than the threshold distance, has been created. It is found that if the distance is increased beyond 1600 km the said dummy variable becomes insignificant for all the categories at the 5 percent error probability level. Judging from the adjusted R-squared criteria; it is found that the dummy for 1600 km fits best[7].

Instead of considering the standard deviation of the relative price as the dependent variable, we have used the correlation of log of relative prices as the dependent variable. We expect that if LOP does not hold, the country dummy will have a negative coefficient in this formulation. Regression results of the equation 3 are reported in table 3.6. We have found a highly significant negative country dummy in all cases. We have also found a significant positive coefficient for the log of distance variable when dependent variable is correlation of food prices in different locations or correlation of CPI in different locations.

In order to get some idea about the economic significance of the border relative to distance in determining price dispersion a statistic has been calculated following ER (1996). The coefficients in table 3.3.A for food are used to highlight this. The reported coefficient on the country dummy is 0.1176 and on log of distance is 0.0054. This implies that crossing a border adds 0.1122 to the average standard deviation of the prices between city pairs. In order to generate the same volatility by distance, the cities should be apart

[7] Regression results are not reported here.

by $287.05*10^{07}$ km[8], which implies that crossing a border adds substantially to price volatility.

3.5. What Explains the Border Effect?

A. Preliminary Results

In this section we have appraised the contributions of suggested possible explanatory variables in border effect. Engel (1993) argues that the failure of LOP may be the main reason behind the failure of Purchasing Power Parity (PPP). He cites four possible textbook explanations for the failure of PPP:

(a) Barriers to trade such as tariffs and transportation costs.
(b) Different consumption preferences across countries.
(c) Presence of non-traded goods in Consumer Price Indexes (CPIs).
(d) Prices are sticky in terms of the currency in which the good is consumed.

We will examine the explanations (a), (c) and (d) in this section. According to the arguments in section 3.4.A., we do not expect a very large difference in consumption preferences in these countries.

Whether exchange rate volatility accounts for the large border effect or not deserves attention. In order to test this empirically, we have calculated exchange rate fluctuation free relative prices by expressing all good prices in a location relative to the overall prices of that location. Then we have computed same measure of variability for relative-relative prices. Summary statistics are reported from this exercise in table 3.2. Average price variability for the full sample is reported in table 3.2.A, while the same for period 1975-84 is reported in table 3.2.B, and in table 3.2.C, the average price variability in later period (1985-95) is reported.

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[8] Calculated as exp (0.1176 /0.0054) kilometers

It is found that the price variability under this new definition (exchange rate fluctuation free prices) is much higher for the city pairs across the border compared to that in city pairs within a country. For Bangladeshi cities, the price variability declines in the later part of the sample while for Indian cities average price variability increases in the later part. For cross border city pairs, the price variability increases for food/cpi while it declines for clothing/cpi.

B. Regression Results

The regression results when variability of relative-relative price (e.g. food prices/CPI in each location) is the dependent variable are reported in table 3.7. In all cases and in all samples both log of distance and country dummy turn out to be highly significant. So border adds significant amount of variation into the variability of exchange rate fluctuation free prices. This result also implies that the exchange rate uncertainty is not the factor responsible for border effect.

Engel and Rogers (2000) argue that the variability of the relative price between two locations depends on the variability of relative prices of non-traded services. The wage volatility is used here to proxy this variability of relative prices of non-traded services. The regression results are reported in table 3.8. As location specific time series wage data are not available for all the cities, we have only 12 cities for this regression with only 66 city pairs. Moreover, we have data for 1976-1995. We ran our regression with and without wage variability as independent variable. We expect positive coefficient for wage variability.

But, contrary to our expectation we find negative coefficients for wage variability in all cases although for food it is not significant. For clothing and CPI the coefficients are significant at 5% level. Moreover, inclusion of wage in right hand side of the regression equation does not change the border coefficient much. So the variability of relative prices of non-traded services does not explain the large border effect.

3.6 Conclusions

The results show that both distance and a border are very important in explaining price volatility in Bangladesh and India. We have also appraised the contributions of some of the variable in generating the variability of consumer prices. Exchange rate uncertainty and the presence of non-traded goods in consumer price indices are unable to explain the large border effect in developing countries[9]. The *yearly* data are used and some of the variations in prices are evened out. Moreover, some exchange rate variations are not reflected in the yearly average exchange rate data. Yet we find a very big border effect on the prices in Bangladesh and India we have also found that the variability of prices declined a little in the second half of the sample period. As Helliwell (1998) argue that due to improvement in the efficiency of transportation of goods or communications or marketing the effect of distance declines over time. Yet the large border effect remains a mystery to be solved.

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[9] Engel and Rogers (2000) have found similar results for developed countries.

Table 3.1.A

Average Price Variability (Prices of same good at different locations) (1975-1995)

Category	Bangladesh-Bangladesh	Bangladesh-India	India-India
Food	0.0428	0.1748	0.0638
Clothing	0.0696	0.2477	0.0771
CPI	0.0541	0.1954	0.0535
No of Pairs	6	76	171
Average Distance (km)	226	1156	1075

Table 3.1.B

Average Price Variability (Prices of same good at different locations) (1975-1984)

Category	Bangladesh-Bangladesh	Bangladesh-India	India-India
Food	0.0500	0.1896	0.0559
Clothing	0.0754	0.2367	0.0533
CPI	0.0576	0.1819	0.0421
No of Pairs	6	76	171
Average Distance (km)	226	1156	1075

Table 3.1.C

Average Price Variability (Prices of same good at different locations) (1985-1995)

Category	Bangladesh-Bangladesh	Bangladesh-India	India-India
Food	0.0176	0.1253	0.0421
Clothing	0.0355	0.2083	0.0770
CPI	0.0231	0.1824	0.0412
No of Pairs	6	76	171
Average Distance (km)	226	1156	1075

Table 3.2.A
Average Price Variability (Prices relative to CPI at each location) (1975-1995)

Category	Bangladesh-Bangladesh	Bangladesh-India	India-India
Food Price/CPI	0.0271	0.0560	0.0352
Clothing Price/CPI	0.0790	0.0980	0.0732
No of Pairs	6	76	171
Average Distance (km)	226	1156	1075

Table 3.2.B
Average Price Variability (Prices relative to CPI at each location) (1975-1984)

Category	Bangladesh-Bangladesh	Bangladesh-India	India-India
Food Price/CPI	0.0253	0.0380	0.0259
Clothing Price/CPI	0.0815	0.0946	0.0580
No of Pairs	6	76	171
Average Distance (km)	226	1156	1075

Table 3.2.C
Average Price Variability (Prices relative to CPI at each location) (1985-1995)

Category	Bangladesh-Bangladesh	Bangladesh-India	India-India
Food Price/CPI	0.0169	0.0650	0.0319
Clothing Price/CPI	0.0263	0.0632	0.0712
No of Pairs	6	76	171
Average Distance (km)	226	1156	1075

Table 3.3.A

Regressions Relating Price Volatility to Distance and Border (Price of the same good at different locations) (1975-1995)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Errors[10]	Coefficient	Standard Errors	Coefficient	Standard Errors
Log (Distance)	0.0054	0.0017	0.0021	0.0020	0.0029	0.0017
Country Dummy	0.1176	0.0043	0.1729	0.0051	0.1395	0.0043
Adjusted R-Squared	0.9059		0.9411		0.9339	

Note: Here 23 city dummy variables are included in regression.

Table 3.3.B

Regressions Relating Price Volatility to Distance and Border (Price of the same good at different locations) (1975-1984)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors
Log (Distance)	0.0068	0.0017	0.0018	0.0014	0.0069	0.0014
Country Dummy	0.1317	0.0044	0.1711	0.0036	0.1270	0.0036
Adjusted R-Squared	0.9345		0.9735		0.9538	

Note: Here 23 city dummy variables are included in regression

Table 3.3.C

Regressions Relating Price Volatility to Distance and Border (Prices of the same good at different locations) (1985-1995)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors
Log (Distance)	-0.0002	0.0012	0.0033	0.0030	-0.0018	0.0017
Country Dummy	0.0956	0.0030	0.1498	0.0077	0.1516	0.0068
Adjusted R-Squared	0.9137		0.8244		0.9313	

Note: Here 23 city dummy variables are included in regression

[10] After calculating bootstrapped distribution for the t -statistics for the coefficient of log (distance) Engel and Rogers (1996) found that the inference from the bootstrapped distribution is approximately the same as from the t-distribution.

Table 3.4.A

Regressions Relating Price Volatility to Distance and Border (Prices of the same good at different locations) (1975-1995)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors
Distance	$2.67*10^{-05}$	$9.40*10^{-06}$	$7.49*10^{-06}$	$1.12*10^{-05}$	$1.92*10^{-05}$	$1.11*10^{-06}$
Distance Squared	$-1.12*10^{-08}$	$4.55*10^{-09}$	$-3.09*10^{-09}$	$5.42*10^{-09}$	$-8.98*10^{-09}$	$4.58*10^{-09}$
Country Dummy	0.1190	0.0043	0.1736	0.0051	0.1407	0.0043
Adjusted R-Squared	0.9051		0.9408		0.9340	

Note: Here in regression 23 city dummy variables are included.

Table 3.4.B

Regressions Relating Price Volatility to Distance and Border (Prices of the same good at different locations) (1975-1984)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors
Distance	$5.85*10^{-06}$	$9.59*10^{-06}$	$-7.65*10^{-07}$	$7.91*10^{-06}$	$1.31*10^{-05}$	$7.98*10^{-06}$
Distance Squared	$1.53*10^{-09}$	$4.64*10^{-09}$	$9.18*10^{-10}$	$3.83*10^{-09}$	$-1.57*10^{-09}$	$3.86*10^{-09}$
Country Dummy	0.1322	0.0044	0.1719	0.0036	0.1270	0.0037
Adjusted R-Squared	0.9334		0.9733		0.9536	

Note: Here in regression 23 city dummy variables are included.

Table 3.4.C

Regressions Relating Price Volatility to Distance and Border (Prices of the same good at different locations) (1985-1995)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors
Distance	$9.97*10^{-06}$	$6.60*10^{-06}$	$1.42*10^{-05}$	$1.67*10^{-05}$	$1.02*10^{-05}$	$9.58*10^{-06}$
Distance Squared	$-5.70*10^{-09}$	$3.19*10^{-09}$	$-4.94*10^{-09}$	$8.10*10^{-09}$	$-7.37*10^{-09}$	$4.64*10^{-09}$
Country Dummy	0.0961	0.0030	0.1498	0.0077	0.1524	0.0044
Adjusted R-Squared	0.9148		0.8238		0.9324	

Note: Here 23 city dummy variables are included in regression.

Table 3.5.A

Regressions Relating Price Volatility to Distance and Border (*Deflated by Log (distance)*) (1975-1995)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Country Dummy	0.1219	0.0038	0.1737	0.0043	0.1419	0.0037
Adjusted R-Squared	0.9110		0.9446		0.9378	

Note: Here in regression 23 city dummy variables are included

Table 3.5.B

Regressions Relating Price Volatility to Distance and Border (*Deflated by Log (distance)*) (1975-1984)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Country Dummy	0.1359	0.0039	0.1731	0.0032	0.1301	0.0033
Adjusted R-Squared	0.9303		0.9735		0.9508	

Note: Here in regression 23 city dummy variables are included

Table 3.5.C

Regressions Relating Price Volatility to Distance and Border (*Deflated by Log (distance)*) (1985-1995)

Variable	Food		Clothing		CPI	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Country Dummy	0.0978	0.0027	0.1504	0.0064	0.1531	0.0037
Adjusted R-Squared	0.9205		0.8287		0.9367	

Note: Here in regression 23 city dummy variables are included

Table 3.6
Regressions Relating Price Volatility to Distance and Border (1975-1995)
Dependent Variable: Correlation of Log of Relative Prices

Variable	Food		Clothing		CPI	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Log (Distance)	0.0013	0.0005	-0.0014	0.0014	0.0012	0.0005
Country Dummy	-0.0377	0.0012	-0.1164	0.0035	-0.0487	0.0013
Adjusted R-Squared	0.929		0.937		0.944	

Note: Here in regression 23 city dummy variables are included

Table 3.7.A
Regressions Relating Price Volatility to Distance and Border (Prices of a good relative to CPI at different locations) (1975-1995)

Variable	Food/CPI		Clothing/CPI	
	Coefficient	Standard Errors	Coefficients	Standard Errors
Log (Distance)	0.0027	0.0008	0.0090	0.0014
Country Dummy	0.0230	0.0021	0.0154	0.0036
Adjusted R-Squared	0.6701		0.7706	

Note: Here in regression 23 city dummy variables are included

Table 3.7.B
Regressions Relating Price Volatility to Distance and Border (Prices of a good relative to CPI at different locations) (1975-1984)

Variable	Food/CPI		Clothing/CPI	
	Coefficient	Standard Errors	Coefficients	Standard Errors
Log (Distance)	0.0009	0.0006	0.0026	0.0016
Country Dummy	0.0117	0.0016	0.0230	0.0042
Adjusted R-Squared	0.7120		0.7813	

Note: Here in regression 23 city dummy variables are included

Table 3.7.C
Regressions Relating Price Volatility to Distance and Border (Prices of a good relative to CPI at different locations) (1985-1995)

Variable	Food/CPI		Clothing/CPI	
	Coefficient	Standard Errors	Coefficients	Standard Errors
Log (Distance)	0.0020	0.0011	0.0073	0.0017
Country Dummy	0.0391	0.0028	0.0092	0.0043
Adjusted R-Squared	0.7312		0.7098	

Table 3.8
Regressions Relating Price Volatility to Distance and Border (1976-1995)
(Wage volatility is included as independent variable in specification 2)

Variable	Food Specification 1		Food Specification 2		Clothing Specification 1		Clothing Specification 2		CPI Specification 1		CPI Specification 2	
Log(Distance)	0.001	0.005	0.003	0.005	0.013	0.006	0.017	0.006	0.007	0.005	0.010	0.005
Country Dummy	0.086	0.007	0.090	0.008	0.139	0.009	0.150	0.010	0.106	0.007	0.113	0.008
Wage Volatility			-0.060	0.048			-0.151	0.060			-0.108	0.047
Adjusted R-Squared	0.912		0.913		0.963		0.967		0.952		0.956	

Note; Here 12 city dummy variables are included in all regression. In specification 1, we have included log (distance), country dummy, and city dummies while in specification2 along with those we have included the variability of relative wages in our regression.

Table 3.9

Standard Deviations of Relative Price of Different Commodities in One Location *vs* Standard Deviations of Relative Price of Same Commodities in Different Locations. (Full Sample)

City/Relative Prices	Food/Cloth	Food/CPI	Cloth/CPI	Food at i /Food at j	Cloth at i /Cloth at j	CPI at i /CPI at j
Dhaka	0.034	0.014	0.040	0.163	0.225	0.188
Chittagong	0.053	0.015	0.050	0.144	0.211	0.161
Rajshahi	0.036	0.015	0.027	0.160	0.202	0.174
Khulna	0.027	0.017	0.027	0.160	0.256	0.181
Hyderabad	0.079	0.025	0.057	0.079	0.139	0.088
Jamshedpur	0.044	0.007	0.040	0.087	0.095	0.076
Ahmedabad	0.069	0.015	0.055	0.078	0.097	0.072
Srinagar	0.051	0.020	0.043	0.116	0.118	0.095
Bangalore	0.103	0.023	0.083	0.077	0.151	0.074
Bhopal	0.072	0.021	0.056	0.081	0.171	0.093
Bombay	0.068	0.017	0.052	0.099	0.099	0.083
Nagpur	0.055	0.014	0.059	0.074	0.105	0.077
Sholapur	0.065	0.011	0.058	0.081	0.091	0.081
Amritsar	0.050	0.020	0.035	0.076	0.097	0.081
Jaipur	0.062	0.016	0.048	0.073	0.096	0.071
Madras	0.064	0.013	0.056	0.084	0.102	0.076
Kanpur	0.053	0.011	0.048	0.075	0.096	0.070
Asansol	0.050	0.012	0.045	0.086	0.103	0.078
Calcutta	0.048	0.012	0.042	0.084	0.098	0.077
Howrah	0.036	0.010	0.032	0.081	0.102	0.075
Jalpaiguri	0.046	0.017	0.036	0.094	0.111	0.095
Raniganj	0.051	0.017	0.045	0.103	0.110	0.091
Delhi	0.067	0.020	0.051	0.079	0.099	0.071

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Appendix 1 (Chapter 3)

Data and Data Sources

Data related to Bangladesh are collected from various issues of *Economic Trends*, a monthly publication of the central bank of Bangladesh: Bangladesh Bank. Indian consumer price data are collected from different issues of *Statistical Abstract India* published by the Central Statistical Organization, India. The annual period average exchange rates are collected from the *International Financial Statistics Yearbook, 1997* published by the IMF. *Taka/Rupee* exchange rate is calculated by dividing *Taka*/US$ exchange rate by *Rupee*/US$ exchange rate. Wage data for India are gathered from various issues of "*Indian Labour Journal*". "Earnings (Basic wage and dearness allowance) of the lowest paid workers/operatives in Cotton Textile Mills" is the wage rate we have used here. Bangladeshi wage data are collected from the *Statistical Yearbook Of Bangladesh.* Average daily wage rate of construction labor (Mason) at principal town is our wage rate for Bangladesh.

PC GLOBE software, *World Book of Atlas,* and *the National Geographic Atlas of the World* are used to calculate distances of the city pairs.

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