

The Social and Economic Impacts of a Washington State Carbon Tax

Benjamin Barenboim

A thesis  
submitted in partial fulfillment of the  
requirements for the degree of

Master of Science

University of Washington

2016

Committee:  
Sergey Rabotyagov  
John Perez-Garcia  
Ernesto Alvarado  
Daisuke Sasatani

Program Authorized to Offer Degree:

School of Environmental and Forest Sciences

©Copyright 2016  
Benjamin Barenboim

University of Washington

**Abstract**

The Social and Economic Impacts of a Washington State Carbon Tax

Benjamin Barenboim

Chair of the Supervisory Committee:

Sergey Rabotyagov. Assistant Professor Environmental Economics

School of Environmental and Forest Sciences

Carbon taxation is becoming a prominent tool to help reduce the greenhouse gas emissions that promote climate change. Using an Input-Output model of Washington State for 2013, I determine the relative carbon intensity of economic sectors and show how a carbon tax in Washington State will impact household consumption, trade, and industrial activity through price increases resulting from that carbon tax. Although many studies have shown that carbon taxes are regressive, Washington State is uniquely positioned to implement a carbon tax that is only mildly regressive due to the reliance on hydro and other renewable sources of electricity as opposed to fossil fuel generated electricity. These remaining regressive effects can be mitigated through revenue recycling of carbon tax receipts.

## INTRODUCTION

It is widely accepted that one of the primary drivers of climate change is anthropogenic greenhouse gas (GHG) emissions. In 2010, global GHG emissions reached their highest ever recorded levels at 49.5 billion tons of carbon dioxide equivalent (CO<sub>2</sub>E) (IPCC 2014). A larger percentage of these emissions is coming from the industrialization of emerging and frontier economies. China, who experienced increased emissions of 80% for the year 2000 – 2006 period, is responsible for 54% of the increase in GHG emissions for the same period, and has since exceeded total annual emissions of the United States to become the single largest global emitter (Gregg, Andres, and Marland 2008).

In 2006, Nicholas Stern wrote a report for the British Government discussing the economic impacts of climate change on a global scale. At 2006 emissions levels, Stern concludes that the costs of climate change will total 5%-20% of global GDP annually. Regulating GHG emissions is an idea that is rapidly moving to the forefront of the climate change debate around the world, and Stern estimates that effective regulation to the point of reducing emissions to tenable levels will cost roughly only 1% of global GDP annually.

Industrialized economies have employed regulations as incentive strategies to accomplish their emissions goals to stabilize and reduce GHG output (IPCC 2014). There are two common ways in which these GHGs are regulated. The first is an emissions tax which is a price, paid as a tax to the government, per designated unit of designated pollutant. For example, an emissions tax scheme could be structured to charge \$10 per ton of CO<sub>2</sub> emitted by a manufacturing facility. The second is a Cap and Trade system, which establishes a cap on how much pollution a facility is permitted to emit and allows for the unused allotment of emissions to be sold on the open market to a facility that requires a larger allotment than is initially allocated.

Regardless of form, climate policy will result in an increase in the price of energy and impose a burden on an economy (Callan et al 2008). In the United States, emissions taxation, commonly referred to as carbon taxation, is often seen as the more politically and economically palatable option, and the federal government, individual states, and even some local districts have begun investigating the implementation of an emissions taxation scheme.

Washington State is working towards implementing a carbon tax of its own. There are a number of proposals (which will not be discussed in detail here) facing the legislature and

potentially the ballot, but they all aim to put a price on carbon consumed in the state and reduce pollution. A general principal is that the tax is applied at the point of production instead of consumption, hitting the producers directly. The expectation is that the cost increases directly realized during production will filter down to consumers as price increases of goods and services and alter consumptions patterns (Grainger and Kolstad 2010).

A pervasive concern is that, as a result of these price increases, income groups will be disproportionately affected due to different consumption bundles and propensities. It is generally shown that carbon taxation on its own is regressive (Metcalf 1999, Jiang and Shao 2014, Robertson et al 2014, Callan et al 2008, Grainger and Kolstad 2010), the extent of which is often determined by make-up of the economy and households, but also how the carbon tax revenue is utilized, such as funding a low income tax rebate or consumer tax breaks (Robertson et al 2014). The impact a carbon tax will have on the prices and consumer behavior of an economy is tied directly to the industrial structure, income distribution, and consumption patterns of the studied economy.

Carbon taxation is beginning to be implemented in various jurisdictions around the world; mostly at the country level, but also some regional and local levels. Additionally, there is an ever increasing amount of research being done to analyze the impacts on specific markets. According to the World Bank, 15 countries operate carbon taxation (The World Bank 2015). One of these programs in British Columbia (BC), Canada, is a sub-national program since it only impacts the single province of BC. The Carbon Tax Center (CTC), a non-profit organization in the United States that tracks and compiles research on carbon taxation, lists Boulder, Colorado as a local Carbon Tax jurisdiction. The CTC also lists Australia as a national system, but Australia has since repealed their Carbon Tax. Each program operates differently in design, scope, and extent but the overall objectives to generate revenue, reduce pollution, and address climate change are the same.

A popular way to determine and explore these price changes is by using Input-Output (IO) analysis. Originally developed by Wassily Leontief in the mid-1930s, IO modeling is used to explore the interrelationships of different industries within an economy by “tak[ing] advantage of the relatively stable pattern of the flow of goods and services among the elements of our economy” (Leontief 1966). These elements include commodities, industries, households, proprietors, and governments. This model can be applied by investigating impacts an economy

may face as a result of a change in the underlying flow of goods and services, or, in this case, the impacts of a production cost push. From this model, I intend to determine the price change that the carbon tax will have on final demand and explore the impacts of these price changes on different income groups. This analysis will be done entirely from the spending side. It is important to note, however, that the impacts of a carbon tax on the income side can be important (Beck et al. 2015), but are not a component of this analysis.

I will use the 2013 Washington State input-output data from IMPLAN for the structure of the economy and 2013 carbon emissions data from the EPA Greenhouse Gas Reporting Program. The process entails incorporating the non-monetary, environmental sector of carbon emissions into the model as an output vector. Similar to any economic sector paying and receiving monetary capital from other sectors, so too do the sectors with carbon, either through direct emissions resulting from operations of that sector, or through virtual carbon embedded within the products of that sector.

## LITERATURE REVIEW

The first instance of a carbon tax for the specific purpose of addressing environmental concerns is from Finland. In 1990, the Finnish government implemented a tax strategy that initially only taxed the carbon content of fuels (Lin and Li 2011). Other European nations including The Netherlands, Norway, and Sweden soon launched their own programs. Over the years, these tax schemes have been altered and refined to better fit with the needs and objectives of the jurisdiction. They do also face a challenge, thus far unique to the rest of the world, in that they must also integrate into the European Union's Emissions Trading System (ETS) (The World Bank 2015).

The analysis of a carbon tax can be divided into two broad categories: impacts on emissions and the impacts on the economy. Within the economic side one could look at the impacts on tax revenues on household consumption. These studies focus mainly on developed markets already implementing or proposing carbon tax plans. The results of these studies share a similar trend of regressivity, however Shah and Larsen (1992) show that the carbon taxation shows progressivity in developing markets due to the lopsided use of fuel or fuel intensive products at the higher income classes.

Grainger and Kolstad (2010) looked at the potential impacts of a nationwide carbon tax in the United States. Using input output data, they combined the structure of the economy with consumption data from the consumer expenditure survey and fuel emissions factors. Their goal was to determine if a US carbon tax would be progressive or regressive. It is stated clearly that the intent was to derive first order effects only by assuming that the full cost of the tax is passed on to the consumer and calculating the direct burden of that additional cost. They are also assuming that there is "no attempt to substitute away from carbon intensive goods" (Grainger and Kolstad 2010).

Grainger and Kolstad associated each income group with a consumption bundle denoted in dollar value and emissions quantity of each product consumed. The emissions consumed values were then totaled up across each income group and then multiplied by the chosen tax rate of \$15/ton. The results of this analysis shows that the burden of a carbon tax is significantly higher in lower income group, as a percentage of annual income, and explores which sectors will see the largest increase in consumer prices. It is also suggested that the burden can be mitigated through tax offsets for lower income groups which are also explored. Quantitatively, Grainger

and Kolstad found that the lowest income group (with income being split into quintile groups) would roughly pay an additional \$325 per year as a result of this carbon tax while the highest group would pay roughly \$1,140. Although nominally higher, the highest income group pays considerably less proportionally than the lowest group.

To offset the tax, Grainger and Kolstad explore lump sum rebates as a means to equalize the burden between income groups. Their objective was to reduce the proportional burden of the tax of each income group down to the same level as the highest income group, which in this case is 1% of total annual income. Since the spending side effects of the tax are being fully nullified, the program is not completely revenue neutral and money still flows to the Federal Government's coffers.

An important study regarding Washington State, is the retrospective investigation on the carbon taxation system in British Columbia, Canada which was implemented in 2008. In "Carbon tax and Revenue Recycling: Impacts on Households in British Columbia," Beck, Rivers, Wigle, and Yonezawa, looked at how the established carbon tax, along with its offsets, has impacted households in British Columbia (BC), Canada. This study is important for Washington since many of the key attributes of the Washington State proposals are modeled after the BC program: namely the tax range and the revenue neutrality programs.

Beck et al (2015) show results in the form of household welfare changes with and without revenue recycling. Revenue recycling is redistributing the revenue from the carbon tax in order to help consumers mitigate price increases resulting from the carbon tax. They show that on an aggregated level, households had a welfare change of -.53% with no revenue recycling and a welfare change of -.01% with revenue recycling. Although the overall welfare is reduced, when broken down into income groups, the BC carbon tax bucks the trend, and shows a slightly progressive result: higher income households incur more of the carbon costs.

There is a tug of war between the consumption-side effects and the income-side effects in any carbon taxed market which pivots around the consumption distribution of fossil fuels. In BC, it is shown that the income-side effects dominate the relatively weak spending-side effects due to hydro-electricity not being part of the taxed consumption bundle and a relatively even distribution of fossil fuel consumption (Beck et al 2014). When looking at just the spending side effects it turns out to be very weakly regressive or even neutral, but turns progressive after including the income side effects.

The consumption share of electricity usage between income groups is often a large driver behind the regressive nature of a carbon tax (Dissou and Siddiqui 2014), such that although “spending share of electricity is decreasing with [increasing] income, the carbon tax does not increase the electricity price because the electricity in BC is mostly generated with hydro” (Beck et al 2014). In other words, lower income groups spend more proportionally on electricity, and will thus realize a proportionally larger savings from hydro-electricity not being taxed.

A similar study conducted on the rest of Canada shows a collectively regressive result for a nationwide carbon tax (Hamilton and Cameron 1994). Comparing the two results (disregarding any major temporal changes), we can see how the impacts of a similar carbon tax program will differ depending on the design of the society and economy in which it is implemented. The big difference between BC and the whole of Canada is that BC generates more electricity from non-taxable hydro than Canada does as a whole (Statistics Canada 2014). It is also important to note here that the BC study conducted by Beck et al (2015) and the Canada study conducted by Hamilton and Cameron (1994) were completed using data discrepancy of about 25 years, so there is potential for some infrastructural change within Canada, mostly concerning electricity generation and fuels usage.

We may expect Washington State to exhibit similar results since Washington State also generates significant portions of its electricity from hydro. To compare: BC generates approximately 86% of its electricity from hydro (EnergyBC 2012) while Washington State generates approximately 61% of its power from hydro (U.S. Energy Information Administration 2015). For the sake of comparison, the United States as a whole generates only 6% of its electricity from hydro (U.S. Energy Information Administration 2015).

There are numerous other studies concerning carbon tax impacts, all of which provide useful information since each market is idiosyncratic in its tax and benefits structure. Brenner, Riddle, and Boyce (2005) look at the potential effects of a carbon tax and revenue recycling program in China. They find that on the whole, the tax shows to be progressive, with wealthier households bearing more of the burden than poor households. This is in line with conclusions of Shah and Larsen (1992) about the progressive trend in developing economies. The take home point made by Brenner, Riddle, and Boyce, however, is the transfer of wealth across special divisions found in the impacts between urban and rural households. Given the fundamental

differences in the consumption bundles between urban and rural households, there is a flow of wealth from the urban population to the rural population, as a result of the revenue recycling.

Callen et al (2008), look at the carbon tax in Ireland. They found that the carbon tax was regressive with the bulk of the impacts coming from heating fuels as opposed to automobile fuels and suggest that there should be additional benefits for those with dependent children. They estimate that, through revenue recycling programs, it would only cost 65% -80% of the carbon tax revenue to make the Irish carbon tax economically progressive and viable. This result shows that a plan may not need to recycle 100% of the carbon tax revenue in order to prove fair and effective freeing up some of the revenue for other purposes.

In Spain, Labandeira and Labeaga (1999) use an input-output model to explore the impacts of a carbon tax on households. They combine fossil fuel use with output data from each industry, calculate the price change of final demand of each industry, and then apply those price changes to consumption bundle of each household group. This study took a slightly different approach than others by dividing households into consumption groups instead of income groups, stating that a level of consumption is more stable over time than income, so a point-in-time consumption measure is more indicative of life time wellbeing than a point-in-time income measure. The parameters by which the deciles are divided, however, are not described. Labandeira and Labeaga show an inconclusive result concerning the impacts on households as their calculations showed neither progressivity nor regressivity at any significant level.

A few key points stand out from the literature:

- Carbon taxation is considered to be regressive in developed economies by placing a higher burden of the tax on lower income households, the extent of which is dependent on the economic idiosyncrasies and structure of the jurisdiction.
- A significant portion of carbon tax expenditure lies within the consumption of electricity and fossil fuels; it is the primary driver of regressivity.
- Revenue recycling such as consumer tax reductions and rebates can be used to mitigate the additional burden borne by lower income households and create a neutral or progressive regime.
- Progressivity of a carbon tax regime can be achieved using less than 100% revenue recycling.

## **ANALYSIS AND OBJECTIVES**

The goal of this paper is to explore the economic and social impacts of a carbon tax in Washington State. I will combine economic data with carbon emissions data to create an input-output model that will determine the price change of final demand of goods and services. I will then look at the impacts of these price changes on the consumption of households broken down into a series of income groups. A comparison can then be done to show the impacts of a carbon tax on different income groups at different tax levels.

The model will be used to find the proportion of income used by each income group to pay the carbon tax on their respective consumption bundle. To be clear, although the model is being divided along income groups, it is still a consumption model since it is based on the consumption of each group; whereas an income model would incorporate the changes in income to each group resulting from the carbon tax. The result is calculated by individual item of consumption and summed up to get the total change. The individual line items of each income group can be compared to see consumption proportion differences of carbon heavy products such as vehicle fuels or electricity. We can then infer the specific causes of the disproportionate impacts.

Once the model is put together, we can find the price changes and examine the specific consumption of each income group to find out which products result in the most spending towards a carbon tax both nominally and proportionally. From that information, we can explore different revenue recycling programs in order to mitigate any disproportionality across income groups.

The model can also be used to simulate economic activity. Expenditure for large projects, such as forest restoration, can be allocated as inputs to the model; emissions created from the additional demand generated from that project and the proportion of the project expenditure going towards the carbon tax can also be determined. Many restoration projects have been conducted in Washington State, and the sectoral expenditure profile of those projects can be plugged into the model to explore how the costs of the project would change based on a carbon tax. We would expect the total cost of the project to increase, but each sector would not increase in the same proportion. Carbon heavy sectors would increase more than carbon light sectors. Project administrators can assess the carbon specific impacts of their projects potentially

substitute expenditure away from carbon heavy sectors to carbon light sectors – depending on availability of appropriate substitutes.

## **DATA**

### *Input-output*

There are two sets of data necessary for this analysis: economic input-output (IO) data and carbon emissions data. The IO data is provided by IMPLAN, which specializes in creating and distributing IO data sets, comprises inter-industry transaction and consumption data. This data can be provided at the US national, state, county, and zip code level. The national data is collected from the Bureau of Economic Analysis and converted and formatted to the IMPLAN sector designations. Data for states, counties, and zip codes are collected and controlled up to the next highest level. The state data are controlled to fit the national data, counties with the states, and zip codes with the counties (IMPLAN Data Components 2015).

In its current iteration, IMPLAN segments the economy into 536 industrial accounts with an additional 24 social accounts. Social accounts are non-production components of the IO model, such as wages, consumption, government, and trade. Along with the data, IMPLAN provides a software package which acts as a portal through which to download the data and run customized analyses using that data. Alternatively, the data can also be extracted into a Microsoft Excel file and manipulated manually. All the analyses done here was conducted manually with the data files extracted from the IMPLAN software.

The extract is formatted as a single MS Excel file with a row of data for each capital transactions. There is a designated payable sector, receivable sector, and value of the capital transferred. For example: sector 1, Oilseed Farming, transferred \$107,815.8 to sector 172, Pesticide and Other Agricultural Chemical Manufacturing. The oilseed farming sector purchased \$107,815.8 worth of goods and services from the pesticide industry (IMPLAN group LLC). This is a logical relationships since farming often requires pesticides. Conversely, sector 1, Oilseed Farming, does not transact at all with sector 107, Manufactured Ice. It is reasonable to assume that oilseed faring does not require the purchasing of manufactured ice, and the data corroborates that assumption.

It is critical to remember that these are purchases made by firms operating within the designated IO economy from firms operating within the same IO economy - In this case Washington State for 2013. Any activity with firms outside the IO economy, are represented in an import or export account.

## *Carbon*

The carbon data proved to be more difficult to attain since it is only collected piecemeal by various agencies, unlike the IO data which maintains a dedicated and organized collected agency and process. I started at the state level with Washington State Department of Natural Resources (DNR) and Department of Ecology (ECY). Neither of these agencies independently compiled comprehensive emissions data for Washington State. There were other sources, either government or non-government, but none proved sufficient; specifically regarding the level of disaggregation.

What was specifically needed was emissions data disaggregated by industry that lined up with the IMPLAN sectors. The idea is to associate each of the 536 IMPLAN sectors with a defined emissions output. I expanded my search and found the EPA Greenhouse Gas Reporting Program (GHGRP) which collects emissions data from large polluters nationally. As a response to FY2008 Consolidated Appropriations Act, the GRHRP was created by the US EPA. The GHGRP mandated the reporting of emissions by firms emitting greenhouse gasses, producing fossil fuels, or transporting greenhouse gas containing fuels. It did, however, only mandate reporting of firms emitting or transporting more than 10,000 metric tons of CO<sub>2</sub> equivalent (EPA Learn About the Greenhouse Gas Reporting Program).

The emissions data can be extracted from the EPA database using the GHGRP Facility Level Information on Greenhouse Gasses Tool (FLIGHT). There are a number of different configurations of the data which can separate out different types of emitters; however, I used the full report for Washington State. The report is list of all the firms that reported emissions to the EPA program. The report lists out information about the firm and the emissions for the given reporting year in terms of CO<sub>2</sub> equivalent (CO<sub>2</sub>E). A foreseen difficulty here is being able to allocate the emissions to the correct IMPLAN sector.

The FLIGHT reports has a North America Industry Classification System (NAICS) code designation for each of the reporting firms. NAICS is a structure by which firms are classified into industries (U.S. Census Bureau 2016). The emissions data for each of the firms can be aggregated by NAICS code in order to find the total emissions reported for each industry. IMPLAN publishes a cross-reference file with which to convert each of IMPLAN's 536 sectors into NAICS codes. Using the NAICS codes as a point of reference, the emissions data for each sector could be appropriately allocated to its respective IMPLAN sector.

One potential problem with this approach was that the GHGRP only requires firms to report if they emit over 10,000 metric tons of CO<sub>2</sub>E resulting in much of the actual emissions within the state to be overlooked and the majority of industries to not be represented. Only 48 out of the 536 sectors were represented on the GHGRP for Washington State. In order to remedy this problem, I pulled the US national emissions data and similarly aggregated it by NAICS code, which proved to have far fewer sector gaps. It represented 256 sectors out of 536. I then took the IMPLAN data for Washington State and the entire United States and found the ratio of output for each of the 536 sectors Washington had of the whole US. The last step was to multiply the national emissions aggregates by the output ratio to get an emissions estimate of the Washington State industries, specifically those not empirically represented in the Washington State data report.

After conducting the price change analysis with the apportioned national data, I found that previously blank sectors, now showed emissions. The ratio of emissions to output, however, was very different. A prime example is electricity generation since the literature suggests that electricity generation is a key industry for emissions analysis. To reiterate, Washington State produces 61% of its electricity from hydro (which does not produce taxable GHG emissions), compared to the national average of 6%. This created an anomalous result when calculating the price changes from the US national data. Since the US nationally produces significantly more electricity from fossil fuels than Washington State, the price impacts of a carbon tax in the electricity generation by fossil fuel sector was much larger than when using just the Washington State emissions data.

Table 1 shows the output and emission of the 20 most polluting sectors in Washington State. Back to the electricity generation example; if we look at sector 42, Electric Power Generation – Fossil Fuel, the emissions were calculated to be nearly triple when derived from the national data. At the same time, Sector 395, Wholesale Trade, was only about 25% when using the derived emissions. This comparison shows that Washington is significantly more dependent on trade, and significantly less dependent on fossil fuel electricity than the US as a whole.

This result illustrates how small changes to the structure of the economy can have large impacts on the results. It also shows the dangers of generating a model by correlating data from a non-target economy, such as deriving Washington State emissions from proportions of national usage relative to the structure of the national economy instead of the empirical data collected for

Washington State. Despite there being large gaps in the Washington State emissions data, it is the preferred choice since it more accurately represents the economic structure of the state.

<b>Table 1: Emissions at the sectoral level</b>			
<b>Sector Number</b>	<b>Sector Name</b>	<b>Emissions MT CO2E</b>	<b>Output \$</b>
<b>395</b>	Wholesale trade	20,521,687.00	33,157,710,837.39
<b>156</b>	Petroleum refineries	13,597,006.00	20,131,474,733.30
<b>42</b>	Electric power generation - Fossil fuel	11,512,829.00	689,968,874.75
<b>147</b>	Paper mills	3,755,958.00	3,251,200,661.36
<b>148</b>	Paperboard mills	2,754,515.00	658,201,848.82
<b>221</b>	Alumina refining and primary aluminum production	1,407,928.00	1,185,695,420.91
<b>471</b>	Waste management and remediation services	1,330,139.00	4,073,108,395.47
<b>134</b>	Sawmills	1,114,105.00	1,925,962,283.17
<b>146</b>	Pulp mills	1,085,192.00	69,002,182.03
<b>413</b>	Pipeline transportation	464,582.00	65,936,935.19

A portion of the aforementioned data gaps come from the lack of any large enough firms that mandate reporting. Incidentally, it is possible that a highly polluting sector is omitted on the grounds that it comprises many small firms. A good example is the trucking industry. Trucks are often targeted as a large if not the largest polluting sector, yet the truck transportation industry remains curiously absent from the GHGRP data. I surmise that this absence is due to the bulk of the trucking industry comprising independent contractors or small haulage firms. Alternatively, a great deal of trucking activity is done by non-transportation specific firms. For example, some kind of manufacturer transporting supplies between facilities.

The total emissions for this activity, however, is not omitted since it is incorporated into the emissions of the processing, storage, and transportation of the fuels according to the guidelines of the GHGRP. While the emissions are captured in the data, the sectoral allocation is a little out of line with who is directly emitting. In other words, instead of the individual truckers being charged a tax for their diesel emissions, the diesel distribution company is charged the tax and the cost is passed onto the individual truckers when purchasing the fuel. There is, however, potential for significant downstream due to this production side and not consumption side emissions allocation (as will be discussed in more detail later).

## **METHODS**

### *History*

Originally developed by Wassily Leontief in the 1930s, input-output modeling was based on the Tableau Economique described by Francois Quesnay in the mid-1700s. In contradiction to the mainstream of the day, “Quesnay insisted that wealth sprang from production and that it flowed through the nation, from hand to hand” (Heilbroner 1999). During the early to mid-20<sup>th</sup> century, the availability of economic data increased significantly, and Leontief observed that there was a fundamental disconnect between the theories and methods of the day with the newly available mountains of raw data (Leontief 1951).

Leontief took Quesnay’s Tableau concept, and instead of using it to deductively explore hypotheticals, as his priors and contemporaries did, he applied real-world, collected data from the 1919 US census to inductively draw conclusions (Leontief 1936). The problem was that the data required computing power attainable neither by people nor any machines of the day, so the IO tables he developed from this data were very aggregated.

In his initial 1936 paper, Leontief refers to a full transactions table as something so large that the “very size of it would constitute a serious impediment to any profitable use of the information contained in it.” As computers began to be developed in the 1940s and 1950s, Leontief observed an increased ability to conduct large scale analysis using full data sets, since large matrix calculations would not be needed to be done by hand (Leontief 1951). This new ability to crunch numbers with speed and precision, allowed the field of economics to transform from a deductive enterprise to an inductive enterprise, and actually utilize the vast quantities of data being collected (Leontief 1951).

Input-output models have been used extensively by governments to assess the current structure of the economy and explore the economy wide impacts that expenditure on capital projects may have. Since the 1960’s many researchers, and even by Leontief himself in 1970, have extended IO models to include non-monetary environmental accounts (Miller and Blair 1985). Theoretically, one can apply any environmental commodity for which sufficient use data is available, and explore the interactions that environmental commodity has with economic sector relationships.

*General Model*

Input-Output models are, as we see in the literature, a very common way of analyzing economy wide sectoral impacts of carbon taxation or other fiscal policy changes. An IO model is a series of matrices that present capital relationships between economic sectors, consumers, and governments. The model is built from observed economic data and produces a snap-shot of the designated economy for the designated period of time. Although the IMPLAN data uses 536 sectors, a model can use any number of sectors as desired by the creator. Some models may have a few, very aggregated sectors, while other may have thousands of very disaggregated sectors (Miller and Blair p. 2). One model may have a single sector listed as Agriculture, while another may have each agricultural product listed as its own sector.

**Figure1: Input-Output model framework.**

	Agri	Const	Mining	Financial	Trans	Households	Gov	Exports	Total Output
Agri									
Const									
Mining		Intermediate Demand				Final Demand			
Financial									
Trans									
Wages									
Prop Income		Value Added							
Gov									
Imports									
Total Output									

The inter-sectoral data is used to generate the transactions matrix. This transaction matrix represents the intermediate demand of the economy, and displays the inputs as rows and outputs as columns such that column sector 1 will transfer cash to row sector 2 in exchange for row sector 2 transferring manufactured goods to row sector 1 (as such the value of the goods transferred equals the cash transferred). This information is displayed in the intersecting cell. There is also a transfer relationship among the same industries whereas sector 1 will transfer goods and cash to and from itself. At a perfect level of disaggregation, however, the diagonal of same-industry relationships will be zero; however, this is usually not the case because some level of aggregation is present in the model so different branches of the model sector are transacting among themselves (Leontief 1936).

Below the transactions matrix are the Value Added vectors. These vectors represent non-industrial inputs to goods and services and include employee wages, proprietor's income (profit), and government. To the right of this transaction matrix are the vectors of final demand which represent the final consumption of goods and services by non-industrial entities such as households, governments, and trade. For a given sector there are two types of demand: the intermediate demand, which is consumed by other sectors as displayed in the transaction matrix, and the final demand, which is consumed by these non-industrial sectors.

This is the base model showing the nominal data. The analysis come from manipulating this data using matrix algebra mechanics. Often, the manipulation is focused on the transaction matrix, but value added, trade, and final demand accounts can be internalized as desired (Doug Olson)

### *Assumptions*

There are a number of important assumptions to understand when using IO models. First, the models represent only a single time period interval (Leontief 1936). Most commonly, the interval is a calendar year. As described by Leontief, it can be seen as an analog of a corporation's income statement since the model records incomes and expenditures through a period of time. Second, the inputs equal the outputs; the column totals equal the corresponding row totals. Third, the model is linear. The results of the model scale arithmetically as the inputs to the model changes. For example, once the model is put together, if we input a project expenditure level of \$2,000,000, the results will be exactly double of those of an expenditure level of \$1,000,000 at the same sectoral allocation.

There are other assumptions built into the analysis of the model. A principal and fundamental assumption in the model is that even after factoring in a carbon tax, the structure of the economy would not significantly change for the year in which the model data was generated. What is referred to as the structure of the economy are the capital flows found in the intermediate demand transactions matrix. The model does not take into account any abatement undertaken by firms in order to pollute less. The model uses the 2013 economic structure as the baseline with which to gauge the price change impacts of the carbon tax. The model assumes that intermediate demand remains the same when calculating price increases.

All costs are assumed to be passed on to the consumer and final demand quantity is assumed to remain the same post carbon tax. In other words, consumers do not substitute away from carbon heavy goods. The change in wages as a result of the carbon tax is not being analyzed in this analysis, as it only examines only first order consumption impacts relative to a stable income.

One other important thing to note when comparing the results is that the tax only impacts production within the study economy, and ignores the consumption of imported goods and services (due to data limitations). As seen in the IMPLAN data, there are many industries that are barely or not at all represented in Washington State, but are represented in the whole US. Any of these industries are potentially not contributing emissions to Washington State consumption, not contributing to the cost increases, and not contributing to any regressive tendency.

### *Adding Carbon*

The notation by which an IO model is manipulated and described can vary by whoever is conducting the analysis, but I will follow the notation as described by Dietzenbacher and Velazquez (2007), as it follows a relatively standard scheme. Transactions matrix  $Z$  is a square matrix representing the total intermediate demand of each inter-industry relationship. In our case,  $Z$  is a 536 by 536 matrix with  $z_{ij}$  representing the transfer of goods from Washington industry  $i$  to Washington industry  $j$ .

**Figure 2: Input-Output Notation**

	Agri	Const	Mining	Financial	Trans	Households	Gov	Exports	Total Output
Agri	<b>Z</b>					<b>F</b>			<b>X</b>
Const									
Mining									
Financial									
Trans									
Wages	<b>V</b>								
Prop Income									
Gov									
Imports									
Total Output	<b>X'</b>								

Matrix  $F$  represents the final demand, with  $f_{ij}$  representing the final demand of consumption group  $j$  of goods or services from industry  $i$ . The final demand categories include

households and private consumption, government and public consumption, investments, and exports. Each of these categories can be aggregated to any level desired, with households being split out into income groups, governments being split out by government level and agency, and exports being split out by region.

The V matrix represents the value added line in which  $v_{ij}$  is the value added component of  $j$  from source  $i$ . Value added sources include wages, proprietor's income, government (taxes), and other items. Vector M represents imports where  $m_{ij}$  represents the imports originating in a foreign sector  $i$  to domestic sector  $j$ . Often times, the import matrix is represented as a single row vector of imports so a specific  $i$  sector is not available. Vector  $x_i$  gives the total output of sector  $i$ . The total output can be found two different ways. First, by summing across a row with  $z_i$  representing the vector of intermediate demand, and  $f_i$  representing the vector of final demand. Second, by summing down each column with  $z_j$  representing the intermediate demand,  $v_j$  representing the value added, and  $m_j$  representing the imports. Corresponding rows and columns equal each other. For  $i = j$ ,  $x_i = x_j$ .

$$\text{Equation 1: } x_i = \sum_j z_{ij} + \sum_j f_{ij}$$

The direct purchase coefficients represented by  $a_{ij}$ , are the ratio of intermediate demand to total output or  $z_{ij}/x_j$ . These direct purchase coefficients “indicate the extra input from sector  $i$  in [Washington] that is required for the extra production of [\$]1 by sector  $j$  in [Washington]” (Dietzenbacher and Velazquez 2007). In matrix notation, this final equation can be written as  $\mathbf{x} = \mathbf{Ax} + \mathbf{f}$ . In other words, the sum of the purchase coefficients for a given sector, multiplied by the total output of that sector, plus the final demand of that sector, equals the total output of that sector. This matrix of direct purchase coefficients is designated the A matrix. Equations 1 and 3 are the same since  $z_{ij} = a_{ij}x_j$ .

$$\text{Equation 2: } a_{ij} = z_{ij}/x_j$$

$$\text{Equation 3: } x_i = \sum_j a_{ij}x_j + \sum_j f_{ij}$$

This A matrix is then subtracted from an identity matrix I. An identity matrix is a matrix of all zeros except for ones going down the top-left to bottom-right diagonal. For the purposes of

IO mechanics, it is always the same size as the A matrix. The inverse of this (I-A) matrix is then calculated to get the Leontief Inverse Matrix, or L. This Leontief Inverse matrix contains the Leontief Multipliers: with each cell,  $l_{ij}$ , representing “extra output in the sector  $i$  that is necessary for [\$]1 extra of final demand in sector  $j$ ,” such that, “ $\sum_i l_{ij}$  indicated the total extra output that must be produced for [\$]1 extra of final demand” (Dietzenbacher and Velazquez 2007).

Equation 4:  $L = (I-A)^{-1}$

$LF = (I-A)^{-1}F$  This is in matrix notation.

This Leontief Inverse, L, is the crux of the model as it is what is primarily used to conduct the various analyses of IO models. For this analysis, L is used to manipulate a series of carbon emissions multipliers in order to estimate the price changes from a carbon tax. Dietzenbacher and Velazquez (2007) do this analysis for water pricing in Andalusia, Spain; but the method can be applied to carbon since a price on carbon is analogous to a price on water in that it is (or will soon become) a cost of production.

Carbon can now be introduced as a vector,  $c$ , that shows the carbon use of each sector. We can divide the carbon produced by the total output of each sector,  $c_j/x_j$ , in order to find the direct carbon coefficient of each sector. This direct carbon coefficient matrix,  $y$ , shows the carbon emissions (metric tons) per dollar of output for each sector. The carbon emissions multipliers can then be found by multiplying the carbon coefficient matrix with the Leontief Inverse matrix.

For each of the 536 sectors, the emissions coefficient,  $y_j$ , is multiplied by each element of the inverse matrix,  $l_{ij}$ , resulting in the summation  $\sum_i y_i l_{ij}$ . This equation shows how much additional carbon is emitted by sector  $i$ , for generating \$1 of final demand in sector  $j$ . These carbon multipliers take into account not only the direct carbon use of industry  $j$  (which is simply the coefficient  $y$ ), but also all the carbon emissions of the intermediate inputs to production of sector  $j$ , from sectors  $i_1$  through  $i_{536}$ . This is done by multiplying and then summing the intermediate input of sectors  $i_1$  through  $i_{536}$  by the carbon coefficient of sectors  $i_1$  through  $i_{536}$ : total emissions equals direct plus indirect emissions.

Equation 5:  $y_j = c_j/x_j$

Equation 6:  $\sum_i y_i l_{ij}$

*Matrix Multiplication Example*

The following is a hypothetical example of how matrix multiplication is used to incorporate the emissions of all the intermediate demand. Matrix A is a 1x3 matrix representing the carbon coefficients of sectors 1 through 3. Matrix B is a 3x3 matrix representing the multipliers of intermediate inputs of a given economy (Leontief Multiplier matrix).

$$A = \text{Carbon Coefficients} = [3 \quad 7 \quad 10] \quad B = \text{Leontief Multipliers} = \begin{bmatrix} .5 & .35 & .15 \\ .2 & .7 & .1 \\ .35 & .25 & .4 \end{bmatrix}$$

Multiplying AxB yields a new 1x3 matrix of carbon multipliers by multiplying the element of column 1 in A by each element in row 1 of matrix B, column 2 of A with row 2 of B, and column 3 of A with row 3 of B.

$$AB = [3 \quad 7 \quad 10] * \begin{bmatrix} .5 & .35 & .15 \\ .2 & .7 & .1 \\ .35 & .25 & .4 \end{bmatrix} = \begin{bmatrix} 3 * .5 & 3 * .35 & 3 * .15 \\ + & + & + \\ 7 * .2 & 7 * .7 & 7 * .1 \\ + & + & + \\ 10 * .35 & 10 * .25 & 10 * .4 \end{bmatrix} = \begin{bmatrix} 1.5 & 1.05 & .45 \\ + & + & + \\ 1.4 & 4.9 & .7 \\ + & + & + \\ 3.5 & 2.5 & 4 \end{bmatrix}$$

Summing down the columns of this matrix of products yields Matrix C.

$$C = \text{Carbon Multipliers} = [6.4 \quad 8.45 \quad 5.15]$$

Since element B<sub>1,2</sub> represents the extra output required from sector 1 to produce 1 additional dollar of final demand in sector 2 (B<sub>1,2</sub>=.35), when multiplying the carbon produced by each sector, by all the multipliers of all inputs to the production of that sector, we get the quantity of carbon produced for each dollar of output of that sector. Sector 1 emits 3 units of carbon for each dollar of output, so if sector 2 requires .35 units of sector 1 to produce its total output, sector 2 requires 3\*.35 units of carbon for 1.05 total units of carbon from sector 1 for sector 2. Sector 2 produces 7 units of carbon for each dollar of output, so .7 units of input is 7\*.7

units of carbon which equals 4.9 units of carbon. Sector 3 produces 10 units of carbon for each dollar of output, so .25 units of input yields 2.5 units of carbon. The total carbon per dollar of output for sector 2, accounting for direct and indirect emissions, equals  $1.05+4.9+2.5=8.45$ : which represents the carbon multiplier for sector 2.

### *Price Changes*

These multipliers calculated in equation 6 represent the price increase to final demand of sector  $j$  for a carbon tax set at \$1 per metric ton of CO<sub>2</sub>E emissions, per \$1 of output for sector  $j$ . Since the model is linear, we can multiply or divide the multiplier by the same factor of 1 at which the carbon tax will be set in order to find the total percentage price change. In other words, multiply the carbon multiplier of a given sector by the carbon tax rate to get the percentage price increase of that sector at that tax rate. The model reduces the unit cost of production of each sector to \$1 and sets the cost equal to the price which is \$1 per unit. By dividing each factor of production (Matrices Z, V, and M) by the total output (X), then sum down the column, we get a result of 1 (equation 7). This relationship shows that the nominal change in the cost of production equals the percentage change in cost of production, and is analogous to the percentage price change of final demand.

$$\text{Equation 7: } 1 = \sum_i (z_{ij}/x_j) + \sum (m_{ij}/x_j) + (v_j/x_j)$$

Can be rewritten to include the Leontief Multipliers

$$\text{Equation 8: } 1 = \sum_i (m_{ij}/x_j) + (v_j/x_j) * l_{ij}$$

If we add a cost of carbon, the price of final demand will change in proportion to the cost change since, by assumption, all the carbon related costs of production are passed on to the consumer. The carbon component can be added in much the same way as the other factors of production by dividing carbon input by total output: for variable “y” from earlier. Variable  $p_i$  indicates the new price of domestic inputs as a result of the carbon price, and  $p_j$  represents the new price of final demand

Equation 9:  $p_j = \sum_i p_i (z_{ij}/x_j) + \sum_i (m_{ij}/x_j) + (v_j/x_j) + (c_j/x_j)$   
 $p_j = \sum_i p_i a_{ij} + \sum_i (m_{ij}/x_j) + (v_j/x_j) + y_j$

The equation can then also be rearranged to incorporate the Leontief Multipliers

Equation 10:  $p_j = \sum_i (m_{ij}/x_j) + (v_j/x_j) + y_j * l_{ij}$

Finally, if we subtract equation 8 from equation 10, all the common variable are removed, and we are left with only the carbon coefficient “y” and the Leontief multipliers, which results in the price equation of just the carbon component.

Equation 11:  $p_j - 1 = \sum_i y_i l_{ij}$   
 $p_j = 1 + \sum_i y_i l_{ij}$

Since the baseline price is set at \$1, the  $1 + \sum_i y_i l_{ij}$  represents the factor by which the final demand price of sector  $j$  changes. Let us say the result of equation 11 for a given sector is 1.16. That means the cost of production for that sector would be multiplied by 1.16, or be 116% of its current level; in other words, the price would increase by 16%. The integer 1 represents the current price without carbon, while the .16 represents the price of only carbon on that \$1 worth of production without carbon. Since outputs must balance inputs and all the costs are passed on to the consumer, the price to final demand is increased by 16% as well. If the result is 2.45, the price changed by 245% or increased by 145%. This vector of price increases can then be multiplied by vectors of final demand to find the total additional expenditure for each category of final demand resulting from the carbon tax.

Equation 12:  $\sum_i y_i l_{ij} f_j$

**Table 2: Equations Summary**

<b>Number</b>	<b>Description</b>	<b>Equation</b>
<b>Equation 1</b>	Total Output	$x_i = \sum_j z_{ij} + \sum_j f_{ij}$
<b>Equation 2</b>	Purchase Coefficient	$a_{ij} = z_{ij}/x_j$
<b>Equation 3</b>	Total Output with Purchase Coefficient	$x_i = \sum_j a_{ij}x_j + \sum_j f_{ij}$
<b>Equation 4</b>	Multiplier Matrix (L)	$L = (I-A)^{-1}$
<b>Equation 5</b>	Carbon Coefficient	$y_j = c_j/x_j$
<b>Equation 6</b>	Emissions Multiplier	$\sum_i y_i l_{ij}$
<b>Equation 7</b>	Price Reduction	$1 = \sum_i (z_{ij}/x_j) + \sum_i (m_{ij}/x_j) + (v_j/x_j)$
<b>Equation 8</b>	Price Reduction with Multipliers	$1 = \sum_i (m_{ij}/x_j) + (v_j/x_j) * l_{ij}$
<b>Equation 9</b>	Price with Carbon	$p_j = \sum_i p_i a_{ij} + \sum_i (m_{ij}/x_j) + (v_j/x_j) + y_j$
<b>Equation 10</b>	Price with Multipliers and Carbon	$p_j = \sum_i (m_{ij}/x_j) + (v_j/x_j) + y_j * l_{ij}$
<b>Equation 11</b>	Price Change with Carbon	$p_j = 1 + \sum_i y_i l_{ij}$
<b>Equation 12</b>	Change in Final Demand	$\sum_i y_i l_{ij} f_j$

## RESULTS

### Prices

<b>Table 3: Large Price Changes at \$1 Tax</b>					
<b>Sector Number</b>	<b>Sector Name</b>	<b>Emissions MT CO<sub>2</sub>E c<sub>j</sub></b>	<b>Output \$ x<sub>j</sub></b>	<b>Carbon Coefficient y<sub>i</sub> = c<sub>j</sub>/x<sub>j</sub></b>	<b>Carbon Multiplier ∑<sub>i</sub>y<sub>i</sub>l<sub>ij</sub></b>
42	Electric power generation - Fossil fuel	11,512,829	689,968,875	0.01669	0.01678
146	Pulp mills	1,085,192	69,002,182	0.01573	0.01605
413	Pipeline transportation	464,582	65,936,935	0.00705	0.00716
148	Paperboard mills	2,754,515	658,201,849	0.00418	0.00444
210	Lime manufacturing	92,857	28,824,489	0.00322	0.00344
205	Cement manufacturing	354,767	115,775,993	0.00306	0.00335
138	Reconstituted wood product manufacturing	71,709	24,787,407	0.00289	0.00310
49	Electric power transmission and distribution	57,889	3,518,094,772	0.00002	0.00173
221	Alumina refining and primary aluminum production	1,407,928	1,185,695,421	0.00119	0.00152
147	Paper mills	3,755,958	3,251,200,661	0.00116	0.00144
525	Local government electric utilities	-	3,795,253,096	0.00000	0.00125
217	Iron and steel mills and ferroalloy manufacturing	128,706	120,653,992	0.00107	0.00124
519	Federal electric utilities	-	1,418,215,934	0.00000	0.00108
169	Nitrogenous fertilizer manufacturing	160,410	218,424,022	0.00073	0.00104
203	Glass container manufacturing	80,742	125,786,355	0.00064	0.00088
201	Flat glass manufacturing	115,378	175,003,311	0.00066	0.00085
140	Cut stock, resawing lumber, and planing	84,591	134,397,675	0.00063	0.00084
134	Sawmills	1,114,105	1,925,962,283	0.00058	0.00083
145	All other miscellaneous wood product manufacturing	52,738	85,511,124	0.00062	0.00082
231	Iron and steel forging	16,441	24,434,878	0.00067	0.00080

Table 3 shows the twenty sectors with the largest percentage price change given by the carbon multiplier column. For sector 42, Electric power generation - Fossil fuel, the carbon multiplier is 0.0167 which is roughly a 1.67% price increase. This percentage represents the increase for each \$1 tax per metric ton of CO<sub>2</sub>E emitted directly by that sector and indirectly by the intermediate inputs to that sector. The 1.67% for sector 42 is the price increase for a \$1 tax on the 11,512,829 metric tons of CO<sub>2</sub>E directly emitted by sector 42 and the proportion of emissions on the inputs to sector 42 from all the other sectors. Applying the results to different tax schemes is simple since the IO mechanics scale linearly. If Washington State is faced with a

\$10 carbon tax, then that 1.67% price increase would become 16.7%. See Appendix A for a full list of multipliers.

Sectors 525 and 519, Local government electric utilities and Federal electric utilities respectively, show no direct emissions, yet are on this list of sectors with the highest expected price changes. These two sectors are a good example of how the structure of the inputs to a sector's production can impact the outputs. Although these two sectors would not be subject to a carbon tax strictly according to the GHGRP data, the price of their outputs would increase due to the price increases of their inputs resulting from that carbon tax. Alternatively, the reporting requirements for these two sectors may fall outside the jurisdiction of the GHGRP and emissions are not represented.

One interesting thing to note about sector 156, Petroleum Refineries, is that it appears on Table 1, top total emitters, but is absent on Table 3, largest price changes; and is due to the structure of Washington State's economy. Nominally, sector 156 emits a lot, but due to the relatively low ratio of output to emissions (the emissions coefficient from Table 1). The total output for sector 156 is \$20,131,474,733.30 with recorded emissions of 13,597,006 CO<sub>2</sub>E; resulting in a coefficient of 0.00067 and the 23<sup>rd</sup> highest price change. Sector 42, Electric Power Generation – Fossil Fuel, has the highest price change. It shows an emissions coefficient of 0.0166 with an output of \$11,512,829.00 and emissions of 689,968,874.75 CO<sub>2</sub>E. The same is true for sectors 395 and 471: Wholesale Trade and Waste Management and Remediation Services respectively.

Conversely, Sector 210, Lime Manufacturing, appears on Table 3 and not Table 1 showing that sectors may appear to have relatively high price changes and relatively low direct emissions due the carbon intensity of the intermediate goods and services used to create the final product of that sector. This disparity may also stem from the value of output being very high or very low relative to carbon use and not just the carbon value of inputs.

Consumption

<b>Table 4: Total Consumption and Total Consumption Changes (In Millions) at \$1 Tax</b>				
<b>Income Group</b>	<b>Total Consumption</b>	<b>Total Consumption After Tax</b>	<b>Total Difference</b>	<b>Total Nominal Difference</b>
<b>&lt;10k</b>	4,903.59	4,904.58	0.9954	995,387.67
<b>10-15k</b>	3,224.94	3,225.58	0.6486	648,554.06
<b>15-25k</b>	9,942.87	9,944.90	2.0258	2,025,830.24
<b>25-35k</b>	12,182.84	12,185.30	2.4619	2,461,919.12
<b>35-50k</b>	18,750.41	18,754.14	3.7256	3,725,608.28
<b>50-75k</b>	32,582.14	32,588.48	6.3398	6,339,751.79
<b>75-100k</b>	28,665.38	28,670.87	5.4893	5,489,269.13
<b>100-150k</b>	41,281.39	41,289.25	7.8644	7,864,420.90
<b>150k+</b>	41,360.96	41,368.70	7.7447	7,744,732.29

IMPLAN disaggregates consumption into nine income group. Table 4 shows the total original consumption, total after tax consumption, and the total difference. The difference represents the additional expenditure required to maintain the same consumption for each income group. It is the difference column which is of greatest interest. You will notice that between some progressing groups the total consumption actually decreases; between <10k and 10-15k for example. That is due to their simply being fewer households in that income group. Although it is counterintuitive to see a richer group spend less, it is important to remember that this table is total expenditure not average household expenditure.

The sectors in Table 3 illustrate how prices will change as a result of a cost push on emissions. They do not, however, necessarily relate to the impacts on consumption. Many of the sectors in Table 3 show little household consumption, and are more intermediate industrial goods sectors. Table 5 shows the sectors which are most consumed by households. When comparing the consumption of the different income group, it is clear they do consume the products of different sectors at different rates. The majority of the top sectors consumed by all income groups, however, are the same.

**Table 5: Largest Household Consumption Sectors for the <10K Income Group at \$1 Tax**

Sector Number	Sector Name	Total \$ Change	Price Change
440	Real estate	83,613	0.0129%
441	Owner-occupied dwellings	65,378	0.0107%
395	Wholesale trade	201,191	0.0743%
482	Hospitals	29,013	0.0119%
475	Offices of physicians	17,293	0.0108%
400	Retail - Food and beverage stores	15,424	0.0138%
156	Petroleum refineries	80,441	0.0741%
502	Limited-service restaurants	13,367	0.0125%
405	Retail - General merchandise stores	12,951	0.0123%
501	Full-service restaurants	13,114	0.0126%
526	Other local government enterprises	13,681	0.0131%
433	Monetary authorities and depository credit intermediation	8,344	0.0096%
396	Retail - Motor vehicle and parts dealers	9,332	0.0117%
503	All other food and drinking places	10,034	0.0126%
428	Wireless telecommunications carriers (except satellite)	7,373	0.0093%
483	Nursing and community care facilities	9,042	0.0128%
399	Retail - Building material and garden equipment and supplies stores	8,169	0.0126%
485	Individual and family services	7,233	0.0115%
504	Automotive repair and maintenance, except car washes	6,705	0.0107%
427	Wired telecommunications carriers	5,295	0.0085%

Despite this disparity between the price change sectors and the household consumption sectors, it is important to reiterate the assumption that all cost increases will be passed on to the final consumer. Although the price of the final product of the most consumed sectors may not increase proportionally as much as the industrial sectors, the price increase (or part thereof) of the industrial sectors is a component of the consumer sectors due to the emissions cost as an intermediate good; all accounted for in the Leontief multipliers at the core of the model.

It is important to note here that although the price change and carbon multipliers are the same value, Table 3 shows the carbon multiplier as a nominal value while Table 5 shows the price change as a percent. Sector 440, Real Estate, from Table 5 shows a price change of 0.0129%. This price change equates to a carbon multiplier of 0.000129. Also keep in mind that these price change values are for each dollar of tax per metric ton. So this first order result is for if the tax is set at \$1. Although these are the most consumed sectors, they are not necessarily the

ones in which the higher total cost increase will be realized. Table 6 shows the sectors that are the most expensive for the <10k income group.

<b>Table 6: Most expensive sectors for &lt;10K Income Group at \$1 Tax</b>			
<b>Sector Number</b>	<b>Sector Name</b>	<b>Total \$ Change</b>	<b>Price Change</b>
395	Wholesale trade	201,191	0.074%
49	Electric power transmission and distribution	92,864	0.173%
440	Real estate	83,613	0.013%
156	Petroleum refineries	80,441	0.074%
441	Owner-occupied dwellings	65,378	0.011%
525	Local government electric utilities	52,505	0.125%
482	Hospitals	29,013	0.012%
475	Offices of physicians	17,293	0.011%
400	Retail - Food and beverage stores	15,424	0.014%
526	Other local government enterprises	13,681	0.013%
502	Limited-service restaurants	13,367	0.013%
501	Full-service restaurants	13,114	0.013%
405	Retail - General merchandise stores	12,951	0.012%
473	Junior colleges, colleges, universities, and professional schools	12,255	0.024%
503	All other food and drinking places	10,034	0.013%
402	Retail - Gasoline stores	9,541	0.041%
396	Retail - Motor vehicle and parts dealers	9,332	0.012%
408	Air transportation	9,086	0.022%
483	Nursing and community care facilities	9,042	0.013%
433	Monetary authorities and depository credit intermediation	8,344	0.010%

Sectors do appear on both tables, but many of them do not. Comparing these two table illustrates the relationship between price change magnitude and consumption magnitude. The sector with the largest price increase many not necessarily provide the largest expenditure increase. Similarly, the sector with the highest consumption may not provide the largest consumption increase. Sectors 395 and 49 which account for the highest expenditure increases, are not presents in Table 5.

## DISCUSSION

### Households

The results examples were given only for the <10k income group. The next phase is to explore these price changes to the consumption bundles of all different income groups. Grainger and Kolstad (2010) and other studies often limit the household impact analysis to a set list of consumer product. Since IMPLAN provides data for every sector, I have used all 536 sectors for this analysis. In order to avoid showing a table with 536 rows, the displayed results will be visually truncated, but based on a full analysis.

Income Group	Percent Change
<10k	0.0203%
10-15k	0.0201%
15-25k	0.0204%
25-35k	0.0202%
35-50k	0.0199%
50-75k	0.0195%
75-100k	0.0191%
100-150k	0.0191%
150k+	0.0187%

Table 7 shows the total percentage of expenditure change per income group. There is a difference of .16 basis points between the lowest income group and the highest; with the lowest group spending more proportionally at a .0203% increase versus a .0187% increase for the highest group.

As discussed earlier, fossil fuel electricity generation is a very large driver of emissions allocation. So while the US nationally produces only about 6% of its electricity with hydro, Washington State produces roughly 61%. This large disparity will allocate proportionally less carbon to electricity generation in Washington than the US as a whole.

Type	Proportion	<10k	10-15k	15-25k	25-35k	35-50k	50-75k	75-100k	100-150k	150k+
Fossil Fuel	0.205	10.99	8.53	21.51	24.62	37.69	57.27	44.72	54.68	44.95
Hydro	0.6172	33.09	25.68	64.77	74.13	113.49	172.44	134.63	164.64	135.33
Nuclear	0.0887	4.75	3.69	9.31	10.65	16.31	24.78	19.35	23.66	19.45
Other	0.0891	4.78	3.71	9.35	10.70	16.38	24.89	19.44	23.77	19.54
Distribution	1	53.61	41.61	104.94	120.11	183.87	279.39	218.13	266.75	219.26

To illustrate this point, Table 8 shows the final consumption of electricity across income groups for Washington in 2013. IMPLAN does not show direct consumption of electricity by households: rather it shows an aggregated consumption amount through sector 49, Electrical Power Transmission and Distribution. In order to disaggregate this value, I used the percentage of each type generated in Washington State from the Energy Information Administration. Since

the IMPLAN data is in dollar value consumed and not units consumed, the retail price of electricity generated from different sources is assumed to be similar. The key is that they will change significantly after a carbon tax is instituted, with the fossil fuel derived electricity increasing substantially in price. Going back to Table 3, we saw the largest price increase was for fossil fuel derived electricity at 1.6% per tax dollar per ton. So although fossil fuel derived electricity shows the largest price increase, it only accounts for about 20% of the total electricity spending, while the other 80% is not subject to an emissions tax.

<b>Sector Number</b>	<b>Sector Name</b>	<b>Price Increase</b>
41	Electric power generation - Hydroelectric	0.013359%
42	Electric power generation - Fossil fuel	1.678454%
43	Electric power generation - Nuclear	0.000000%
44	Electric power generation - Solar	0.011268%
45	Electric power generation - Wind	0.011552%
46	Electric power generation - Geothermal	0.000000%
47	Electric power generation - Biomass	0.013381%
48	Electric power generation - All other	0.013259%
49	Electric power transmission and distribution	0.173236%

Since it is only the fossil fuel derived electricity that is subject to a carbon tax, when exploring the relationship of electricity to income, it is reasonable to look at the impacts of electricity price increases as it relates only to fossil fuel. Although, the other forms of power generation would, presumably, not be subject to an emissions tax directly, there are some indirect effects accounted for in the multiplier which produces small price increases. Table 9 shows these different. It is clear that the fossil fuel shows the largest price increase by a wide margin. Note that Sector 49 is an aggregate of sectors 41-48 plus additional intermediate carbon unrelated to sectors 41-48, but related to the distribution component.

There is a small discrepancy that is important to note here. IMPLAN shows zero production of nuclear power in Washington State while the Energy Information Administration show roughly 8.8% is generated from nuclear. Currently, Washington does have one fully operational Nuclear Power Plant (US EIA 2015). IMPLAN may lump this nuclear power facility into a government enterprise sector, since the nuclear power facility in Washington is a joint venture with the federal government.

Averaged across the entire state, the price change differences between electricity sources do not mean much, but if the spatial resolution of analysis is reduced, impacts between regions that draw power predominately from different sources will show different consumption impacts. The exact electricity source type consumption profile of individual counties in Washington State is not available, but we can intuitively conclude that a county that relies more heavily on fossil fuel derived electricity will realize a greater electricity price increase than a county that relies more on hydro and other renewable.

The price changes are constant across income groups, when averaged for the entire state, so all expenditure changes relative to original expenditure will be equally higher by the same proportion across each sector for all income groups. There are proportional changes in the sums of the entire consumption bundle across income groups since the consumption bundles are different, but these consumption expenditure changes do not mean much when compared to original expenditure regarding the affordability of the tax for the different income group.

The expenditure increase must instead be compared to the average income of each income group. The average is used since the income groups are designed as ranges. Once again, IMPLAN provides this data. Reducing the data to the household level is done by dividing each cell in Table 4 and the total income for each income group by the number of households in the respective income group.

<b>Table 10: Expenditure Change per Household at \$1 Tax Level Relative to Income.</b>			
<b>Income Group</b>	<b>Mean Income</b>	<b>Mean Additional Expenditure</b>	<b>Percent of Income</b>
<b>&lt;10k</b>	5,849.00	5.60	0.096%
<b>10-15k</b>	15,683.00	5.29	0.034%
<b>15-25k</b>	23,686.00	7.48	0.032%
<b>25-35k</b>	31,487.00	9.11	0.029%
<b>35-50k</b>	39,810.00	9.87	0.025%
<b>50-75k</b>	55,379.00	11.95	0.022%
<b>75-100k</b>	77,076.00	14.98	0.019%
<b>100-150k</b>	100,098.00	21.19	0.021%
<b>150k+</b>	179,408.00	33.42	0.019%

The <10k income group realizes a cost change that is nominally 6 times larger and proportionally 5.5 times greater than the 150k+ group. These first order impacts prove to be

regressive since the lower income groups must spend more relative to income to compensate for the carbon related price increases.

If the consumption bundles of every income group are identical, the consumption expenditure, relative to income, would also increase at identical proportions. The differences in consumption bundles causes the expenditure changes to differ across the groups. As Beck et al. (2015) point out, consumption related directly or indirectly to fossil fuels produce the largest impact on expenditure, particularly automobile fuel and electricity or heating fuels, and that lower income groups, relative to income, spend proportionally more on fuels and electricity than higher income groups. Table 11 shows proportion of fossil fuel spending relative to income.

<b>Income Group</b>	<b>Electricity</b>	<b>Natural Gas</b>	<b>Gasoline</b>	<b>Total</b>
<b>&lt;10k</b>	5.15%	0.82%	2.23%	8.20%
<b>10-15k</b>	2.17%	0.36%	0.64%	3.17%
<b>15-25k</b>	1.64%	0.28%	0.77%	2.68%
<b>25-35k</b>	1.41%	0.25%	0.70%	2.36%
<b>35-50k</b>	1.22%	0.23%	0.53%	1.99%
<b>50-75k</b>	0.95%	0.18%	0.46%	1.59%
<b>75-100k</b>	0.77%	0.16%	0.42%	1.35%
<b>100-150k</b>	0.72%	0.16%	0.52%	1.40%
<b>150k+</b>	0.53%	0.13%	0.49%	1.15%

The lowest income group spends nearly 10 times more proportionally on electricity than the highest income group, and more than double that of the second lowest. Natural Gas and Gasoline spending follows a similar structure with the lowest income group spending considerably more proportionally than the higher ones. Although higher income group may consume nominally more energy than lower income groups, the lower income groups will be disproportionately impacted by a carbon tax due to the higher proportion of energy in their consumption bundles relative to income. Looking at the second lowest, the 10-15k group, however, shows that the fossil fuel usage of different income groups is relatively flat. The 10-15k group is only double that of the median income (50-75k group) and less than triple that of the highest income group. The relatively flat disparity in fossil fuel usage across income groups suggests a carbon tax that would be only mildly regressive.

These results for Washington State can be compared to those of Grainger and Kolstad (2010) for the whole US. It is important to note that the data used by Grainger and Kolstad is from 2003. Grainger and Kolstad used 5 income group, whereas this study used nine. The groups can still be compared across a more general range; lining up the lowest with the lowest and highest with highest, and manually assessing the relationships between the middle groups. Two important things to note are that the results for the US were changed to reflect a \$25 per ton carbon tax (for the sake of ease of being consistent with the rest of this analysis), and the <10k income group was dropped since Grainger and Kolstad omitted the <10k group from their analysis.

<b>Table 12: Total expenditure increase to income comparison at \$25 Tax Level</b>			
	<u>Lowest</u>	<u>Middle</u>	<u>Highest</u>
<b>USA % per HH</b>	6.31%	3.82%	2.12%
<b>USA per HH</b>	\$686.75	\$1,298.00	\$2,349.00
<b>WA State % per HH</b>	0.84%	0.54%	0.47%
<b>WA State per HH</b>	\$132.36	\$298.79	\$835.61

Table 12 show that proportionally, the results differ significantly with the USA showing a relative expenditure increase roughly 5 times for the lowest group, nearly 4.5 times for the middle group, and 2.8 times for the highest group. The key, once again, is how the consumption bundle of each income group differs between Washington State and the US as a whole. Most importantly, the comparison of fossil fuel consumption between the average Washington household and the average US household for each income group.

Nominally, the Washington State numbers are also significantly lower: ranging from \$132, for the lowest group, to \$835 for the highest. The US shows \$686 for the lowest and \$2,349 for the highest. Washington State shows relative expenditure increase of six to one, while the US shows roughly three-and-a-half to one. In other words, for every \$1 cost increase for lowest group, there is a \$6 and \$3.5 cost increase for the richest group in Washington State and the US respectively. This ratio also supports that a Washington State tax is less regressive than a US national tax since the higher income groups spend more on carbon relative to the lower income groups.

Since the income groups do not line up perfectly between the two analyses, some margin of error exists in the data comparison. For example, the mean income for the highest group in

Grainer and Kolstad’s study is \$110,878 while the mean income for the highest group in the Washington State data is \$179,408.

When comparing the same tax regime in the different jurisdictions, it is clear that although the Washington Carbon tax is regressive, it is regressive to a much lower degree than the same regime applied to the entire US. We have already seen how Washington generates ten times more of its electricity using hydro than the US. Table 13 shows that the US as a whole generates more than thrice the quantity of electricity using fossil fuels than does Washington State, which plays a key role in why US average households will pay more for their

**Table 13: US and WA State Electricity Generation by Source**

Type	USA	WA State
Fossil Fuel	67%	21%
Hydro	6%	62%
Nuclear	20%	9%
Other	7%	8%

consumption: it is more carbon intensive. Since households disproportionately consumes more carbon through lower income group, relative to higher income groups, and that Washington produces proportionally less carbon, relative to the US on a commodity

responsible for the majority of emissions, and we can argue that electricity plays an important role in reduced regressive impacts when comparing a Washington State carbon tax to a United States carbon tax.

*Washington Policy*

We can also look at the impacts if Washington follows in the footsteps of BC, Canada and enacts an emissions tax program at \$25 per ton of CO<sub>2</sub>E, as is currently being proposed. Table 14 shows the summary results at \$25 per ton. Since the model is linear, the cost increases are scaled at 25 times those for the initial \$1 tax level cost increases. What does not change, however, are the household income averages for the different groups, so the percentage of income the cost increases represents has also increased 25 times. Each household making less than \$10,000 per year, will increase spending by \$139.93 in order to maintain the same level of unit consumption.

**Table 14: Expenditure Change per Household at \$25 Tax Level Relative to Income.**

Income Group	Mean Income	Additional Expenditure (\$/year)	Percent of Income
<10k	5,849.00	139.93	2.3924%
10-15k	15,683.00	132.36	0.8440%
15-25k	23,686.00	186.93	0.7892%
25-35k	31,487.00	227.82	0.7235%
35-50k	39,810.00	246.68	0.6196%
50-75k	55,379.00	298.79	0.5395%
75-100k	77,076.00	374.5	0.4859%
100-150k	100,098.00	529.79	0.5293%
150k+	179,408.00	835.61	0.4658%

The consumptions bundles of these income groups can be disaggregated to explore the different consumption patterns of different income groups and the carbon related cost increased associated with those patterns. These breakdowns can be viewed in two ways. First, we can look at how the emissions tax will impact the sectors most consumed by each group. Second, we can look at the sectors most responsible for the consumption cost increases. This comparison was briefly done in the prior section with Tables 5 and 6, but here they will be expanded to include all income groups at a \$25 tax level.

**Table 15: Top 20 Most Consumed and Contributing Sectors**

Income Group	Pre-Tax		Most Contributing		Post-Tax	
	Value	%	Value	%	Value	%
<10k	86.74	61.99%	106.62	76.20%	86.74	61.99%
10-15k	80.59	60.89%	102.08	77.12%	80.59	60.89%
15-25k	118.92	63.62%	143	76.50%	118.92	63.62%
25-35k	146.02	64.09%	173.29	76.06%	146.02	64.09%
35-50k	157.2	63.73%	186.82	75.73%	157.2	63.73%
50-75k	192.53	64.44%	224.11	75.01%	192.53	64.44%
75-100k	243.46	65.01%	278.31	74.32%	243.46	65.01%
100-150k	344.54	65.03%	386.73	73.00%	344.54	65.03%
150k+	538.33	64.42%	598.07	71.57%	538.33	64.42%

Table 15 shows the top 20 sectors aggregated for each income group for both the most consumed and most contributing categories. The most pre-tax category represents the carbon tax increase to the 20 sectors with the highest dollar value of consumption before the implementation of a carbon tax. The post-tax category represents the carbon tax increase to the 20 sectors with the highest level of dollar value consumption after the implementation of the carbon tax. The

most contributing category represents the carbon tax increase to the 20 sectors with the highest increase. Each category is broken down into nominal value per household and percent of total additional consumption.

The ranking of sector consumption remains unchanged before and after the tax. Although the carbon tax did cause cost increases at different rates to each of the top 20 consumed sectors, the tax did not impact individual sectors enough to create a new ranked consumption order. It is clear that the most contributing sectors, however, do not entirely match the most consumed sectors. Across the income groups, these top 20 sectors ranges from 60%-65% of total cost increase for the pre and post-tax groups, and 71%-76% for the most contributing groups. These comparisons show that the cost difference between the sectors most consumed and the sectors with the largest nominal cost increase is roughly 10% across the board.

In other words, a sector with high consumption, but low carbon cost, will not as greatly impact households as a sector with low consumption but high carbon cost (this of course is assuming no substitution). A good example is with sector 504, Automotive Repair and Maintenance Except Car Washes. It is one of the most consumed sectors overall, placing at 19 on the top 20 list of most consumed. Sector 504 does, however, fall to 27 on the list of top price increase contributors. Not a very far fall, but a fall far enough to illustrate how a sector responsible for a large portion of total consumption is responsible for a small portion of the carbon consumption.

Conversely, sector 473, Junior Colleges, Colleges, Universities, and Professional Schools, moved from 27 on the list of most consumed, to 14 on the list of highest price increase contributors. Although not emitting directly here in great quantity, the emissions of the inputs are high enough (most likely due to the electricity use by the facilities), to cause households to disproportionately spend more on education than other sectors of which they would normally consume more.

What it all comes down to is affordability: balancing the needs to regulate pollution with households' cost of living. One good or service, though consumed in great quantity, may not increase much in price and therefore not contribute much to the cost increase, while another may be consumed much less but prove to contribute much more to the carbon cost of consumption. The two commodities may swap financial priority (in the real world where substitution does occur) in a consumption bundle, particularly at the lower income groups where resources are

more limited. Although deep analysis of these sectoral reorganizations and relationships resulting from a carbon may not prove to be very enlightening, cursory analysis shows how the impacts of a tax may alter the consumption decisions of households. For example, choosing to spend the extra dollars on fixing the car to get to work over taking night classes, instead of being able to afford both.

### *Recycling*

The regressive tendencies of carbon taxation can be counteracted with the use of revenue recycling programs (Parry et al 2005), and are often built directly into the carbon policy. The general idea of revenue recycling is instead of using the carbon taxation revenue to expand government, it is to plough the revenue back into the existing economy to produce economic gains (Parry 1997). There are a number of different kinds of plough-backs discussed in the literature which can take the form of direct consumer rebates, consumer tax breaks, increasing spending on government programs that aid lower income groups, corporate tax breaks, and government debt reductions; often times a single policy will comprise a combination of these recycling strategies. (Grainger and Kolstand 2010, Parry 1997, Keseljevic and Koman 2015).

For this study, the focus is put on rebates and sales tax reductions; income tax reductions are more commonly used in the literature, but are not applicable since there is no income tax in Washington State. The purpose is to analyze the impacts of a recycling program on households.

A regressive policy, as we have defined it, is one that negatively impacts lower income groups, relative to income, more than higher income groups. That definition can be applied to a neutral or progressive policy for the purpose of analyzing recycling strategies. Specifically, how much of a rebate or tax break is required to equalize the carbon spending, as a proportion of income, of all income groups to that of the highest income group. The highest income group spends \$835.61 or .4658% of income on carbon. How many revenue recycling dollars does each other income group require to only spend .4658% of their income on carbon?

**Table 16: Rebate Comparisons**

Income Group	Increase	Rebate per HH by %	Difference
<10k	139.93	112.69	(27.24)
10-15k	132.36	59.31	(73.05)
15-25k	186.93	76.61	(110.32)
25-35k	227.82	81.17	(146.65)
35-50k	246.68	61.26	(185.42)
50-75k	298.79	40.86	(257.93)
75-100k	374.50	15.51	(358.99)
100-150k	529.79	63.57	(466.22)
150k+	835.61	-	(835.61)

Table 16 shows the per household rebate value for each income group. The 150k+ income group will not receive any rebate since it is the benchmark against which the rebates for the other groups are calculated. It is important to

observe how when equalizing the percentage, although every income groups (except the largest) receives some money back, they do all, on net, still pay for the carbon. The per household rebate is not strictly inversely proportional to income, but what is important, however, is the difference column that shows that higher income groups are still spending, on net, more for carbon.

Multiplying the results in Table 16 by the number of households horizontally and summing vertically, will yield the total recycling requirements for each income group.

**Table 17: Total Rebate per Income Group (\$)**

Income Group	Total Rebate per Income Group (\$/year)
<10k	20,040,046.14
10-15k	7,265,876.18
15-25k	20,755,981.41
25-35k	21,927,928.18
35-50k	23,130,690.28
50-75k	21,672,685.22
75-100k	5,683,882.03
100-150k	23,592,774.20
150k+	-
<b>Total Rebate</b>	<b>144,069,863.63</b>
<b>Revenue</b>	<b>1,535,240,725</b>
<b>Difference</b>	<b>\$1,391,170,861.37</b>

The next step is to assess the affordability of the recycling program. Multiplying the total carbon emissions by the carbon tax rate yields a gross tax revenue. Total Washington State carbon emissions of 61,409,629 tons CO<sub>2</sub>E multiplied by \$25 per ton tax yields \$1,535,240,725 of gross carbon tax revenue, and a pool of funds from which recycling dollars are drawn. Table 17 shows the breakdown of total rebate per

income group and revenue collected.

It is often the case that tax rebate benefits will max out at certain income levels as it seems unreasonable to provide rebates to households of a certain wealth. The median income for Washington State is \$57,000, which can be used as a guideline. If rebates are to be given directly to only the lowest 5 income groups, the \$144,069,863.63, from Table 17, would be distributed

inversely proportional to income; the lower the income, the higher the rebate, terminating at an income of somewhere between 35k and 50k per year. Again, the \$144,069,863.63 is based on equalizing the percentage of income spent on carbon to that of the highest income group. Since the total for all income groups is being distributed to only the 5 lowest, each will receive significantly more than is listed in Table 16. In some cases, even realizing a net positive.

The rates at which each of those income groups receives additional rebate is mutable. Which income groups are included is also mutable. I picked the 5 lowest for the sake of argument, but the specific legislation can be sculpted to include any composition. The important point is that the fewer number of households receiving rebate, the more each household will receive since the total rebate value remains unchanged.

The composition of a recycling program is often motivated by the political palatability of the plan components. For example, society may desire tax cuts over rebates. If that is the case, Washington may allocate more money towards tax cuts and much less towards direct rebates. Alternatively, if Washington State has greater affinity for rebates, a much larger portion of the funds will go towards rebates instead of tax cuts. For the sake of argument, we can look at a recycling program that comprises a combination of rebates and tax cuts.

The remaining \$1,391,170,861.37 in revenue can then potentially be used to fund tax cuts. Since Washington State does not have a personal income tax, a good alternative would be to institute reductions to the state sales tax, currently set at 6.5% (Washington State Department of Revenue 2016), with state sales tax receipts totaling \$7,704,626,558 (Washington State Department of Revenue, 2013). The per 1% sales tax receipts equals \$1,185,327,162.81.

The sales tax receipts for Washington State broken down by income group is not available, so an in-depth analysis was not performed. Sales taxes, however, are commonly viewed as being highly regressive (Davis et al, 2015), so reducing the sales tax will diminish the regressive tendencies of the sales tax. Sales taxes are a linear function of direct consumption, but since there are sales tax exceptions or rate differences to which certain goods and services are subject, it is the composition, as opposed to the total value, of the household consumption bundle that determines how much sales tax is paid.

A one percentage basis point reduction in the state sales tax from 6.5 to 5.5 would result in a total consumer savings of \$1,185,327,162.81. Table 18 shows a summary of the rebates and tax reductions. There is a remainder of roughly \$205 million. The remainder corroborates the

conclusions of Callen et al (2008) that suggest 100% of the revenue does not need to be recycled in order to make the carbon tax neutral or progressive, since the \$144million rebate already neutralized the regressive tendencies of the tax, and the sales tax reductions gave additional dollars back to households. This remainder can be used to further increase the rebates, increase the sales tax cuts, reduce other taxes, fund social programs, or be put towards other programs.

<b>Table 18: Recycling Plan (\$)</b>	
<b>Total Receipts</b>	1,535,240,725
<b>Rebates</b>	144,069,932.00
<b>Sales Tax Reduction</b>	1,185,327,162.81
<b>Remainder</b>	205,843,630.19
<b>Total Recycling</b>	1,535,240,725

The rates at which rebates are given and taxes are reduced are highly mutable. The key is for the offsets to never exceed the carbon tax receipts. The rebates and sales tax reduction are

popular uses for the revenue since they put money directly into the pockets of consumers; the rebates designed to specifically target low income households, and the sales tax reduction implemented to assist all consumers.

### *Carbon Washington*

Rebates and sales tax decreases are components of a carbon tax and recycling plan created and promoted by the Carbon Washington (CW) Initiative (Carbon Washington 2016).

The Carbon Washington plan also proposes additional cuts to the Business and Occupancy

<b>Table 19: Carbon Washington Recycling Plan (\$)</b>	
<b>Total Receipts</b>	1,700,000,000
<b>Rebates</b>	200,000,000
<b>B&amp;O Tax Reduction</b>	200,000,000
<b>Sales Tax Reduction</b>	1,300,000,000
<b>Total Recycling</b>	1,700,000,000

(B&O) tax on top of rebates and sales tax cuts. Table 19 shows the breakdown of the Carbon Washington recycling plan. In total, CW estimates

roughly \$1.7 billion in receipts (Carbon Washington 2016) and recycling; about \$200 million more than our model calculated. The difference ultimately stemming from a difference in quantity of emissions being tax (CW also uses a \$25 per ton tax). This model estimated 61.4 million tons, while CW estimated 83 million tons (Carbon Washington 2016). This \$1.7 billion in recycling comprises a 1 percentage point reduction in state sales tax, partial funding of the Working Families Rebate, and a partial elimination of the Business and Occupancy (B&O) tax for manufacturers. This combination assists firms impacted by the carbon tax by reducing other taxes to which they are subjected, puts money directly in the pockets of households, and reduces

the purchase price of good and services through sales tax cuts. The results of our model are similar to those of CW.

If we were to include a B&O tax reduction to our model, it would require offsets to other recycling components. Comparing revenues on the whole, the total B&O receipts for Washington are approximately \$3.2 billion while the carbon tax receipts only total \$1.5 billion. A total elimination of the B&O tax would produce a net negative \$1.7 billion to the tax receipts. The literature proposes (as well as CW) that most if not all emissions taxes focus solely on manufacturing, utilities, and fuels usage, so if these three categories are isolated, the resulting carbon tax revenue is \$1,523,435,275 (99% of the total emissions tax revenue of \$1,535,240,725). These three sectors, however, only comprise \$441,315,574 worth of the total \$3.2 billion B&O Tax. The sectors comprising nearly 99% of emissions tax revenue pays only

<b>Table 20: Recycling Plan (\$)</b>	
<b>Total Receipts</b>	1,523,435,275
<b>Rebates</b>	144,069,932.00
<b>Sales Tax Reduction</b>	1,185,327,162.81
<b>B&amp;O Tax Reduction</b>	194,038,180.19
<b>Total Recycling</b>	1,523,435,275

13.7% of total B&O tax receipts. If the B&O tax was eliminated for these sectors in exchange for a carbon tax, the sectors would still pay a net positive \$1,093,925,151 in taxes. If the remaining

revenue is used to fund a B&O tax reduction, it would reduce the B&O tax bill of manufacturing and utilities sectors to \$247,277,393.81 or roughly a 43% reduction.

One of the main purposes of an emissions tax is to punish firms that pollute, so it seems strange to return tax revenue back to polluting firms to reduce those punitive effects. Those funds can alternatively be use used to fund additional rebates, or potentially even cut the B&O tax to non-polluting firms, as the form a reward for not polluting. Supporting non-polluting firms through tax breaks can create a competitive advantage for those firms in Washington State: eventually shifting the economic structure of the state to one that pollutes significantly less. The short run is incentivizing firms to pollute less, while the long run is shifting the structure of the economy to one comprising non-polluting sectors.

CW estimates an average of \$500 rebate per applicable household with \$200 million in total being distributed: maxing out at \$1,500 each. Comparing the CW numbers to our model, shows how the structure of the rebate program can drastically change the benefits to which households. The four lowest household groups in our model comprises roughly 841,000 households, while the CW model proposes rebates for only 400,000 (CW does not specify along

what criteria they chose 400,000 households, except by referencing the Working Families Rebate). \$144 million divided among 841,000 households yields an average rebate of roughly \$171 per household. If the B&O tax portion of our model was allocated to rebates, the new calculation would be \$338 million divided among 841,000 households, yielding roughly a \$400 rebate per household.

A key component of the Carbon Washington proposal, as well as many from the literature, is that the carbon tax rate increases over time. As firms innovate and reduce their carbon output, tax revenues will decrease. Increasing the tax rate helps make up for the lost tax revenue but also helps to continue to incentivize firms to reduce emissions. A firm may hit a certain level of emissions that is comfortable to their financial situation, continual changes to the tax rate throws that financial complacency into flux and forces firms to further reduce emissions or absorb higher costs. Using this model to explore future impacts of a carbon tax, as the rates under a tax program increase, is irresponsible since IO models capture only a single period of time. It is expected that future economies would be structured differently so using today's model to gauge impacts 5,10, or 30 years and beyond is not possible.

### *Other Recycling*

There are many other revenue recycling options not yet discussed. Alternative to tax cuts, the revenue can be used for purposes such as to fund programs and services utilized by lower income groups, thereby providing additional non-monetary gains to society. The fundamental purpose of a carbon tax is to help mitigate damage done to the environment by harmful gasses produced by our economy. The results being twofold: protect the environment and better society. Reducing harmful pollution as a means to achieve some level of environmental protection is a clear and straightforward goal, but less so with the betterment of society; which can be defined in many different ways.

Bettering society could mean improving individual health by reducing harmful gasses in the air, providing social programs, transportation, infrastructure projects, public parks, and many more. For example, the King County Parks department, in Washington, are mainly funded through a direct property levy, as opposed to the general King County budget. This property levy can be reduced in exchange for a budget appropriation from the state department of revenue. The King County Parks levy brought in roughly \$66 million in 2014 (King County Parks 2015).

With a population of 7.061 million (US Census Quick Facts), the total \$1.5 billion in carbon revenue represents a per capita allocation of \$215. King County, as the most populous county in Washington State at 1.98 million, would receive \$426 million. The \$66 million parks levy represents only 15% of the total county allotment and would save households \$18.77 per hundred thousand of home value. With the average home value in King County roughly \$455,000 (Zillow.com), replacing the levy with carbon revenue would save King County homeowners an average of \$84.40 per year. The remaining \$360 million could increase the full King County Metro budget by roughly 25% (King County Budget 2015-2016) to strengthen and expand public transit service around the county or reduce current fares.

The annual fare collections of King County Metro for each of last few years is roughly \$150 million (Transit Fare Rev - Cumulative. Rep: Financial 2015): which is only 35% of the King County allotment. In other words, for only one third of King County’s carbon revenue allotment, public transit service can be provided free of fares or at significantly reduced fares. The increase in public transit use would potentially decrease the use of personal vehicles, and reduce the total emissions produced by personal vehicles. Table 21 shows the savings, relative to income, households would realize if King County Metro fares would eliminated. Fare expenses were estimated by taking the current fare of \$2.75 twice a day on 21 commuting days per month. This number is a very rough estimate due to peak time pricing and other considerations, but it serves as a good guideline. Those in the 10k-15k income group who commute, may save nearly a 10% of their income just on bus fares.

**Table 21: KCM Commuting Cost**

Income Group	KCM % of Income
<10k	23.70%
10-15k	8.84%
15-25k	5.85%
25-35k	4.40%
35-50k	3.48%
50-75k	2.50%
75-100k	1.80%
100-150k	1.38%
150k+	0.77%

In 2015, the Washington State Supreme Court determined the state had illegally shirked its duty to properly fund public schools (O'Sullivan and Brunner 2015). Although the court decision did not specify how much money the legislature would have to provide (they ended up finding an additional \$1.3 billion, while the plaintiffs suggested no less than \$5 billion), some or all of the funds could be appropriated to partially fill this mandated school funding increase.

These are just several examples of ways the carbon revenue can be used. There are potentially limitless other combinations of uses for this revenue depending on the demands of the people and the political climate and will to satisfy those demands.

One passive impact of recycling, as observed by Brenner, Riddle, and Boyce (2005), is the flow of capital from urban to rural households in China as a result of revenue recycling, which may also hold true for Washington. By looking at Washington State broken down by county, cross referencing the population density with the median income of each county, it is clear that wealthier households are clustered more in urban areas, yet the recycling efforts are targeted to benefit poorer households, which comprise larger portions of rural areas. King County, the most densely populated and wealthiest (by income), would expect a wealth drain, while Garfield, the most rural and 11<sup>th</sup> poorest, would experience a wealth inflow. Of Washington's 39 counties, the most rural 3<sup>rd</sup> have a median income of \$43,358, while the most urban 3<sup>rd</sup> have a median income of \$57,840.

This process starts by firms being charged a carbon tax. The price increases from that carbon tax is paid nominally more by wealthier households who consume more. The revenue is then recycled through rebates, tax cuts, or social programs. On a household level, either through cash in pocket or services spending, wealth transfers from urban areas to rural areas.

It is critical to remember that the viability of any recycling plan is directly dependent on who is getting taxed and how much. In the King County metro example, if direct gasoline or diesel use was being taxed (as opposed to its production, keep in mind the carbon tax regime can be structured in many different ways), the transit service would be taxed directly for the busses that use diesel engines, and may require the subsidy just to keep the budget and fares at the current levels, let alone reduce them.

### *Trade*

The price changes to exports can be found in the same way in which the household expenditure changes were found. The vector of price changes is multiplied by the vector of exports. These results show how much the consumption cost of export goods has increased due to the carbon tax. Table 22 shows the

breakdown of current electricity exports and the impact at a \$25 carbon tax. As with the income group consumption, the increase in consumption of the export vector is proportional to the carbon content of the output. Any sector with a higher carbon multiplier, will cost more for other

**Table 22: Price change of Exports (Millions) at \$25 Tax**

	<u>Foreign</u>	<u>Domestic</u>
<b>Total Exports:</b>	\$ 72,967.49	\$ 148,198.70
<b>Difference:</b>	\$ 344.13	\$ 832.23
<b>New Total Exports:</b>	\$ 73,311.62	\$ 149,030.94
<b>Percent Increase:</b>	0.472%	0.562%

regions to import from Washington State compared to sectors with low carbon multipliers.

Again, electricity is a good example. Table 23-1 shows that electricity comprises .29% of total domestic exports, but accounts for 7% of the total domestic export cost increase. Electricity comprises a very small portion of total exports, but accounts for a large portion of exported carbon value. Table 23-2 shows the percentage increase in electricity exports. The value of

**Table 23-1: Percent of Electricity to Exports**

	<u>Foreign</u>	<u>Domestic</u>
<b>Total Exports:</b>	0.0218%	0.2943%
<b>Cost Increase:</b>	0.2003%	7.0181%

electricity increases by 13.3% for domestic exports and 4.3% for foreign exports.

**Table 23-2: Electricity Exports \$MM**

	<u>Foreign</u>	<u>Domestic</u>
<b>Tot Elec Exports:</b>	\$15.92	\$436.20
<b>Cost Increase:</b>	\$0.69	\$58.41
<b>Percent Increase:</b>	4.33%	13.39%

Interestingly, IMPLAN gives a breakdown of which type of electricity is being exported (as opposed to aggregating consumption for Washington Household consumption), so we can see the difference in the composition of electricity by source that is being exported,

based on the cost increase. Fossil Fuel electricity comprises 25% of exported electricity, but 80% of the electricity export cost increase.

**Table 24-1: Percent of Electricity to Exports**

	<u>Foreign</u>	<u>Domestic</u>
<b>Total Exports:</b>	1.041%	3.538%
<b>Cost Increase:</b>	11.514%	21.301%

The same analysis can be conducted using forest products sectors. Table 24-1 shows the aggregated forest products sectors separated by foreign and domestic exports. Domestically, forest products sectors account for 3.5% of total exports, yet account for 21% of the increase. Table 24-2 shows the cost increase to forest

**Table 24-2: Forest Products to Exports \$MM**

	<u>Foreign</u>	<u>Domestic</u>
<b>Tot FP Exports:</b>	759.65	5,243.06
<b>Cost Increase:</b>	39.62	177.28
<b>Percent Increase:</b>	5.22%	3.38%

products exports. The wood and paper sectors have proven to be very carbon heavy, and that

carbon has caused the price of exported wood products to increase; perhaps even to uncompetitive levels compared to California, Oregon, Idaho, or British Columbia. Some of the big increases come from Reconstituted Wood Products Manufacturing at 7.75%, Paperboard Mills at 11%, Paper Mills at 3.6%, and Pulp Mills at 40%.

The increase in price of the Washington produced goods may also trigger larger consumption of imported goods which may now be cheaper. Similarly, the price increases may cause other regions to halt the importing of, now, more expensive goods from Washington. Realistically, however, electricity exports will perhaps not change much since it is an inelastic commodity with very high capital costs to produce.

A full analysis of the import side of trade is not possible due to limitation in the IMPLAN data. While IMPLAN gives a full breakdown of how much output of each sector is exported, all imports are aggregated into one input element. The import row is a single aggregated value of imports used by each sector, as opposed to a total breakdown of how much of each sector is imported by each other sector.

Recently, firms in Washington have been transporting petroleum and coal products through the state to facilities along the coast in order to export to Asia, and even plan to construct new processing and export facilities (de Place 2012). This business has become very contentious in Washington and a carbon tax may prove fatal to operations. To recall, the EPA GHGRP accounts for carbon emissions of any fossil fuels that a firm transports or processes, so a carbon tax plan that uses a similarly designed carbon inventory protocol, would impact those transport and processing operations, even though the coal is not being burned in Washington. The additional cost of moving fossil fuels through the state may stop the trains in their tracks and depress the fossil fuel export industry.

The coal moving through Washington is from the Powder River Basin in Wyoming which is classified as Sub-bituminous coal (Clyde Bergemann Power Group). Sub-bituminous coal produces 1.85 tons of CO<sub>2</sub>e emissions per ton of coal burned (US EIA 2016). So each ton of coal moved through the state would have a carbon tax value of \$46, at the \$25 carbon tax level. There are currently six export facilities being proposed for Washington State. If all were operating at maximum capacity, they would be able to process 141 million tons of coal per year (de Place 2012), which means an additional 141 million tons of coal will be running through the state annually. A \$25 tax level, would result in a tax charge of \$6.5 billion to move this coal

through Washington, a significant cost indeed (remember that the \$25 is per ton of emissions not per ton of coal). One issue I see with this scenario is the potential for double taxation. Since the rail firms are transporting the coal, and the export firms are processing it, who should get taxed? Under the protocol of the EPA GHGRP both would be subjected to a tax on the coal.

*Spatial Variation*

<b>Table 25: Price Increase by Industry Group</b>	
<b>Industry</b>	<b>Average Price Increase</b>
<b>Utilities</b>	4.4802%
<b>Transportation</b>	2.9841%
<b>Manufacturing</b>	0.6470%
<b>Retail</b>	0.4879%
<b>Construction</b>	0.4114%
<b>Agriculture</b>	0.3195%
<b>Natural Resources</b>	0.3025%
<b>All Services</b>	0.2976%

Table 25 shows the average cost / price increase, at a \$25 tax level, for aggregated groups of the IMPLAN sectors. Since all the costs are passed on to consumers, the price increase is analogous to a total cost increase. A county with an economy that focuses on manufacturing is going to be impacted more by the carbon

tax, than one that focuses on natural resources. Including utilities in a comparison may not be useful due to the inelastic nature of the industry. In the long run, however, a carbon tax may persuade municipalities to switch utilities providers, from a coal plant to a windfarm for example, thereby depressing the incomes and economy of a country hosting the coal power industry.

Industries and regions relying more heavily on carbon as an input to production, will experience a larger impact from a carbon tax. A county that relies on manufacturing may be hit hard as similar firms from out of state gain a competitive advantage over Washington firms reducing exports from and increase imports to Washington. The reduced activity may result in lower output, loss of incomes, job cuts, and lower tax revenue. A natural resource based county, on the other hand, would perhaps be relatively less affected by a carbon tax, and be able to more easily absorb the costs and keep business running as usual.

The markets will force either environmental innovation for the polluting firms or a shuttering of the factories. The long term may see Washington shift farther away from manufacturing, and other highly polluting industries and further embrace natural resources and services as components of the economy. Alternatively, the firms may innovate their production

processes to pollute less, helping to protect the environment and regain some of their competitive advantage.

Another component of a carbon tax may be to tax the carbon value of imports. This model only shows price changes and consumptions of good and serviced produced in Washington State, incorporating the direct emissions of each sector and the indirect emissions from inputs also produced in Washington State. But much of the total consumption is of products originating outside Washington. A good example is IMPLAN sector 156 - Petroleum Refineries. Washington State produces \$1.67 billion worth of petroleum products, but imports (from combined foreign and domestic sources) \$15.14 billion. Which, when referring back to Table 11, price impacts of gasoline seem relatively low. Should carbon value of imports be taxed, the retail price of gasoline would cost significantly more than if just Washington refined petroleum was taxed. These tariffs may shift competitive advantage back to Washington firms.

### *Restoration*

The Washington State IO model has the ability to not only show the price increases resulting from a carbon tax, but can also show the quantity of carbon produced from additional activity in a given sector. This carbon quantity value represents not only the direct emissions from the activity, but also all the emissions related to the production of inputs to that sector. If you recall, many industries do not have direct emissions built into the model, yet show carbon multipliers.

It is these carbon multipliers that are used to calculate the quantity of additional carbon produced. Not only do they represent the percent price change of final demand, they also represents the quantity of carbon, in tons of CO<sub>2</sub>E, produced by that sector, for each \$1 of activity. Looking back at Table 3, sector 42, fossil fuel electricity generation, shows a multiplier of 0.0167. This multiplier means that sector 42 has a price increase of 1.67% (at the \$1 tax level), but also means that for every \$1 worth of output in sector 42, 0.0167 tons of CO<sub>2</sub>E is emitted.

The expenditure profile of a forest restoration project, for example, can be plugged in as an input to the model with the output showing the quantity of carbon produced as a result of that restoration project. Speaking more generally, any forestry activity, perhaps a routine harvest conducted by the Washington State Department of Natural Resources, can also be input. One important assumption is that all expenditure is being accounted for within the Washington State

economy; meaning, for example, that the logging firm is a Washington based firm, and the trucking company and saw mills are all within Washington State. From that carbon production, the project cost increase can then be determined. This cost increase is not a direct tax on the project, rather it represents the price increase of the sectors involved in conducting the project, resulting from a carbon tax.

The US Forest Service conducted a cost analysis of riparian restoration at the Gifford Pinchot National Forest. The Mine Reach restoration site comprised 3 miles of river and surrounding riparian forest zone with a total cost of \$184,860: \$61,620 per river mile (Brian Bair 2006).

Table 26 shows the allocation of expenditure to IMPLAN sectors and shows the quantity of carbon emissions produced from the Mine Reach restoration project. The carbon results are broken down by the carbon directly produced by the sectors, based on the carbon multipliers of those sectors, while the indirect carbon is produced by all the sectors indirectly stimulated by the restoration expenditure.

<b>Table 26: Mine Reach Cost Allocation and Carbon Output at \$25 tax</b>				
<b>Sector Number</b>	<b>Expenditure</b>	<b>Carbon (tons CO<sub>2</sub>E)</b>	<b>Carbon Cost</b>	<b>Sector Name</b>
<b>15</b>	\$22,340	2.59	\$64.70	Forestry, forest products, and timber tract production
<b>16</b>	\$18,000	2.38	\$59.60	Commercial logging
<b>19</b>	\$97,680	11.73	\$293.21	Support activities for agriculture and forestry
<b>411</b>	\$1,000	0.20	\$4.95	Truck transportation
<b>6</b>	\$27,500	3.44	\$85.90	Greenhouse, nursery, and floriculture production
<b>455</b>	\$18,340	1.94	\$48.39	Environmental and other technical consulting services
<b>Indirect</b>		57.90	\$1,447.49	
<b>Total</b>	\$184,860	<b>80.17</b>	\$2,004.24	

The Mine Reach restoration project produced 80 metric tons of carbon throughout the economy costing the US Forest Service and additional \$2,000, at the \$25 tax level; increasing the cost of the project by a little over 1% to \$186,864. Broken down further, the Mine Reach project produces 26 tons of carbon per river mile costing an extra \$668 per river mile. Another way, the project produced .0004337 tons of emissions per \$1 of expenditure.

Since each sector has a different carbon multiplier, and each type of project has a different cost profile, it is clear that each project will have a different carbon output. The Mine Reach restoration is a riparian restoration plan representing only one of many permutations of restoration and forestry projects. The Washington DNR, for example, conducts timber harvests on its land, the cost of which can be used as inputs to the model.

The exact cost profiles of actual timber sales on DNR land were not available, but an estimated profile was constructed using summary data of the WA DNR timber sales summary report for 2012 and a cost estimate spreadsheet provided by the DNR. Table 27 shows the results of a Westside DNR harvest.

<b>Table 27: WA State Westside DNR Harvest Example at \$25 tax</b>				
<b>Sector Number</b>	<b>Expenditure</b>	<b>Carbon (tons CO<sub>2</sub>E)</b>	<b>Carbon Cost</b>	<b>Sector Name</b>
<b>15</b>	\$293,601.35	34.01	\$850.27	Forestry, forest products, and timber tract production
<b>16</b>	\$100,800.00	13.35	\$333.74	Commercial logging
<b>19</b>	\$6,600.00	0.79	\$19.81	Support activities for agriculture and forestry
<b>411</b>	\$100,800.00	19.97	\$499.35	Truck transportation
<b>6</b>	\$6,000.00	0.75	\$18.74	Greenhouse, nursery, and floriculture production
<b>455</b>	\$5,000.00	0.53	\$13.19	Environmental and other technical consulting services
<b>Indirect</b>		176.03	\$4,400.77	
<b>Total</b>	<b>\$512,801.35</b>	<b>245.44</b>	<b>\$6,135.88</b>	

The Mine reach restoration requires much more consultation and engineering services than did the DNR harvest, which is a low carbon intense sector, and did mostly drop-and-leave for the timber that was felled, so there was minimal trucking involved. Conversely, the DNR harvest focused on commercial logging and moving timber out of the forest to the mill, requiring significant expenditure in the trucking sector which is a carbon intense sector. This cost profile difference causes an increase in carbon expenditure by 1.18% (17 basis points above the restoration), at \$4.86 per MBF (thousand board feet), produces .19 tons of CO<sub>2</sub>E per MBF, or produces .000479 tons of carbon per dollar of expenditure.

We can even estimate the value added component of the DNR harvest and find the induced carbon produced. The induced effects are the effects cause by the proprietors and employees spending their wages and salaries, which in turn stimulated production. By looking at

cost and profit levels for each sector, I estimate the value added to total approximately \$127,000. The induced effects from this harvest would create approximately 37 additional tons of carbon emissions.

The downstream of these harvest activities can be seen by using the market value of the timber as inputs to the different wood products manufacturing sectors. The three main raw timber types produced from harvesting are saw-logs, chip-and-saw logs, and pulp wood. By allocating the percentage of each type of timber to the total quantity of timber harvested, and inputting those values into the model, we can see how much carbon the processing of that timber will produce.

Dividing between sawmills and pulpmills, the total carbon emissions from processing the timber is roughly 1,800 tons of CO<sub>2</sub>E. Passing that on to the consumers, the sawmills and pulpmills will increase their prices by an average of \$35 per MBF's worth of input material.

In a more general sense, the specific products made with this timber also generates different emissions. \$1million worth of plywood manufacturing produces 672 tons of CO<sub>2</sub>E versus flooring which produces 600 tons of CO<sub>2</sub>E for the same \$1million. Keep in mind that these emissions are not only produced directly by the wood processing facility, but also generated by other inputs to production. The cost of production (and therefore price of final demand) will increase by the product of total carbon output of the production function and carbon tax rate.

## DRASTIC MEASURES

There have been a number of climate change studies which illustrate the need for a much higher level of emissions taxation than any currently implemented program or proposal. What is often referred to as the social-cost of carbon is the monetary value of the damage that emissions are doing to the economy and society. A US government study concluded that the social-cost of carbon for 2015 emissions is \$37 per ton. These findings were refuted by Moore and Delavane (2015), who estimate that the social-cost of carbon is considerably higher at \$220 per ton. The idea with these studies is to gauge the impacts of climate change at a certain point in the future and compare the business-as-usual scenario and with an environmentally acceptable abatement scenario.

This social-cost is often equated with the carbon taxation level needed to not just reduce the emissions, but also to force polluters to pay for the damage caused from that pollution. If one ton of emissions causes \$220 worth of damage to society, the entity responsible for those emissions is required to pay for that \$220 worth of damage. That payment is made through an emissions tax charge. Although emissions are a point-source factor that can be measured and taxed within designated geographical jurisdictions, the effects can be realized globally. Table 28 shows the consumption cost increase at \$37 and \$220 for each Washington State income group.

<b>Table 28: Social Cost of Carbon Estimates</b>		
<b>Income Group</b>	<b>Increase @ \$37 Tax</b>	<b>Increase @ \$220 Tax</b>
<b>&lt;10k</b>	3.5408%	21.0528%
<b>10-15k</b>	1.2491%	7.4270%
<b>15-25k</b>	1.1680%	6.9451%
<b>25-35k</b>	1.0708%	6.3671%
<b>35-50k</b>	0.9171%	5.4529%
<b>50-75k</b>	0.7985%	4.7479%
<b>75-100k</b>	0.7191%	4.2758%
<b>100-150k</b>	0.7833%	4.6576%
<b>150k+</b>	0.6893%	4.0987%

Even though Washington State has a relatively clean economy the state will still realize the damages of greenhouse gasses produced globally. Despite the notion that, the social-cost of carbon for a hypothetical Washington

State that is segregated from the global economy, may be considerably lower than the social-cost estimated for the rest of the world, the nonpoint-source nature of climate change impacts demands that all jurisdictions are subject to the same social-cost function: be it \$25, \$37, or \$220.

In his review, Nicholas Stern concludes that bringing emissions down to environmentally tenable levels would cost only 1% of global GDP annually (Stern 2006). Applying that formula to Washington: for 2015, Washington State had a GDP of \$446 billion, 1% of which equals \$4.46 billion. To raise \$4.46 billion in revenue (at current emissions levels recording by the GHGRP), the Washington State carbon tax would need to be set at roughly \$75 per ton. The receipts of \$25 level we have explored in this analysis only equals .32% of the 2015 Washington State GDP.

## **SHORTFALLS**

Many assumptions were made when building this model and conducted this analysis. It is clear that the linearity of the measured impacts may not accurately reflect reality, given individual price elasticities and shifting of the demand functions of each item in the consumption bundles. It is assumed that all carbon tax costs will be passed on to consumers and consumers will not substitute away from carbon intensive goods, which is unlikely to be the case in both respects should a carbon tax be initiated. As a result, the price change results and nominal tax revenue produced by this model are, perhaps, high. The overall impacts discussed are also only applicable for the very short term. They do, however, still illustrate the regressive trend expected from a carbon tax and provides insight into the sectoral allocation of the downstream carbon pricing impacts at the industrial level.

This analysis did not explore the impacts a carbon tax would have on incomes. The literature is torn between a positive and negative impact on incomes. In some cases a carbon tax causes a net positive long term income change while in some cases it causes a net negative income change.

It is also important to note that carbon taxation programs generally have a schedule by which the tax rate increases over the years. For example, the Carbon Washington plan has a two year phase in schedule starting at \$10 per ton and settling on \$25 per ton. There is a subsequent schedule increasing the tax to \$100 per ton gradually over the subsequent 40 years. Although the linearity of this models allows us to simply multiply the results by whatever factor we desire, it is unreasonable to apply the structure of the economy for 2013 to an expectations analysis of 40 years from now. The structure and emissions coefficients of the Washington State economy may fundamentally change over the next 40 years especially if a carbon tax is enacted today.

Further analysis can be conducted for Washington State to gauge the impacts on incomes. Additionally, more research can be done to explore the demand shift impacts and emissions reduction estimates.

## CONCLUSION

It should be very clear that this thesis is by no means a policy recommendation regarding the specific design of a carbon tax in Washington State. It is simply an exploration of some of the impacts and revenue recycling possibilities using the data that is currently available. The specific tax levels discussed, emissions data collection protocol, what sectors are impacted, how revenue is utilized are all entirely mutable and customizable depending on the political will of the jurisdiction. I am in no way claiming that this analysis is the definitive policy that should be or will be adopted by Washington State.

Climate change and environmental degradation are complex issues with carbon taxation as a prominent mitigation tool. This IO model shows how a carbon tax in Washington State will impact household consumption, trade, and industrial activity through price increases resulting from that carbon tax. The model also allows us to explore revenue recycling strategies in order to mitigate the regressive tendencies of carbon taxation. How regressive the carbon policy is, is not only dependent on the carbon tax level, but also the composition of the consumption bundle of different income groups, focusing on fossil fuel usage in the form of electricity, automotive gasoline, heating oil, natural gas, and others.

The model shows that at a tax level of \$25, the price increases will range from near zero to roughly 40%, with the lowest income group spending 5 times more on carbon, relative to income, than the highest income group. Although lower income groups will bear a larger portion of the carbon cost relative to income, the first order impacts of a carbon tax in Washington State prove considerably less regressive than other regions due to Washington generating a significant portion of its electricity with hydro power; since fossil fuel electricity contributes the majority of carbon to household consumption bundles. Overall, a carbon tax in Washington proves to be only minimally regressive. The \$1.5million in collected carbon tax revenue can be used to mitigate these regressive impacts through tax rebates to low income households, additional funding for social programs, public transit subsidies, sales tax cuts, and many others strategies.

The new cost of carbon will also cause the price tag for government sponsored forestry and restoration projects to increase, creating greater strain on public budgets for both federal, state, and local agencies. The state's balance of trade may be impacted, shifting towards imports as goods and services originating in Washington State lose their competitive advantage from the increase in price resulting from a carbon tax.

Overall, a carbon tax in Washington State may have a minimal impact on the economy, and in many ways help improve the social and economic structure of the state regarding environmental impacts. Ultimately, I do generally support the use of carbon taxation as a means to help reduce harmful emissions and mitigate climate change. Since a carbon tax regime can be fully customized to meet the needs and desires of the jurisdiction in which it is being implemented, it is imperative that the administrators of any such carbon policy fully examine the impacts of that policy and measure the needs of the people affected by it. An intelligently crafted policy can achieve both the goals of slowing climate change and bettering society by forcing industry to pollute less and improving the socioeconomic equality of everyone within Washington State.

## SOURCES

- Bair, Brian. 2006. "Stream Restoration Cost Estimates" USDA Forest Service. Gifford-Pinchot National Forest.
- Beck, M., Rivers, N., Wigle, R., & Yonezawa, H. (2015). Carbon tax and revenue recycling: Impacts on households in British Columbia. *Resource and Energy Economics*, 41, 40–69.
- Brenner, M., Riddle, M., & Boyce, J. K. (2007). A Chinese sky trust?. Distributional impacts of carbon charges and revenue recycling in China. *Energy Policy*, 35(3), 1771–1784.  
<http://doi.org/10.1016/j.enpol.2006.04.016>
- Callan, T., Lyons, S., Scott, S., Tol, R. S. J., & Verde, S. (2009). The distributional implications of a carbon tax in Ireland. *Energy Policy*, 37, 407–412.
- Davis, Carl, and Kelly Davis, et al. Who Pays? A Distributional Analysis of the Tax Systems in All 50 States. Rep. 5th ed. Washington D.C.: INSTITUTE ON TAXATION & ECONOMIC POLICY, 2015. <http://www.itep.org/pdf/whopaysreport.pdf>
- Carbon Tax Center. (2015, November 28). Retrieved January 6, 2016, from <http://www.carbontax.org/where-carbon-is-taxed/#Other>
- Carbon Washington. 2016. Our Policy Plain Language. <http://yeson732.org/plain-language/>
- De Place, Eric. Northwest Coal Exports: Some Common Questions about Economics, Health, and Pollution. Rep. N.p.: n.p., 2012. Print.
- Department of Natural Resources Board Sales Results. Rep. Olympia WA: Washington State Department of Natural Resources, 2013. Print.
- Dietzenbacher, E., & Velázquez, E. (2007). Analysing Andalusian Virtual Water Trade in an Input–Output Framework. *Regional Studies*, 41(January 2015), 185–196.  
<http://doi.org/10.1080/00343400600929077>
- Dissou, Y., & Siddiqui, M. S. (2014). Can carbon taxes be progressive? *Energy Economics*, 42, 88–100.
- Environment. U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, "Carbon Dioxide Emissions Coefficients by Fuel." 2 Feb. 2016. Web. 27 Apr. 2016.
- Grainger, C. a., & Kolstad, C. D. (2010). Who pays a price on carbon? *Environmental and Resource Economics*, 46(3), 359–376.

- Gregg, J. S., R. J. Andres, and G. Marland (2008), China: Emissions pattern of the world leader in CO2 emissions from fossil fuel consumption and cement production, *Geophys. Res. Lett.*, 35, L08806
- Hamilton, K., & Cameron, G. (1994). Simulating the Distributional Effects of a Canadian Carbon Tax. *Canadian Public Policy / Analyse de Politiques*, 20(4), 385–399. <http://doi.org/10.2307/3551997>
- Heilbroner, R. (1999). *The Worldly Philosophers : The lives, times, and ideas of the great economic thinkers* (Rev. 7th ed.). New York: Simon & Schuster.
- "IMPLAN Data Components." IMPLAN Knowledge Base. 2015. Web. 20 Jan. 2016. [http://implan.com/index.php?option=com\\_content&view=article&id=395:395&catid=228:228](http://implan.com/index.php?option=com_content&view=article&id=395:395&catid=228:228)
- IMPLAN Group LLC, IMPLAN System (data and software),16905 Northcross Dr., Suite 120, Huntersville, NC 28078 [www.IMPLAN.com](http://www.IMPLAN.com)
- IPCC (2014). *Climate Change 2014: Mitigation of Climate Change . Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Jiang, Z., & Shao, S. (2014). Distributional effects of a carbon tax on Chinese households: A case of Shanghai. *Energy Policy*, 73, 269–277. <http://doi.org/10.1016/j.enpol.2014.06.005>
- Keseljevic, Aleksandar, Koman, Matjaz (2015). “Analysis of the Effects of Introduction of an Additional Carbon Tax on the Slovenian Economy Considering Different Forms of Recycling”. *Economic and Economic and Business Review* vol 16(3),247-277
- Labandeira, X., & Labeaga, J. M. (1999). Combining input-output analysis and micro-simulation to assess the effects of ... *Fiscal Studies*, 20(3), 305 – 320.
- "Learn About the Greenhouse Gas Reporting Program (GHGRP)." EPA. Environmental Protection Agency. Web. <http://www.epa.gov/ghgreporting/learn-about-greenhouse-gas-reporting-program-ghgrp>
- Leontief, Wassily. (1951) "Input-Output Economics." *Input-Output Economics*. New York: Oxford UP, 1966. 13-29. Print
- Leontief, W. (1936). Quantitative input and output relations in the economic system of the United States. *Review of Economic Statistics*, 18, 105-125.

- Lin, B., & Li, X. (2011). The effect of carbon tax on per capita CO2 emissions. *Energy Policy*, 39(9), 5137–5146. <http://doi.org/10.1016/j.enpol.2011.05.050>
- Metcalf, Gilbert. "A Distributional Analysis of Green Tax Reform." *National Tax Journal* LII.4 (1999): 655-81. Print.
- Median Household Income Estimates by County. 26 Feb. 2015. Raw data. Office of Financial Management, Olympia, WA
- Miller, Ronald E., and Peter D. Blair. *Input–Output Analysis: Foundations and Extensions*. Second Edition ed. 1985 Cambridge UP. Print.
- Moore, Frances C., and Delavane B. Diaz. "Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy." *Nature Climate Change* 5 (2015): 127-31. doi:10.1038/nclimate2481
- Office of Financial Management, Forecasting and Research Division. (2015). Estimates of April 1 Population Density and Land Area by County (Rep.). Olympia, WA
- Olson, Doug. "Explaining the Type Sam Multiplier". IMPLAN Group LLC [http://blogs.edweek.org/edweek/state\\_edwatch/TYPE%20SAM%20MULTIPLIER.pdf](http://blogs.edweek.org/edweek/state_edwatch/TYPE%20SAM%20MULTIPLIER.pdf)
- O'Sullivan, Joseph, and Jim Brunner. "School Funding Back on Table as Court Fines State \$100,000 a Day." *The Seattle Times*. 13 Aug. 2015. Web. 5 Apr. 2016.
- Parry IWH, Hilary S, Margaret W, Robertson W III (2005) The incidence of pollution control policies. RFF Discussion Paper 05-24 2005 Cambridge, Mass. National Bureau of Economic Research
- Parry, I. (1997). Revenue Recycling and the Costs of Reducing Carbon Emissions, (2).
- "Power Stations Currently in Operation." *EnergyBC: Where British Columbia Gets Its Electricity*. University of Victoria, BC, 2012. <<http://www.energybc.ca/map/bcenergymap.html>>.
- "PRB Coal Properties." Clyde Bergemann Power Group. <Http://www.cba-ssd.com/Applications/knowledgeBase/PRBcoal/PRBcoalProperty.htm>, n.d. Web.
- Robertson C, W. I., Gordon, H., Burtraw, D., Carbone, J. C., & Morgenstern, R. D. (2014). The Initial Incidence of a Carbon Tax across Income Groups. *Resources for the Future Discussion Papers*, 14-24(August), 195–214.
- Shah, A., Larsen, B., 1992. Carbon taxes, the greenhouse effect, and developing countries. Policy Research Working Paper Series 957, The World Bank.

- State and Local Government Finances. (2013). American Fact Finder. United States Census Bureau. State and Local Government Finances by Level of Government and by State: 2013 <http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk>
- Statistics Canada, Installed generating capacity, by class of electricity producer, annual, Ottawa: Statistics Canada, 2014 <http://www5.statcan.gc.ca/>
- Stern, N. (2006). "Stern Review on The Economics of Climate Change (pre-publication edition). Executive Summary". HM Treasury, London. Archived from the original on 31 January 2010. Retrieved 31 January 2010
- Sugino, M., Arimura, T. H., & Morgenstern, R. D. (2013). The effects of alternative carbon mitigation policies on Japanese industries. *Energy Policy*, 62, 1254–1267.
- Than, Ker. "Estimated Social Cost of Climate Change Not Accurate, Stanford Scientists Say." Stanford News [Stanford, CA] 12 Jan. 2015: n. pag. Print.
- The World Bank "Putting a Price on Carbon with a Tax. Rep". 2015 Print. [http://www.worldbank.org/content/dam/Worldbank/document/SDN/background-note\\_carbon-tax.pdf](http://www.worldbank.org/content/dam/Worldbank/document/SDN/background-note_carbon-tax.pdf)
- Transit Fare Rev - Cumulative. Rep: Financial 2015. Seattle WA: King County, 2016. Print. <http://metro.kingcounty.gov/am/reports/monthly-measures/financial.html#fare-revenue>
- "U.S. Energy Information Administration." U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. 1 Sept. 2015. <<http://www.eia.gov/state/?sid=WA#tabs-4>>.
- "U.S. Energy Information Administration." U.S. Energy Information Administration - EIA - Carbon Dioxide Emissions Coefficients, February, 2, 2016. [https://www.eia.gov/environment/emissions/co2\\_vol\\_mass.cfm](https://www.eia.gov/environment/emissions/co2_vol_mass.cfm)
- U.S. Census Bureau. 2016 "North American Industry Classification System." (NAICS). <http://www.census.gov/eos/www/naics/>
- U.S. Census Bureau 2016 "Quick Facts Washington" <http://www.census.gov/quickfacts/table/PST045215/53,00>
- Washington State Department of Revenue (2016) "Local Sales and Use Tax Rates by City / County." [http://dor.wa.gov/Content/GetAFormOrPublication/FormBySubject/forms\\_LSUAlpha.aspx](http://dor.wa.gov/Content/GetAFormOrPublication/FormBySubject/forms_LSUAlpha.aspx)
- Washington State Department of Revenue, 2013. Summary of Washington State Taxes; FY 2012 - 2013. Rep. Leech, Beth. Olympia WA:. Print

King County Parks (2015) “Levy”. Parks, Trails, and Open Space Replacement Levy  
<http://www.kingcounty.gov/services/parks-recreation/parks/about/levy.aspx>

King County Budget (Operating & Capital) 201-2016. King County Metro Online.  
<http://metro.kingcounty.gov/am/budget/>

Zillow.com, 2016, “King County Home Prices & Values” <http://www.zillow.com/king-county-wa/home-values/>

## APPENDIX A – Full List of Carbon Multipliers

Sector	Sector Name	Carbon Multiplier
1	Oilseed farming	0.00012649
2	Grain farming	0.000179386
3	Vegetable and melon farming	0.000121213
4	Fruit farming	0.000118844
5	Tree nut farming	0.000121683
6	Greenhouse, nursery, and floriculture production	0.000124938
7	Tobacco farming	0
8	Cotton farming	0
9	Sugarcane and sugar beet farming	0.000130589
10	All other crop farming	0.000142267
11	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming	0.00028575
12	Dairy cattle and milk production	0.000171496
13	Poultry and egg production	0.000151495
14	Animal production, except cattle and poultry and eggs	0.000114944
15	Forestry, forest products, and timber tract production	0.00011584
16	Commercial logging	0.000132438
17	Commercial fishing	0.000141454
18	Commercial hunting and trapping	0.000131633
19	Support activities for agriculture and forestry	0.000120069
20	Extraction of natural gas and crude petroleum	6.94714E-05
21	Extraction of natural gas liquids	9.23597E-05
22	Coal mining	0.000110775
23	Iron ore mining	0
24	Gold ore mining	0.000185157
25	Silver ore mining	0
26	Lead and zinc ore mining	0.000123094
27	Copper ore mining	0.000137896
28	Uranium-radium-vanadium ore mining	0
29	Other metal ore mining	0.000184323
30	Stone mining and quarrying	0.000126458
31	Sand and gravel mining	0.000152041
32	Other clay, ceramic, refractory minerals mining	0.000117206
33	Potash, soda, and borate mineral mining	0
34	Phosphate rock mining	0
35	Other chemical and fertilizer mineral mining	0.000124768
36	Other nonmetallic minerals	0.000636212
37	Drilling oil and gas wells	7.25851E-05

38	Support activities for oil and gas operations	0.000125186
39	Metal mining services	0.000111508
40	Other nonmetallic minerals services	0.000135909
41	Electric power generation - Hydroelectric	0.000133594
42	Electric power generation - Fossil fuel	0.016784536
43	Electric power generation - Nuclear	0
44	Electric power generation - Solar	0.000112677
45	Electric power generation - Wind	0.000115524
46	Electric power generation - Geothermal	0
47	Electric power generation - Biomass	0.000133808
48	Electric power generation - All other	0.000132589
49	Electric power transmission and distribution	0.001732363
50	Natural gas distribution	0.000270538
51	Water, sewage and other systems	0.000297459
52	Construction of new health care structures	0.000165978
53	Construction of new manufacturing structures	0.000150662
54	Construction of new power and communication structures	0.000156672
55	Construction of new educational and vocational structures	0.000174767
56	Construction of new highways and streets	0.000198448
57	Construction of new commercial structures, including farm structures	0.000156709
58	Construction of other new nonresidential structures	0.000162676
59	Construction of new single-family residential structures	0.000145705
60	Construction of new multifamily residential structures	0.000159901
61	Construction of other new residential structures	0.000158059
62	Maintenance and repair construction of nonresidential structures	0.000162112
63	Maintenance and repair construction of residential structures	0.00015807
64	Maintenance and repair construction of highways, streets, bridges, and tunnels	0.00018978
65	Dog and cat food manufacturing	0.000128659
66	Other animal food manufacturing	0.00016529
67	Flour milling	0.000204651
68	Rice milling	0
69	Malt manufacturing	0.00028523
70	Wet corn milling	0.000208544
71	Soybean and other oilseed processing	0.000126629
72	Fats and oils refining and blending	0.000138319
73	Breakfast cereal manufacturing	0.000152807
74	Beet sugar manufacturing	0
75	Sugar cane mills and refining	0

<b>76</b>	Nonchocolate confectionery manufacturing	0.000157275
<b>77</b>	Chocolate and confectionery manufacturing from cacao beans	0.000155126
<b>78</b>	Confectionery manufacturing from purchased chocolate	0.000161566
<b>79</b>	Frozen fruits, juices and vegetables manufacturing	0.000410613
<b>80</b>	Frozen specialties manufacturing	0.000172324
<b>81</b>	Canned fruits and vegetables manufacturing	0.000141665
<b>82</b>	Canned specialties	0.000179576
<b>83</b>	Dehydrated food products manufacturing	0.000207169
<b>84</b>	Fluid milk manufacturing	0.000185389
<b>85</b>	Creamery butter manufacturing	0.000182535
<b>86</b>	Cheese manufacturing	0.000318677
<b>87</b>	Dry, condensed, and evaporated dairy product manufacturing	0.000306067
<b>88</b>	Ice cream and frozen dessert manufacturing	0.000150118
<b>89</b>	Animal, except poultry, slaughtering	0.000182654
<b>90</b>	Meat processed from carcasses	0.000134002
<b>91</b>	Rendering and meat byproduct processing	0.000119195
<b>92</b>	Poultry processing	0.000105467
<b>93</b>	Seafood product preparation and packaging	0.000108132
<b>94</b>	Bread and bakery product, except frozen, manufacturing	0.000125787
<b>95</b>	Frozen cakes and other pastries manufacturing	0.000159628
<b>96</b>	Cookie and cracker manufacturing	0.000142115
<b>97</b>	Dry pasta, mixes, and dough manufacturing	0.000155802
<b>98</b>	Tortilla manufacturing	0.000144797
<b>99</b>	Roasted nuts and peanut butter manufacturing	0.000127354
<b>100</b>	Other snack food manufacturing	0.000195269
<b>101</b>	Coffee and tea manufacturing	0.000168946
<b>102</b>	Flavoring syrup and concentrate manufacturing	0.000116025
<b>103</b>	Mayonnaise, dressing, and sauce manufacturing	0.000129821
<b>104</b>	Spice and extract manufacturing	0.000144744
<b>105</b>	All other food manufacturing	0.000159872
<b>106</b>	Bottled and canned soft drinks & water	0.000114389
<b>107</b>	Manufactured ice	0.000186615
<b>108</b>	Breweries	0.000173468
<b>109</b>	Wineries	0.000158442
<b>110</b>	Distilleries	0.000138091
<b>111</b>	Tobacco product manufacturing	0.000126567
<b>112</b>	Fiber, yarn, and thread mills	7.76215E-05
<b>113</b>	Broadwoven fabric mills	9.41863E-05
<b>114</b>	Narrow fabric mills and schiffli machine embroidery	7.82206E-05

<b>115</b>	Nonwoven fabric mills	0.000111655
<b>116</b>	Knit fabric mills	0
<b>117</b>	Textile and fabric finishing mills	0.000131635
<b>118</b>	Fabric coating mills	0.000103866
<b>119</b>	Carpet and rug mills	6.25207E-05
<b>120</b>	Curtain and linen mills	0.000109199
<b>121</b>	Textile bag and canvas mills	7.71516E-05
<b>122</b>	Rope, cordage, twine, tire cord and tire fabric mills	0.000111035
<b>123</b>	Other textile product mills	0.000119962
<b>124</b>	Hosiery and sock mills	8.31998E-05
<b>125</b>	Other apparel knitting mills	9.69404E-05
<b>126</b>	Cut and sew apparel contractors	0.000133063
<b>127</b>	Men's and boys' cut and sew apparel manufacturing	0.000142892
<b>128</b>	Women's and girls' cut and sew apparel manufacturing	0.000131027
<b>129</b>	Other cut and sew apparel manufacturing	0.000142832
<b>130</b>	Apparel accessories and other apparel manufacturing	0.000150509
<b>131</b>	Leather and hide tanning and finishing	0.000175397
<b>132</b>	Footwear manufacturing	0.000146513
<b>133</b>	Other leather and allied product manufacturing	0.000127259
<b>134</b>	Sawmills	0.000833287
<b>135</b>	Wood preservation	0.000273972
<b>136</b>	Veneer and plywood manufacturing	0.000206878
<b>137</b>	Engineered wood member and truss manufacturing	0.000268358
<b>138</b>	Reconstituted wood product manufacturing	0.0030987
<b>139</b>	Wood windows and door manufacturing	0.000187746
<b>140</b>	Cut stock, resawing lumber, and planing	0.000836464
<b>141</b>	Other millwork, including flooring	0.000233653
<b>142</b>	Wood container and pallet manufacturing	0.000211816
<b>143</b>	Manufactured home (mobile home) manufacturing	0.000133782
<b>144</b>	Prefabricated wood building manufacturing	0.000194953
<b>145</b>	All other miscellaneous wood product manufacturing	0.000822636
<b>146</b>	Pulp mills	0.016053401
<b>147</b>	Paper mills	0.001440733
<b>148</b>	Paperboard mills	0.004439506
<b>149</b>	Paperboard container manufacturing	0.000454356
<b>150</b>	Paper bag and coated and treated paper manufacturing	0.000294465
<b>151</b>	Stationery product manufacturing	0.00038484
<b>152</b>	Sanitary paper product manufacturing	0.000306366
<b>153</b>	All other converted paper product manufacturing	0.000482303
<b>154</b>	Printing	0.000168153
<b>155</b>	Support activities for printing	0.000130868

<b>156</b>	Petroleum refineries	0.000741082
<b>157</b>	Asphalt paving mixture and block manufacturing	0.000290475
<b>158</b>	Asphalt shingle and coating materials manufacturing	0.000295019
<b>159</b>	Petroleum lubricating oil and grease manufacturing	0.000152182
<b>160</b>	All other petroleum and coal products manufacturing	0
<b>161</b>	Petrochemical manufacturing	6.88196E-05
<b>162</b>	Industrial gas manufacturing	0.000774134
<b>163</b>	Synthetic dye and pigment manufacturing	0
<b>164</b>	Other basic inorganic chemical manufacturing	0.000220779
<b>165</b>	Other basic organic chemical manufacturing	0.000203048
<b>166</b>	Plastics material and resin manufacturing	9.99035E-05
<b>167</b>	Synthetic rubber manufacturing	9.6542E-05
<b>168</b>	Artificial and synthetic fibers and filaments manufacturing	0
<b>169</b>	Nitrogenous fertilizer manufacturing	0.001038389
<b>170</b>	Phosphatic fertilizer manufacturing	0
<b>171</b>	Fertilizer mixing	0.000195391
<b>172</b>	Pesticide and other agricultural chemical manufacturing	0.000123263
<b>173</b>	Medicinal and botanical manufacturing	0.000162741
<b>174</b>	Pharmaceutical preparation manufacturing	0.000137692
<b>175</b>	In-vitro diagnostic substance manufacturing	0.000137157
<b>176</b>	Biological product (except diagnostic) manufacturing	0.000183915
<b>177</b>	Paint and coating manufacturing	0.00010241
<b>178</b>	Adhesive manufacturing	0.000165578
<b>179</b>	Soap and other detergent manufacturing	0.00014145
<b>180</b>	Polish and other sanitation good manufacturing	0.000129569
<b>181</b>	Surface active agent manufacturing	0
<b>182</b>	Toilet preparation manufacturing	0.000123864
<b>183</b>	Printing ink manufacturing	0.000124174
<b>184</b>	Explosives manufacturing	0
<b>185</b>	Custom compounding of purchased resins	7.71323E-05
<b>186</b>	Photographic film and chemical manufacturing	0.000201687
<b>187</b>	Other miscellaneous chemical product manufacturing	0.000149317
<b>188</b>	Plastics packaging materials and unlaminated film and sheet manufacturing	0.000117107
<b>189</b>	Unlaminated plastics profile shape manufacturing	0.000130599
<b>190</b>	Plastics pipe and pipe fitting manufacturing	9.71901E-05
<b>191</b>	Laminated plastics plate, sheet (except packaging), and shape manufacturing	0.000187644
<b>192</b>	Polystyrene foam product manufacturing	0.000114717
<b>193</b>	Urethane and other foam product (except polystyrene) manufacturing	0.000143283
<b>194</b>	Plastics bottle manufacturing	0.000123319

195	Other plastics product manufacturing	0.000119266
196	Tire manufacturing	0.000116194
197	Rubber and plastics hoses and belting manufacturing	0.000117589
198	Other rubber product manufacturing	0.00011258
199	Pottery, ceramics, and plumbing fixture manufacturing	0.000129973
200	Brick, tile, and other structural clay product manufacturing	0.000163744
201	Flat glass manufacturing	0.000849828
202	Other pressed and blown glass and glassware manufacturing	0.00019198
203	Glass container manufacturing	0.000875854
204	Glass product manufacturing made of purchased glass	0.00017904
205	Cement manufacturing	0.003345187
206	Ready-mix concrete manufacturing	0.000403399
207	Concrete block and brick manufacturing	0.000253359
208	Concrete pipe manufacturing	0.000214259
209	Other concrete product manufacturing	0.000199811
210	Lime manufacturing	0.003444535
211	Gypsum product manufacturing	0.000647205
212	Abrasive product manufacturing	0.000126506
213	Cut stone and stone product manufacturing	0.000130699
214	Ground or treated mineral and earth manufacturing	0.000176197
215	Mineral wool manufacturing	0.000183755
216	Miscellaneous nonmetallic mineral products manufacturing	0.000361215
217	Iron and steel mills and ferroalloy manufacturing	0.001240511
218	Iron, steel pipe and tube manufacturing from purchased steel	0.000124937
219	Rolled steel shape manufacturing	0.000144272
220	Steel wire drawing	0.000136908
221	Alumina refining and primary aluminum production	0.001517369
222	Secondary smelting and alloying of aluminum	0.000273515
223	Aluminum sheet, plate, and foil manufacturing	0.000444313
224	Other aluminum rolling, drawing and extruding	0.000308975
225	Nonferrous metal (exc aluminum) smelting and refining	0.00068779
226	Copper rolling, drawing, extruding and alloying	0
227	Nonferrous metal, except copper and aluminum, shaping	9.3546E-05
228	Secondary processing of other nonferrous metals	0.000155607
229	Ferrous metal foundries	0.000174647
230	Nonferrous metal foundries	0.000206955
231	Iron and steel forging	0.000801299
232	Nonferrous forging	0.000158998
233	Custom roll forming	0.000117977
234	Crown and closure manufacturing and metal stamping	0.000117912

235	Cutlery, utensil, pot, and pan manufacturing	0.000142396
236	Handtool manufacturing	0.000133161
237	Prefabricated metal buildings and components manufacturing	0.00011185
238	Fabricated structural metal manufacturing	0.000108293
239	Plate work manufacturing	0.000109532
240	Metal window and door manufacturing	0.000111205
241	Sheet metal work manufacturing	0.000118457
242	Ornamental and architectural metal work manufacturing	0.000112456
243	Power boiler and heat exchanger manufacturing	0.000104093
244	Metal tank (heavy gauge) manufacturing	0.000106466
245	Metal cans manufacturing	0.000191779
246	Metal barrels, drums and pails manufacturing	0.000157244
247	Hardware manufacturing	0.000123301
248	Spring and wire product manufacturing	0.000115621
249	Machine shops	0.00011603
250	Turned product and screw, nut, and bolt manufacturing	0.000126603
251	Metal heat treating	0.000149273
252	Metal coating and nonprecious engraving	0.000108099
253	Electroplating, anodizing, and coloring metal	0.00013871
254	Valve and fittings, other than plumbing, manufacturing	0.000124564
255	Plumbing fixture fitting and trim manufacturing	0
256	Ball and roller bearing manufacturing	0
257	Small arms ammunition manufacturing	0.000141004
258	Ammunition, except for small arms, manufacturing	0
259	Small arms, ordnance, and accessories manufacturing	9.7343E-05
260	Fabricated pipe and pipe fitting manufacturing	0.000110857
261	Other fabricated metal manufacturing	0.000128868
262	Farm machinery and equipment manufacturing	0.000101824
263	Lawn and garden equipment manufacturing	9.98212E-05
264	Construction machinery manufacturing	0.000114101
265	Mining machinery and equipment manufacturing	9.40207E-05
266	Oil and gas field machinery and equipment manufacturing	0
267	Food product machinery manufacturing	0.000122481
268	Semiconductor machinery manufacturing	0
269	Sawmill, woodworking, and paper machinery	0.000103632
270	Printing machinery and equipment manufacturing	0.000108375
271	All other industrial machinery manufacturing	0.000127383
272	Optical instrument and lens manufacturing	0.000136106
273	Photographic and photocopying equipment manufacturing	0.000162225
274	Other commercial service industry machinery manufacturing	0.000153071

<b>275</b>	Air purification and ventilation equipment manufacturing	0.000117113
<b>276</b>	Heating equipment (except warm air furnaces) manufacturing	0.000125714
<b>277</b>	Air conditioning, refrigeration, and warm air heating equipment manufacturing	0.000132343
<b>278</b>	Industrial mold manufacturing	0.000124536
<b>279</b>	Special tool, die, jig, and fixture manufacturing	0.000121086
<b>280</b>	Cutting tool and machine tool accessory manufacturing	0.000114715
<b>281</b>	Machine tool manufacturing	0.000114114
<b>282</b>	Rolling mill and other metalworking machinery manufacturing	0.000119056
<b>283</b>	Turbine and turbine generator set units manufacturing	0.000120004
<b>284</b>	Speed changer, industrial high-speed drive, and gear manufacturing	0.000114852
<b>285</b>	Mechanical power transmission equipment manufacturing	0.000121968
<b>286</b>	Other engine equipment manufacturing	0.0001206
<b>287</b>	Pump and pumping equipment manufacturing	0.000123519
<b>288</b>	Air and gas compressor manufacturing	0.0001229
<b>289</b>	Measuring and dispensing pump manufacturing	0.000138499
<b>290</b>	Elevator and moving stairway manufacturing	0.000118798
<b>291</b>	Conveyor and conveying equipment manufacturing	0.000119587
<b>292</b>	Overhead cranes, hoists, and monorail systems manufacturing	0.00010522
<b>293</b>	Industrial truck, trailer, and stacker manufacturing	0.000118751
<b>294</b>	Power-driven handtool manufacturing	0.000115203
<b>295</b>	Welding and soldering equipment manufacturing	0.000117219
<b>296</b>	Packaging machinery manufacturing	0.000115251
<b>297</b>	Industrial process furnace and oven manufacturing	0.000111062
<b>298</b>	Fluid power cylinder and actuator manufacturing	0.00011645
<b>299</b>	Fluid power pump and motor manufacturing	0.000145124
<b>300</b>	Scales, balances, and miscellaneous general purpose machinery manufacturing	0.000135406
<b>301</b>	Electronic computer manufacturing	0.000103416
<b>302</b>	Computer storage device manufacturing	9.99155E-05
<b>303</b>	Computer terminals and other computer peripheral equipment manufacturing	0.000128332
<b>304</b>	Telephone apparatus manufacturing	0.000111469
<b>305</b>	Broadcast and wireless communications equipment manufacturing	0.000118857
<b>306</b>	Other communications equipment manufacturing	0.000127001
<b>307</b>	Audio and video equipment manufacturing	0.00012013
<b>308</b>	Bare printed circuit board manufacturing	0.000120604
<b>309</b>	Semiconductor and related device manufacturing	0.00020034

<b>310</b>	Capacitor, resistor, coil, transformer, and other inductor manufacturing	0.000136354
<b>311</b>	Electronic connector manufacturing	0.000112082
<b>312</b>	Printed circuit assembly (electronic assembly) manufacturing	9.27956E-05
<b>313</b>	Other electronic component manufacturing	0.000138958
<b>314</b>	Electromedical and electrotherapeutic apparatus manufacturing	0.0001103
<b>315</b>	Search, detection, and navigation instruments manufacturing	0.000108389
<b>316</b>	Automatic environmental control manufacturing	0.000112338
<b>317</b>	Industrial process variable instruments manufacturing	0.000112706
<b>318</b>	Totalizing fluid meter and counting device manufacturing	0.000100848
<b>319</b>	Electricity and signal testing instruments manufacturing	0.000106644
<b>320</b>	Analytical laboratory instrument manufacturing	0.000111279
<b>321</b>	Irradiation apparatus manufacturing	0.000118592
<b>322</b>	Watch, clock, and other measuring and controlling device manufacturing	0.000108289
<b>323</b>	Blank magnetic and optical recording media manufacturing	0.000117155
<b>324</b>	Software and other prerecorded and record reproducing	0.000160478
<b>325</b>	Electric lamp bulb and part manufacturing	0.00021965
<b>326</b>	Lighting fixture manufacturing	0.000149408
<b>327</b>	Small electrical appliance manufacturing	0.000129042
<b>328</b>	Household cooking appliance manufacturing	0.000124891
<b>329</b>	Household refrigerator and home freezer manufacturing	0.000120253
<b>330</b>	Household laundry equipment manufacturing	0
<b>331</b>	Other major household appliance manufacturing	0.000113926
<b>332</b>	Power, distribution, and specialty transformer manufacturing	0.000138229
<b>333</b>	Motor and generator manufacturing	0.000131972
<b>334</b>	Switchgear and switchboard apparatus manufacturing	0.000127723
<b>335</b>	Relay and industrial control manufacturing	0.000153937
<b>336</b>	Storage battery manufacturing	0.000108004
<b>337</b>	Primary battery manufacturing	0
<b>338</b>	Fiber optic cable manufacturing	0
<b>339</b>	Other communication and energy wire manufacturing	0
<b>340</b>	Wiring device manufacturing	0.000129194
<b>341</b>	Carbon and graphite product manufacturing	0.000179369
<b>342</b>	All other miscellaneous electrical equipment and component manufacturing	0.000136685
<b>343</b>	Automobile manufacturing	9.83259E-05
<b>344</b>	Light truck and utility vehicle manufacturing	9.53652E-05
<b>345</b>	Heavy duty truck manufacturing	0.000103673

<b>346</b>	Motor vehicle body manufacturing	9.70959E-05
<b>347</b>	Truck trailer manufacturing	0.000110777
<b>348</b>	Motor home manufacturing	0
<b>349</b>	Travel trailer and camper manufacturing	0.000129647
<b>350</b>	Motor vehicle gasoline engine and engine parts manufacturing	0.000113346
<b>351</b>	Motor vehicle electrical and electronic equipment manufacturing	0.000102227
<b>352</b>	Motor vehicle steering, suspension component (except spring), and brake systems manufacturing	0.000113719
<b>353</b>	Motor vehicle transmission and power train parts manufacturing	0.00011331
<b>354</b>	Motor vehicle seating and interior trim manufacturing	0.000115904
<b>355</b>	Motor vehicle metal stamping	0
<b>356</b>	Other motor vehicle parts manufacturing	0.000115276
<b>357</b>	Aircraft manufacturing	8.39756E-05
<b>358</b>	Aircraft engine and engine parts manufacturing	6.39624E-05
<b>359</b>	Other aircraft parts and auxiliary equipment manufacturing	0.000125084
<b>360</b>	Guided missile and space vehicle manufacturing	0
<b>361</b>	Propulsion units and parts for space vehicles and guided missiles manufacturing	7.78039E-05
<b>362</b>	Railroad rolling stock manufacturing	0.000115913
<b>363</b>	Ship building and repairing	0.000108865
<b>364</b>	Boat building	0.000114231
<b>365</b>	Motorcycle, bicycle, and parts manufacturing	0.000141472
<b>366</b>	Military armored vehicle, tank, and tank component manufacturing	0
<b>367</b>	All other transportation equipment manufacturing	9.83703E-05
<b>368</b>	Wood kitchen cabinet and countertop manufacturing	0.000162882
<b>369</b>	Upholstered household furniture manufacturing	0.000148095
<b>370</b>	Nonupholstered wood household furniture manufacturing	0.000174909
<b>371</b>	Other household nonupholstered furniture manufacturing	0.000164703
<b>372</b>	Institutional furniture manufacturing	0.000135925
<b>373</b>	Wood office furniture manufacturing	0.000160428
<b>374</b>	Custom architectural woodwork and millwork	0.000138007
<b>375</b>	Office furniture, except wood, manufacturing	0.000139368
<b>376</b>	Showcase, partition, shelving, and locker manufacturing	0.000131306
<b>377</b>	Mattress manufacturing	0.000124457
<b>378</b>	Blind and shade manufacturing	0.000160626
<b>379</b>	Surgical and medical instrument manufacturing	0.000122844
<b>380</b>	Surgical appliance and supplies manufacturing	0.000143914
<b>381</b>	Dental equipment and supplies manufacturing	0.000106279

<b>382</b>	Ophthalmic goods manufacturing	0.000118859
<b>383</b>	Dental laboratories	0.000112554
<b>384</b>	Jewelry and silverware manufacturing	0.000113998
<b>385</b>	Sporting and athletic goods manufacturing	0.000136327
<b>386</b>	Doll, toy, and game manufacturing	0.000137507
<b>387</b>	Office supplies (except paper) manufacturing	0.000130629
<b>388</b>	Sign manufacturing	0.000123874
<b>389</b>	Gasket, packing, and sealing device manufacturing	0.000104681
<b>390</b>	Musical instrument manufacturing	0.000109213
<b>391</b>	Fasteners, buttons, needles, and pins manufacturing	0.00010868
<b>392</b>	Broom, brush, and mop manufacturing	0.000118241
<b>393</b>	Burial casket manufacturing	0
<b>394</b>	All other miscellaneous manufacturing	0.000127946
<b>395</b>	Wholesale trade	0.000743199
<b>396</b>	Retail - Motor vehicle and parts dealers	0.00011714
<b>397</b>	Retail - Furniture and home furnishings stores	0.000126051
<b>398</b>	Retail - Electronics and appliance stores	0.000128708
<b>399</b>	Retail - Building material and garden equipment and supplies stores	0.000125867
<b>400</b>	Retail - Food and beverage stores	0.000138356
<b>401</b>	Retail - Health and personal care stores	0.000125241
<b>402</b>	Retail - Gasoline stores	0.000411462
<b>403</b>	Retail - Clothing and clothing accessories stores	0.00012776
<b>404</b>	Retail - Sporting goods, hobby, musical instrument and book stores	0.000126176
<b>405</b>	Retail - General merchandise stores	0.000122544
<b>406</b>	Retail - Miscellaneous store retailers	0.000125074
<b>407</b>	Retail - Nonstore retailers	0.000119357
<b>408</b>	Air transportation	0.000215234
<b>409</b>	Rail transportation	0.0002244
<b>410</b>	Water transportation	0.000255576
<b>411</b>	Truck transportation	0.000198155
<b>412</b>	Transit and ground passenger transportation	0.000157112
<b>413</b>	Pipeline transportation	0.007164734
<b>414</b>	Scenic and sightseeing transportation and support activities for transportation	0.000140402
<b>415</b>	Couriers and messengers	0.00018317
<b>416</b>	Warehousing and storage	0.000138756
<b>417</b>	Newspaper publishers	0.00015222
<b>418</b>	Periodical publishers	0.000113309
<b>419</b>	Book publishers	0.00011201
<b>420</b>	Directory, mailing list, and other publishers	0.000109171

421	Greeting card publishing	0.000129077
422	Software publishers	0.000114622
423	Motion picture and video industries	8.79883E-05
424	Sound recording industries	0.0001016
425	Radio and television broadcasting	9.91573E-05
426	Cable and other subscription programming	7.77266E-05
427	Wired telecommunications carriers	8.50838E-05
428	Wireless telecommunications carriers (except satellite)	9.32279E-05
429	Satellite, telecommunications resellers, and all other telecommunications	9.55739E-05
430	Data processing, hosting, and related services	0.000115063
431	News syndicates, libraries, archives and all other information services	9.45572E-05
432	Internet publishing and broadcasting and web search portals	0.000100428
433	Monetary authorities and depository credit intermediation	9.57432E-05
434	Nondepository credit intermediation and related activities	0.000101045
435	Securities and commodity contracts intermediation and brokerage	8.89156E-05
436	Other financial investment activities	9.09679E-05
437	Insurance carriers	9.37738E-05
438	Insurance agencies, brokerages, and related activities	9.87586E-05
439	Funds, trusts, and other financial vehicles	7.26847E-05
440	Real estate	0.000128894
441	Owner-occupied dwellings	0.000106743
442	Automotive equipment rental and leasing	0.000122666
443	General and consumer goods rental except video tapes and discs	0.000138393
444	Video tape and disc rental	0.000162679
445	Commercial and industrial machinery and equipment rental and leasing	0.000146225
446	Lessors of nonfinancial intangible assets	9.56157E-05
447	Legal services	0.000105565
448	Accounting, tax preparation, bookkeeping, and payroll services	0.000106031
449	Architectural, engineering, and related services	0.000104497
450	Specialized design services	0.00011116
451	Custom computer programming services	0.000101615
452	Computer systems design services	0.000105747
453	Other computer related services, including facilities management	0.000104415
454	Management consulting services	0.000105068
455	Environmental and other technical consulting services	0.00010555
456	Scientific research and development services	0.000105023

457	Advertising, public relations, and related services	0.000107166
458	Photographic services	0.000122031
459	Veterinary services	0.000122662
460	Marketing research and all other miscellaneous professional, scientific, and technical services	0.000109875
461	Management of companies and enterprises	0.000116064
462	Office administrative services	0.000108304
463	Facilities support services	0.00012258
464	Employment services	0.000103602
465	Business support services	0.00010803
466	Travel arrangement and reservation services	0.000104471
467	Investigation and security services	0.000107235
468	Services to buildings	0.000117991
469	Landscape and horticultural services	0.000133168
470	Other support services	0.000113818
471	Waste management and remediation services	0.000466119
472	Elementary and secondary schools	0.000123291
473	Junior colleges, colleges, universities, and professional schools	0.000238655
474	Other educational services	0.000106737
475	Offices of physicians	0.000108163
476	Offices of dentists	0.000120747
477	Offices of other health practitioners	0.000112536
478	Outpatient care centers	0.000119079
479	Medical and diagnostic laboratories	0.000113628
480	Home health care services	0.0001084
481	Other ambulatory health care services	0.000113032
482	Hospitals	0.000119115
483	Nursing and community care facilities	0.000127627
484	Residential mental retardation, mental health, substance abuse and other facilities	0.000118973
485	Individual and family services	0.000114952
486	Community food, housing, and other relief services, including rehabilitation services	0.000111853
487	Child day care services	0.000124449
488	Performing arts companies	9.8687E-05
489	Commercial Sports Except Racing	0.000106422
490	Racing and Track Operation	0.000106456
491	Promoters of performing arts and sports and agents for public figures	0.000131833
492	Independent artists, writers, and performers	9.91281E-05
493	Museums, historical sites, zoos, and parks	0.000129988

494	Amusement parks and arcades	0.000133208
495	Gambling industries (except casino hotels)	0.000108426
496	Other amusement and recreation industries	0.000133983
497	Fitness and recreational sports centers	0.000137172
498	Bowling centers	0.000148758
499	Hotels and motels, including casino hotels	0.000137862
500	Other accommodations	0.000140031
501	Full-service restaurants	0.0001257
502	Limited-service restaurants	0.00012465
503	All other food and drinking places	0.00012635
504	Automotive repair and maintenance, except car washes	0.000107416
505	Car washes	0.000123251
506	Electronic and precision equipment repair and maintenance	0.000101598
507	Commercial and industrial machinery and equipment repair and maintenance	0.000109927
508	Personal and household goods repair and maintenance	0.000111249
509	Personal care services	0.000118478
510	Death care services	0.000123554
511	Dry-cleaning and laundry services	0.000149014
512	Other personal services	0.000110526
513	Religious organizations	0.000101902
514	Grantmaking, giving, and social advocacy organizations	0.000102578
515	Business and professional associations	0.000132659
516	Labor and civic organizations	0.00011683
517	Private households	0.000104264
518	Postal service	0.000115885
519	Federal electric utilities	0.001084267
520	Other federal government enterprises	0.000118184
521	State government passenger transit	0
522	State government electric utilities	0
523	Other state government enterprises	0.00012201
524	Local government passenger transit	0.000602498
525	Local government electric utilities	0.00125407
526	Other local government enterprises	0.000131326
527	* Not an industry (Used and secondhand goods)	0
528	* Not an industry (Scrap)	0
529	* Not an industry (Rest of world adjustment)	0
530	* Not an industry (Noncomparable foreign imports)	0
531	* Employment and payroll of state govt, non-education	0.000104264
532	* Employment and payroll of state govt, education	0.000104264
533	* Employment and payroll of local govt, non-education	0.000104264

<b>534</b>	* Employment and payroll of local govt, education	0.000104264
<b>535</b>	* Employment and payroll of federal govt, non-military	0.000104264
<b>536</b>	* Employment and payroll of federal govt, military	0.000104264