WSU CGE ANALYSIS OF CARBON WA:
TECHNICAL DOCUMENTATION

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WSU CGE Analysis of Carbon WA:
*Technical Documentation*

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Abstract:
This paper provides a detailed description of the updates made to the 2007 Washington-Idaho Computable General Equilibrium Model created by Holland et al. in order to evaluate the impact of a revenue neutral carbon tax on the Washington State Economy. We modify the Holland et al. (2007) model by incorporating four significant changes which allow us to assess the effect of the revenue-neutral carbon tax policy. First, we impose a $0.14/gal tax and $0.24/gal tax on fossil fuels, in the first two years of the policy, which are equivalent to the $15/ton of carbon and $25/ton of carbon from fossil fuels in all sectors except agriculture. Second, we reduce the sales tax collected from the consumer by 0.5% in the first year and then 1% in the second year. Third, we reduce the business and occupation tax for the manufacturing sector from 0.484% to 0.001%. Finally, we rebate households in the lowest income bracket an amount equal to $157.74 million in the first year and $262.90 million during the second year.

JEL Codes: C68, H23, Q48

Keywords: Computable General Equilibrium Model, Washington State Initiative 732, Double Dividend, Revenue Neutral Carbon Tax
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Introduction:
Washington State has, for the past several years, been attempting to curb their carbon emissions with several proposed bills and expanded use of the Clean Air Rule. Carbon Washington’s I-732 was simultaneously trying to design an effective and economic policy that would achieve the same, or similar, environmental outcomes but with the potential second dividend of reduced distortionary taxes that lead to market inefficiencies. The following analysis shows how to implement the I-732 policy in a Computable General Equilibrium (CGE) framework. Using the 2007 Washington-Idaho CGE model created by Holland et al. We analyze a $0.14/gal tax and $0.24/gal tax on fossil fuels, in the first two years of the policy, which are equivalent to the $15/ton of carbon and $25/ton of carbon from fossil fuels in all sectors except agriculture. Second, we reduce the sales tax collected from the consumer by 0.5% in the first year and then 1% in the second year. Third, we reduce the business and occupation tax for the manufacturing sector from 0.484% to 0.001%. Finally, we rebate households in the lowest income bracket an amount equal to $157.74 million in the first year and $262.90 million during the second year.
Section 1: IMPLAN Social Accounting Matrix (SAM)

The IMPLAN SAM has a high degree of flexibility and is already designed to work with the Washington-Idaho Computable General Equilibrium model discussed in the next Chapter. It was for these reasons that we chose to use this data set. Assumptions about the IMPLAN SAM and the way the data is partitioned is discussed in the next three subsections of this chapter.

The IMPLAN SAM data is used to calculate initial values of various parameters and calibrate others once the policy shocks are implemented. It is worth noting that the SAM data is derived from a national SAM that has been regionalized to Washington State. We corroborated gross state product, total state and local government revenues, and industry output levels to ensure the data from IMPLAN aligned with the locally produced data. A comparison of these variables is provided in Appendix 1 at the end of this report.

The SAM is a square matrix composed of A industries (often referred to as activities in the CGE context), C commodities (representing both inputs to and outputs from the activities), F factors of production (labor, capital, and government payments), Institutions (households, federal & local governments, and investments), and foreign and domestic trade (FT and DT). The structure of the SAM is provided in Figure 1 below.

Figure 1: WA-ID CGE Aggregated SAM

Reading down a column will tell you where that column is spending its money. For example, reading down an industry column, such as Agriculture, will show you that the agricultural industry is spending money to buy various commodities that it will use in its production process: fertilizer, seed, accounting services etc. These data are reflected in the “USE” table of the matrix. Reading across a row tells you where that row is receiving its income or whom it is selling its output to. Agricultural commodities may be sold to households, government, exported to foreign and domestic markets, or sold to other industries for use in their production processes.
Sectoral Descriptions

Industries (A)
IMPLAN produces data on approximately 530 distinct industry sectors. These sectors are then aggregated into the 11 distinct sectors for use in the CGE model (Agriculture, Forestry, Mining, Utilities, Fossil fuel, Construction, Processed food, Wholesale and retail trade, Services, Manufacturing, and Miscellaneous). The 11 industries and their associated IMPLAN codes are described in Appendix 2.

These industries use commodities and factors in their production process. The mix of commodities, labor, capital, and payments to government represent the industries production technology. As is the case with all social accounts, the ratio of these inputs are held fixed in the short run, meaning that production technology is held constant. The CGE model does allow for some substitutability between labor and capital, as will be discussed in the next chapter. Fewer input payments for production results in less output being produced.²

Commodities (C)
The commodities align almost identically with the industries i.e., agricultural industries produce agricultural commodities. In some cases industries produce byproducts as well e.g., an apple orchard may have a forestry byproduct. The only other major issue with the commodities is that institutions can produce commodities as well. The clearest example of this might be a state owned and operated power plant³ (e.g., Bonneville Power). This is why the commodities column in the SAM includes not only the Make matrix but the institutional Make matrix, or IMAKE matrix, as well. Unlike the industries, which cannot be traded, commodities can be imported and exported from both foreign and domestic regions. This allows for cross hauling which is prevalent in the data and accounted for in the CGE model using Armington Trade specifications.

Factors (F)
There are three factors of production in the model Labor, Capital, and Payments to government. Labor is represented in IMPLAN as code 5001. Capital has two components: Proprietary Income and Other Property Income, codes 6001 and 7001, respectively. Payments to government are referred to in two ways in the model either as Indirect Business Taxes (INDT), or more traditionally as Taxes on Production and Imports (TOPI), code 8001. Labor and capital are partially substitutable in the CGE model through the use of a Leontief-CES hybrid production function.

² We hardwire the payments to government variable since in the short run public goods are relatively fixed implying that industries could free ride on that portion of their production expenses. This has effects on the calibration of the Walras variable.
³ Bonneville Power is a state owned and operated power plant. This would be a state government (institution) producing and selling energy as though it were a private industry.
Institutions (INST)
Institutions are represented by, 9 distinct household sectors (broken out by income levels), 3 federal government sectors (defense, non-defense, and Federal investment), 3 state government sectors (education, non-education, and State investments), and a private investment sector (corporate investments, private fixed investments, and inventory additions and deletions).

Household income is derived from payments to labor and capital as well as transfer payments from other households. Since the government acts as a pass-through organization for transfer payments they do not directly appear in the governments budgets. The government does receive income from commodity sales, TOPI, property taxes, sales taxes, and fines or fees levied on households as well as intergovernmental transfers$^4$. The investment sector operates quite differently from the other Institutions. Households, governments, and commodities$^5$ all contribute to or buy investments. Those investments then make annual payments to commodities and institutions.

Trade (FT, DT)
The trade sectors are important from a general equilibrium perspective since domestic and world prices will govern the volumes of imports and exports. As far as this paper is concerned we do not directly influence these sectors. Trade will be indirectly influenced through the domestic policy shocks that will have implications on prices, which will in turn have implications on foreign and domestic demand for regionally produced goods. In the context of this report foreign refers to non-U.S. quantities and prices, domestic refers to out-of-region but within the U.S. quantities and prices, and regional refers to Washington state.

The Carbon Sector
The Carbon sector in the model was created by taking the carbon producing industries and grouping them together. Applying a tax on these industries will cause the price of the goods produced by these industries to increase. Such price increases will then be passed on to final consumers of the carbon sector. The rational for modeling the tax in this way was that it would directly influence commodity prices and those increased prices would then be passed through the production process to the end user. This ensured that all carbon consumption, even in the intermediate stages of production would be influenced. Table 1 below outlines which IMPLAN sectors were included in the Fossil-Fuel sector.

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$^4$ Care must be used when calculating total government revenues since intergovernmental transfers may lead to some double counting.

$^5$ Commodities contribute to the investment sector through additions and deletions from their stock of inventory. For example, excess production of natural gas may be stored, contributing to inventory reserves.
Table 1: Description of the Fossil-Fuel Sector

<table>
<thead>
<tr>
<th>IMPLAN Code</th>
<th>Industry title</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Extraction of natural gas and crude petroleum</td>
</tr>
<tr>
<td>21</td>
<td>Extraction of natural gas liquids</td>
</tr>
<tr>
<td>22</td>
<td>Coal mining</td>
</tr>
<tr>
<td>37</td>
<td>Drilling oil and gas wells</td>
</tr>
<tr>
<td>38</td>
<td>Support activities for oil and gas operations</td>
</tr>
<tr>
<td>156</td>
<td>Petroleum refineries</td>
</tr>
</tbody>
</table>

**Prices and Taxes**

It is important to note that in the base SAM prices are all normalized to 1 and taxes are embedded in the values of the goods sold. The only initial tax rates calculated by the model then are the indirect business tax rates, and the household income/property tax rates. The SAM by itself would hold these prices and taxes fixed, as supply and demand are assumed by the SAM to be perfectly elastic and inelastic respectively. It is only through the use of the CGE model that these values are able to fluctuate.

In the initial model, sales and commodity taxes are indexed solely on commodities. It was our intention to be able to vary these taxes for each industry and household. Doing this allowed us to change the B&O tax rate for manufacturing only. In the downloadable version of the WA-ID model this would not have been possible since the sales tax was only indexed on commodities. This required us to change the original \( tb(C) \) to \( tb(A, C) \). This change made it possible for us to change, for example, the tax the agricultural industry paid for their fuel commodity i.e.,

\[
tb_2(AGR - A', 'Fossil - C') = \frac{1}{MT} C_{0.2}
\]

That is to say farmers, in year two, would pay an additional dollar per metric ton of carbon emissions from their fuel consumption.\(^6\)

**Section 2: WA-ID CGE Model**

The CGE model developed by economists at University of Idaho and Washington State University was built to work with the IMPLAN Data set and has many attractive attributes. It has a fully specified Armington trade model which is important when modeling states with international air and sea ports and heavily reliant on export markets. It is fairly well commented as far as computer programs go so tracing through various modeling procedures can be done relatively smoothly. Perhaps the most appealing part of the model is that it is open source and does not require one to start building a full CGE model from scratch. It is important to note that since it is produced in GAMS, it has a host of built in solvers that can quickly converge on equilibria, but those solvers are not themselves transparent.

\(^6\) This translates into roughly .38% per gallon of fuel.
Overall the model is broken into 6 primary components: parameters (some of which are calculated from the initial data), variables, the consumer’s problem, the producer’s problem, the government’s balanced budget conditions, and the trade components. In what follows we will explain in technical terms the key components of each of these aspects of the model.\(^7\)

**Parameters**

The parameters in the CGE model may be assumed at the outset, such as the demand elasticity for capital and labor, or calculated based on the base SAM, such as the intermediate input of a particular commodity per unit of output from a particular industry/activity\(^8\). Table 2 below shows the initial parameter values as set by the user. Appendix 3 outlines the other parameters that are calculated by the base SAM. The corresponding calculations can be found in the WA-ID CGE documentation but for the sake of brevity are not presented here\(^9\).

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\(^7\) The goal here is to provide the reader with the basic understanding of our modeling approach, what we have altered and why. Complete replication of our results should be possible if the reader were to download and use the 2014 Washington State IMPLAN SAM, the WA-ID CGE model, and follow the procedures outlined in this chapter.

\(^8\) Because we are now discussing the CGE model it is more common to refer to industries as activities. Though these two terms are synonymous it is more traditional to speak of industries when referring to the static SAM and activities when discussing the CGE model.

\(^9\) The WA-ID CGE documentation may be found at http://www.agribusiness-mgmt.wsu.edu/Holland_model/docs/DocumentationR.pdf
Table 2: Initial Prices And Parameters Set by The User

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Initial Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>XRO(T)</td>
<td>Initial exchange rate</td>
<td>1</td>
</tr>
<tr>
<td>PWEO(C,T)</td>
<td>Initial world export price in foreign currency</td>
<td>1</td>
</tr>
<tr>
<td>PMO(C)</td>
<td>Initial composite import price in regional currency</td>
<td>1</td>
</tr>
<tr>
<td>PEO(C)</td>
<td>Initial composite export price in regional currency</td>
<td>1</td>
</tr>
<tr>
<td>PQO(C)</td>
<td>Initial composite commodity price</td>
<td>1</td>
</tr>
<tr>
<td>PDO(C)</td>
<td>Initial regional price of regional output</td>
<td>1</td>
</tr>
<tr>
<td>PXO(C)</td>
<td>Initial producer price</td>
<td>1</td>
</tr>
<tr>
<td>PAO(A)</td>
<td>Initial activity price</td>
<td>1</td>
</tr>
<tr>
<td>pwm(T,C)</td>
<td>World import price in foreign currency (exogenous)</td>
<td>1</td>
</tr>
<tr>
<td>frisch(C)</td>
<td>Frisch parameter for Stone-Geary utility function</td>
<td>-1</td>
</tr>
<tr>
<td>ine(C,H)</td>
<td>Income elasticity</td>
<td>1</td>
</tr>
<tr>
<td>xed(C,T)</td>
<td>Elasticity of demand for world export demand function</td>
<td>-50</td>
</tr>
<tr>
<td>esubp(A)</td>
<td>Elasticity of substitution for production function</td>
<td>0.99</td>
</tr>
<tr>
<td>esubd(C)</td>
<td>Elasticity of substitution between regional output and imports</td>
<td>2</td>
</tr>
<tr>
<td>esubs(C)</td>
<td>Elasticity of transformation between regional output and exports</td>
<td>2</td>
</tr>
<tr>
<td>esube(C)</td>
<td>Elasticity of transformation between foreign and regional exports</td>
<td>2</td>
</tr>
<tr>
<td>esubm(C)</td>
<td>Elasticity of substitution between foreign and regional imports</td>
<td>2</td>
</tr>
<tr>
<td>tq(A,C)</td>
<td>Sales tax activity A pays for commodity C</td>
<td>0</td>
</tr>
<tr>
<td>tc(H,C)</td>
<td>Consumption tax rate (paid only by households)</td>
<td>0</td>
</tr>
<tr>
<td>tqs(C)</td>
<td>Sales tax rate on services not previously taxed</td>
<td>0</td>
</tr>
<tr>
<td>tm(T,C)</td>
<td>Import tax rate</td>
<td>0</td>
</tr>
<tr>
<td>te(C,T)</td>
<td>Export tax rate</td>
<td>0</td>
</tr>
<tr>
<td>efac(FF)</td>
<td>Demand elasticity for factors of production</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Endogenous Variables**

There are three types of endogenous variables in the model: prices, quantities, and accounting variables. These variables are calibrated by the model for a given shock. A negative shock to the consumption tax will simultaneous cause prices, quantities, government revenues and expenditures, household gross and net income, etc. to adjust. Thus, one shock may influence price and quantity variables, and the “accounting” variables such as government revenue or household income will also fluctuate.

These variables are all embedded in the mathematical formulation of the model discussed in the next subsections. It is how these endogenous variables move given a specific shock, or set of shocks, that is critical. The results of the model are all reflective of the changes in these variables. The following three tables list these variables.

Table 3 shows the endogenous price variables that are all initially set to 1. After the shock is implemented these values are recalibrated to their new equilibrium and the change represents the relative price changes caused by the shock. Thus, a price of 1.1 can be interpreted as a 10% increase in the price of that good.
Table 3: Endogenous Price Variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>XR</td>
<td>Exchange rate</td>
</tr>
<tr>
<td>CPI</td>
<td>Consumer price index</td>
</tr>
<tr>
<td>PMR</td>
<td>Regional import price in regional currency</td>
</tr>
<tr>
<td>PWE</td>
<td>World export price in foreign currency</td>
</tr>
<tr>
<td>PER</td>
<td>Regional export price in regional currency</td>
</tr>
<tr>
<td>PM</td>
<td>Composite import price in regional currency</td>
</tr>
<tr>
<td>PE</td>
<td>Composite export price in regional currency</td>
</tr>
<tr>
<td>PQ</td>
<td>Composite commodity price</td>
</tr>
<tr>
<td>PD</td>
<td>Regional price of regional output</td>
</tr>
<tr>
<td>PX</td>
<td>Producer price</td>
</tr>
<tr>
<td>PA</td>
<td>Activity price</td>
</tr>
<tr>
<td>PVA</td>
<td>Value added price</td>
</tr>
<tr>
<td>WF</td>
<td>Average wage or rental rate for factor FF</td>
</tr>
</tbody>
</table>

Table 4 shows the endogenous quantity variables. Recall that in the base case, since prices were set to 1, the initial “quantities” represented both quantity and value i.e., \( P \cdot Q = Q = V \). After the prices change these equilibrium quantities adjust as well, requiring us to show quantities of goods produced and the associated value of production separately.

Table 4: Endogenous Quantity Variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>QMR</td>
<td>Regional imports</td>
</tr>
<tr>
<td>QER</td>
<td>Regional exports</td>
</tr>
<tr>
<td>QM</td>
<td>Composite import quantity</td>
</tr>
<tr>
<td>QE</td>
<td>Composite export quantity</td>
</tr>
<tr>
<td>QQ</td>
<td>Composite quantity supplied to regional demanders</td>
</tr>
<tr>
<td>QD</td>
<td>Quantity of regional output supplied to regional demanders</td>
</tr>
<tr>
<td>QX</td>
<td>Quantity of regional output</td>
</tr>
<tr>
<td>QA</td>
<td>Activity level</td>
</tr>
<tr>
<td>QINT</td>
<td>Quantity of intermediate use of commodity C by activity A</td>
</tr>
<tr>
<td>IMAKEQ</td>
<td>Institutional make matrix (quantity)</td>
</tr>
<tr>
<td>QF</td>
<td>Quantity of factor FF demanded by activity A</td>
</tr>
<tr>
<td>QH</td>
<td>Household consumption</td>
</tr>
<tr>
<td>QINV</td>
<td>Investment demand</td>
</tr>
<tr>
<td>QIINV</td>
<td>Investment demand by institutions</td>
</tr>
<tr>
<td>QFS</td>
<td>Factor supply</td>
</tr>
<tr>
<td>INDT</td>
<td>Indirect business taxes receipts for each government unit</td>
</tr>
</tbody>
</table>

Lastly, table 5 displays the accounting variables. These variables are in some sense just the names of various equations in the model: Income, expenditure, savings levels etc. These equations are the heart of the model used to calibrate the equilibrium values. The one exception is the Walras dummy variable which insures the model is not under identified.
Table 5: Endogenous Accounting Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>YF</td>
<td>Transfer of income to institution I from factor FF</td>
</tr>
<tr>
<td>YH</td>
<td>Gross household income</td>
</tr>
<tr>
<td>NYH</td>
<td>Net household income</td>
</tr>
<tr>
<td>YFG</td>
<td>Federal government income</td>
</tr>
<tr>
<td>EFG</td>
<td>Federal government expenditure</td>
</tr>
<tr>
<td>YSG</td>
<td>State government revenue</td>
</tr>
<tr>
<td>ESG</td>
<td>State government expenditure</td>
</tr>
<tr>
<td>FSAVX</td>
<td>Foreign savings (export column)</td>
</tr>
<tr>
<td>FSAVM</td>
<td>Foreign savings (import row)</td>
</tr>
<tr>
<td>DSAVX</td>
<td>RUS savings (export column)</td>
</tr>
<tr>
<td>DSAVM</td>
<td>RUS savings (import row)</td>
</tr>
<tr>
<td>WFDIST</td>
<td>Factor price distortion factor</td>
</tr>
<tr>
<td>SGADJ</td>
<td>State government spending adjustment factor</td>
</tr>
<tr>
<td>SHIFTFF</td>
<td>Factor supply equation shift variable</td>
</tr>
<tr>
<td>WALRAS</td>
<td>WALRAS dummy variable (should be 0)</td>
</tr>
</tbody>
</table>

Baseline Results

The baseline results show the beginning values in the model prior to any policy shocks being implemented. All subsequent analysis will be compared relative to these values so that net change in economic values may be observed. This particular section therefore sets the stage and is truly just a representation of the IMPLAN data that currently describes the economy.

Table 6 gives a list of the 11 industrial sectors in column 1, their value added or GRP in column 2, and their business tax payments in column 3. All values are reported in millions of dollars and the “State” row shows total gross state product, and total tax revenues by sector. It is important to note that total state tax revenue from the industries does not equal the total state tax revenue since states derive income from other sources as discussed in the government sub-section of chapter two.

Table 6: Baseline value added and government payments by sector

<table>
<thead>
<tr>
<th>Industrial Sectors</th>
<th>Baseline GDP</th>
<th>Baseline State Revenues</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGR-A</td>
<td>8,710</td>
<td>120</td>
</tr>
<tr>
<td>FOREST-A</td>
<td>685</td>
<td>29</td>
</tr>
<tr>
<td>CONST-A</td>
<td>17,124</td>
<td>532</td>
</tr>
<tr>
<td>UTIL-A</td>
<td>5,649</td>
<td>1,229</td>
</tr>
<tr>
<td>Fossil-A</td>
<td>3,071</td>
<td>96</td>
</tr>
<tr>
<td>TRAD-A</td>
<td>50,848</td>
<td>12,203</td>
</tr>
<tr>
<td>MIN-A</td>
<td>616</td>
<td>19</td>
</tr>
<tr>
<td>FOOD-A</td>
<td>4,337</td>
<td>401</td>
</tr>
<tr>
<td>MAN-A</td>
<td>49,271</td>
<td>1,033</td>
</tr>
<tr>
<td>SER-A</td>
<td>223,556</td>
<td>15,790</td>
</tr>
<tr>
<td>MISC-A</td>
<td>64,761</td>
<td>87</td>
</tr>
<tr>
<td>State (Million)</td>
<td>428,629</td>
<td>89,402</td>
</tr>
</tbody>
</table>

Table 7 outlines the imports and exports of the Washington economy by commodity. As stated before, the goal of this exercise is not to delve into the rigors of the current and
capital accounts. This data is simply here as a baseline to see how trade is incorporated in the analysis, a component that is often left out of such policy analyses. It is worth noting here, however, that Washington does import a large amount of crude oil for processing.

### Table 7: Value/Quantity of Trade

<table>
<thead>
<tr>
<th>Industrial Sectors</th>
<th>Imports</th>
<th>Exports</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGR-C</td>
<td>5,273</td>
<td>7,625</td>
</tr>
<tr>
<td>FOREST-C</td>
<td>151</td>
<td>472</td>
</tr>
<tr>
<td>CONST-C</td>
<td>1,827</td>
<td>132</td>
</tr>
<tr>
<td>UTIL-C</td>
<td>4,826</td>
<td>3,888</td>
</tr>
<tr>
<td>Fossil-C</td>
<td>20,075</td>
<td>5,644</td>
</tr>
<tr>
<td>TRAD-C</td>
<td>4,465</td>
<td>15,399</td>
</tr>
<tr>
<td>MIN-C</td>
<td>512</td>
<td>455</td>
</tr>
<tr>
<td>FOOD-C</td>
<td>14,563</td>
<td>15,503</td>
</tr>
<tr>
<td>MAN-C</td>
<td>126,911</td>
<td>109,721</td>
</tr>
<tr>
<td>SER-C</td>
<td>63,800</td>
<td>81,073</td>
</tr>
<tr>
<td>MISC-C</td>
<td>12,182</td>
<td>4,780</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>254,585</strong></td>
<td><strong>244,692</strong></td>
</tr>
</tbody>
</table>

Other critical baseline values are the amount of each commodity used by each industry in their production process (table 8) and household purchases of commodities (table 9).

### Table 8: commodity use by Industry

<table>
<thead>
<tr>
<th>AGR-C</th>
<th>FOREST-C</th>
<th>CONST-C</th>
<th>UTIL-C</th>
<th>Fossil-C</th>
<th>TRAD-C</th>
<th>MIN-C</th>
<th>FOOD-C</th>
<th>MAN-C</th>
<th>SER-C</th>
<th>MISC-C</th>
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<tbody>
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<td>279</td>
<td>14</td>
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<td>1,161</td>
<td>489</td>
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<tr>
<td>65</td>
<td>134</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>36</td>
<td>-</td>
<td>13</td>
<td>29</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>-</td>
<td>17</td>
<td>146</td>
<td>1,405</td>
<td>6,142</td>
<td>338</td>
<td>-</td>
<td>8,686</td>
<td>3,775</td>
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<td>-</td>
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<td>-</td>
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<td>435</td>
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<tr>
<td>27</td>
<td>-</td>
<td>234</td>
<td>755</td>
<td>243</td>
<td>1,486</td>
<td>0</td>
<td>17</td>
<td>1,527</td>
<td>18,552</td>
<td>269</td>
</tr>
<tr>
<td>0</td>
<td>-</td>
<td>39</td>
<td>41</td>
<td>108</td>
<td>42</td>
<td>84</td>
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<td>123</td>
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<td>1</td>
</tr>
<tr>
<td>6,389</td>
<td>7</td>
<td>91</td>
<td>363</td>
<td>96</td>
<td>2,196</td>
<td>-</td>
<td>4,060</td>
<td>2,447</td>
<td>3,047</td>
<td>128</td>
</tr>
<tr>
<td>257</td>
<td>644</td>
<td>478</td>
<td>1,919</td>
<td>1,073</td>
<td>6,897</td>
<td>623</td>
<td>573</td>
<td>64,117</td>
<td>17,240</td>
<td>984</td>
</tr>
<tr>
<td>108</td>
<td>0</td>
<td>4,083</td>
<td>2,718</td>
<td>3,486</td>
<td>5,167</td>
<td>129</td>
<td>1,836</td>
<td>14,764</td>
<td>103,400</td>
<td>3,575</td>
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<tr>
<td>86</td>
<td>-</td>
<td>3,285</td>
<td>229</td>
<td>1,125</td>
<td>401</td>
<td>11</td>
<td>559</td>
<td>1,093</td>
<td>6,614</td>
<td>238</td>
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</table>

### Table 9: Total Household Commodity

<table>
<thead>
<tr>
<th>Industrial Sectors</th>
<th>HH all</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGR-C</td>
<td>1,608</td>
</tr>
<tr>
<td>FOREST-C</td>
<td>-</td>
</tr>
<tr>
<td>CONST-C</td>
<td>-</td>
</tr>
<tr>
<td>UTIL-C</td>
<td>5,525</td>
</tr>
<tr>
<td>Fossil-C</td>
<td>5,268</td>
</tr>
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<td>TRAD-C</td>
<td>35,113</td>
</tr>
<tr>
<td>MIN-C</td>
<td>5</td>
</tr>
<tr>
<td>FOOD-C</td>
<td>14,346</td>
</tr>
<tr>
<td>MAN-C</td>
<td>28,325</td>
</tr>
<tr>
<td>SER-C</td>
<td>176,871</td>
</tr>
<tr>
<td>MISC-C</td>
<td>16,948</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>284,009</strong></td>
</tr>
</tbody>
</table>
Other baseline values exist, for example, baseline prices are all normalized to 1. These prices will adjust according to the resulting equilibrium but are interpreted as price changes. Similarly, since prices are all 1 in the base case, base case values are the same as base case quantities. When looking at changes in quantity and value after the implementation of the policy shock these must incorporate the new prices.

**Consumer Problem**

The consumer’s problem in this model is represented by the Linear Expenditure System, derived from the Stone-Geary utility function, and the net and gross household income equations.

**Gross household income:**

Household income may be derived from a variety of sources. The obvious sources are from the households’ ownership and payments to their labor and capital, $\sum_F YF_{H,F}$, the value of their investments, $QINV_{H}$, and any transfer payments they receive from government, $CPI \cdot \sum_G SAM_{H,G}$. However, households may also receive income through direct interhousehold transfers, $\sum_H (trh_{H,H} \cdot (1 - \sum_G ty_{G,H})YH_{H})$, domestically selling commodities they produce, $\sum_C PX_C \cdot IMAKEQ_{H,C}$, or sales made via international and domestic trade, $CPI \cdot \sum_T SAM_{H,T}$.

$$YH_{H} = \sum_F YF_{H,F} + \sum_C PX_C \cdot IMAKEQ_{H,C} + CPI \cdot \sum_G SAM_{H,G} + QINV_{H}$$

$$+ \sum_H (trh_{H,H} \cdot (1 - \sum_G ty_{G,H})YH_{H}) + CPI \cdot \sum_T SAM_{H,T}$$

Where $YH_{H}$ is gross household income, $YF_{H,F}$ is the households income by factor (labor and capital), $PX_C$ is the price of commodity C received by the institutions (households in this case) and $IMAKEQ_{H,C}$ as the quantity of commodity C produced by each household. The $CPI$ is the consumer price index calibrated by the model given the shocks and $SAM_{H,G}$ represents the value of transfers from governments to households as calculated in the base SAM. $QINV_{H}$ is the quantity of investments indexed by households. $trh_{H,H}$ is the inter-household transfer rate and $ty_{G,H}$ is the household effective income tax rate. $SAM_{H,T}$ is simply the household sales to foreign and domestic trade sectors in the base SAM.

**Net household income:**

To turn the above gross household income to net household income, taxes, transfer payments, etc. must be removed. Net household income, $NYH_{H}$, is calculated as
\[ NYH_H = YH_H - \sum_H \left( trh_{H,H} \cdot \left( 1 - \sum_G ty_{G,H} \right) YH_H \right) - SADJ \cdot mps_{H,H} \cdot \left( 1 - \sum_G ty_{G,H} \right) YH_H \\
- \sum_G ty_{G,H} \cdot YH_H - CPI \cdot \sum_T SAM_{H,T} \]

Where \( NYH_H \) is the net household income. Inter-household transfers, effective income tax rates, gross household income, the CPI and SAM variables are as before. \( SADJ \) is a household savings adjustment variable, \( mps_{H,H} \) is the households marginal propensity to save, and \( ty_{G,H} \) is the effective income tax rate\(^{10} \).

**Household consumption demand:**

We can now use the Linear Expenditure System to calculate the household consumption demand. Traditionally the Stone-Geary utility function, \( U = \prod_i (q_i - \lambda_i)^{\beta_i} \), assumes a minimum level of expenditure, \( \lambda_i \), for each of the i-commodities. If this assumption is removed the Stone-Geary function becomes Cobb-Douglas. The value in using the Stone-Geary utility is that excess income, income remaining after the minimum purchases of the i-commodities are made, is assumed to be spent in constant proportions on each good. The Linear Expenditure System then becomes

\[ QH_{C,H} = \lambda_{C,H} + \frac{\beta_{C,H} \cdot \left( NYH_H - \sum_C \left( \lambda_{C,H} \cdot PQ_{C,H} \cdot (1 + tc_{H,C}) \right) \right)}{PQ_C \cdot (1 + tc_{H,C})} \]

where \( QH_{C,H} \) is the households demand of commodity \( C \), \( \lambda_{C,H} \) is the minimum household purchase of commodity \( C \), \( \beta_{C,H} \) is the marginal share of the household's budget going to commodity \( C \), \( PQ_C \) is the consumer price for commodity \( C \), and \( tc_{H,C} \)\(^{11} \) is the consumption tax rate the household pays on commodity \( C \).

**Producer Problem**

The primary alteration to the production process is that we held industry payments to government fixed in the short run i.e., we held the industries payment to government fixed at the original value of the SAM. The reason for this was that reducing the B&O rate should make production more profitable and result in higher output, but from a strictly Leontief prospective the tax is an input to the production process and reducing it would have made the quantity produced go down. Thus the original Leontief-CES production function, \( q_i =

\(^{10}\) The income tax rate in Washington is zero, but the effective rate includes federal income tax, fees, fines, and other household payments to government not including consumption tax revenue.

\(^{11}\) Because this variable differs from the original model the average tax for all households is used.
\[
\min \left(\frac{z_{i1}}{a_{i1}}, \frac{z_{i2}}{a_{i2}}, \ldots, \frac{z_{i11}}{a_{i11}}\right) \ast (a_i K_i^\rho_i + (1 - a_i) L_i^\rho_i)^{\frac{1}{\rho_i}}, \text{ where } z_{ij} \text{ is quantity of commodity } j \text{ firm } i \text{ uses and } a_{ij} \text{ is the corresponding technical coefficient. The } \min(\cdot) \text{ component of the function represents the Leontief component and the remaining factors represent the standard CES component. This equation takes on a slightly different form in the model, becoming}
\]
\[
QA_A = \frac{ad_A}{1 - \left(\frac{SAM_{\text{INDT},A}}{SAM_{\text{TOTAL},A}}\right) - \sum_C ic_{CA} \left(\sum_F del_{F, A} \times QF_{F, A}^{-\rho_A}\right)^{-\frac{1}{\rho_A}}}
\]

Where \(QA_A\) is the output of activity A, \(ad_A\) is a production shift parameter, \(ic_{CA}\) is the quantity of commodity C used in producing a unit of activity A’s output, \(del_{F, A}\) is the share parameter of the production function, \(QF_{F, A}\) is the quantity of factor F used in the production process of activity A, and \(\rho_A\) reflects an elasticity of substitution between labor and capital for industry A. The values \(SAM_{\text{INDT},A}\) and \(SAM_{\text{TOTAL},A}\) are the industry payments to government and industry total outlays from the base SAM respectively.

The important thing to note about this production function is that it is CES with respect to the factors of production but Leontief with respect to the other commodities. This Hybrid production function allows for some flexibility in the production form which is an improvement beyond what a multi-regional input-output model could afford.

**Government Problem**

The state government problem is simply to ensure that the state revenues and state expenditures balance. The balanced budget condition guarantees this by forcing the variables in each equation to adjust until a balance is struck. We do not address the federal government equations in this section since the complexities of the current accounts are not our primary focus. It is important to note that the original CGE model double counted state-intergovernmental transfers and that component of revenues and expenditures needed to be removed from the equations.

**State government revenue**

In this model government revenue is derived from 10 different sources: income/property tax revenue\(^{12}\), tariffs, federal transfers to state government, sales of state produced commodities, the asset value of state investments, employment taxes, taxes on production, sales taxes paid by industries, sales taxes paid by consumers, and taxes on services. Because the IMPLAN SAM does not break out government revenues in this way several of

---

\(^{12}\) This is a generic reference to payments from households to government that do not include consumption tax revenues.
the assumed initial tax rates are set to zero as shown in the parameters section of the previous chapter. It is important to note that in the original model state intergovernmental transfer were included. This resulted in a double counting of some state dollars. In order to reproduce the results shown in this paper such transfers must be removed from the state government revenue equation.

\[ Y_{SG} = \sum_{H,SG} ty \cdot Y_H + CPI \cdot \sum_{T,SG} SAM_{SG,T} + CPI \cdot \sum_{SG,FG} SAM_{SG,FG} + \sum_{C,SG} PX_C \cdot IMAKEQ_{SG,C} + \sum_{SG} QIINV_{SG} + \sum_{SG,F} YF_{SG,F} + \sum_{SG} INDT_{SG} + \sum_C (PM_C \cdot QM_C \cdot CM_C + PD_C \cdot QD_C) \cdot tq_{A,C} + \sum_{H,C} PQ_C \cdot QH_{C,H} \cdot tc_{H,C} \]

Where \( Y_{SG} \) is state government revenue, \( ty \) is the effective income tax rate, \( Y_H \) is the households gross income, \( CPI \) is the consumer price index, and \( SAM_{SG,T} \) is the state’s output sold to domestic and foreign markets as calculated by the base SAM. \( SAM_{SG,FG} \) represents the intergovernmental transfers from the federal government to the state in the bass SAM. \( PX_C \) is the producer price of commodity C and \( IMAKEQ_{SG,C} \) is the state’s output of commodity C. \( QIINV_{SG}, YF_{SG,F}, \) and \( INDT_{SG} \) represent the value of state investments, the returns to state government from state owned capital and payments to state employees, and lastly the indirect business taxes industries pay to the state government. \( PM_C \) is the composite commodity price of imported goods, \( QM_C \) is the quantity of composite commodity imported, and \( CM_C \) is a dummy variable that takes on a value of 1 if there are imports of commodity C and 0 otherwise. \( PD_C \) and \( QD_C \) are the price and quantity of domestically produced and sold goods. The sales tax rate, which may be thought of as the tax industries pay on production is \( tq_{A,C} \). The household consumption tax revenue received by the state is captured as the price of commodity C, \( PQ_C \), times the quantity of commodity C sold to household H, \( QH_{C,H} \), times the newly introduced consumption tax rate, \( tc_{H,C} \).

State government Expenditures

The state government spends money on investments such as state pensions, imports, commodities used in their production processes, and transfers. As in the case of their revenues many of these expenditures are adjusted with the CPI.

\[ ESG = CPI \times \sum_{SG,I} SAM_{I,SG} + CPI \times \sum_{SG,T} SAM_{T,SG} + SGADJ \times \sum_{SG,C} PQ_C \cdot qg_{C,SG} - \sum_H \text{trans}_H - CPI \times sgovbal \]
Where $ESG$ is the states expenditures. The $CPI$ is as it was before and $SAM_{t,SG}$ is state government payments to other institutions as calculated in the base SAM. $SAM_{T,SG}$ is the value of state purchases of imports from U.S. and foreign markets. $SGADJ$ is a state government sales adjustment factor, $PQ_C$ remains the composite commodity price level, and $qg_{C,SG}$ is state government consumption of commodity $C$. In order to force government budgets down to account for the residual payment to households from the carbon policy $trans_H$ was included directly in the governments expenditures. The $sgovbal$ is simply a balanced budget variable that ensures expenditures match the revenues. Because the household rebate is modeled as a residual payment it actually reduces the government’s overall budgets.

**Section 3: Modeling the Proposed Policy**

The code for the following Shocks to the model can be found in Appendix 4. It should replace the initial shock in the CGE code.

```
  " * Set counterfactual
  xshift('MAN-C','FT') = 10.0*xshift('MAN-C','FT');"
```

This shock is just a default that allows the model to run a scenario. Effectively it increases the foreign trade of the manufacturing sector in much the way an I-O model would were exogenous final demand to increase by a factor of 10.

**Sales Tax Reduction**

For the purposes of our model the reduction in “Sales” tax is a reduction in the consumption tax rate paid by households. Currently that rate is 6.5%. It is quite true that food is not taxed in Washington and Alcohol and Tabaco are taxed at higher rates. Because our model is not capturing the entirety of the Washington State tax code these nuances are ignored. However, there are several issues with the underlying SAM that require us to adjust some measures of the sales tax in both years of our analysis. The first and largest issue is how housing is handled in the SAM this sector in the model falls under services and is known as Owner Occupied Dwellings. What is standard in both input-output and SAMs is to allow this vector to operate as though the owner of a home is paying rent to himself. Clearly this element and others like it need to be exempted from the tax rates, which are why different rates are applied to the service sector and all other household consumption.

Because the consumption tax rate is initially set at zero and all changes are modeled as a percentage reduction i.e., a -.01 would represent a 1% reduction in the current rate. For the service sector rate the same methodology applies but only to the percentage of services effected by the consumption tax reduction e.g. -.01*30%.
**Business and Operations Tax Reduction**

The B&O tax reduction only applies to the manufacturing sector and we have ignored some of the intricacies of how semi-conductor manufacturing, for example, may be affected differently from other manufacturing sectors. Essentially we calculate the portion of TOPI reflective of B&O, and reduce that portion of the TOPI rate originally at .4%\(^{13}\) to .001%. This portion of the code stays constant in both years of the model since it is fully implemented in the first year and does not change.

**Carbon Tax**

The Carbon tax payment, as stated previously is a tax we place on the fossil fuel sector itself. Again, this tax was originally set at 0 and we need to turn the annual $25 per metric ton of CO2 into a percentage tax rate. From various source we estimated 8.9kg of CO2 per unit of output from the fossil fuel sector, 907.185kg equals a metric ton. So a $25 per metric ton rate became a 7.6% price increase when the estimated price per unit of output from the fossil fuel sector was $3.23. Thus, in the second year the increased sales tax for non-exempt industries was 7.6% and for the agricultural sector it was 0.38%.

**Transfer Payment**

The transfer payments came directly from the lobby group Carbon Washington at $157.74 million in the first year and $262.9 in the second year. Because the total state budgets were declining absent the transfer this money was withdrawn from the states investment funds, as can be seen in the following results.

---

\(^{13}\) Even though the official rate was .484% the original SAM was producing a .4% in the base case. This may have been a result of other manufacturing sectors, such as semiconductor manufacturing, bringing the sector average down slightly.
Appendix 1: Validation of Base IMPLAN Data for Washington

There is always a need to externally verify the data used in these models so we did several preliminary checks to ensure the numbers we were working with resembled the published data from various government sources. The first and easiest check was to ensure that the Gross State product matched that reported by IMPLAN. IMPLAN reported this number at $428.6 billion and the BEA\(^{14}\) reported it at $422.8 billion. This represented only a 1.3% difference, which we were comfortable with. Initial state government revenues including operating and non-operating budgets were reported by IMPLAN at $89.4 billion and by the 2012 Census of Governments\(^ {15}\) at $88.5 billion.

The last check we did was to see how total regional output by industry lined up with the BEA’s measures. Table A.1 shows a relatively close match, usually within 1-2% of one another.

<table>
<thead>
<tr>
<th>Industrial Sectors</th>
<th>IMPLAN Data</th>
<th>BEA DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGR-A</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>FOREST-A</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>CONST-A</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>UTIL-A</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Fossil-A</td>
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<td>0%</td>
</tr>
<tr>
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<td>12%</td>
</tr>
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<td>MIN-A</td>
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<td>0%</td>
</tr>
<tr>
<td>FOOD-A</td>
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</tr>
<tr>
<td>MAN-A</td>
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<td>11%</td>
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<tr>
<td>SER-A</td>
<td>52%</td>
<td>50%</td>
</tr>
<tr>
<td>MISC-A</td>
<td>15%</td>
<td>17%</td>
</tr>
</tbody>
</table>

\(^{14}\) See the BEA’s regional GDP by state in millions of current dollars [http://www.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=2#reqid=70&step=10&isuri=1\&7003=200&7035=-1&7004=naics&7005=1&7006=53000&7036=-1&7001=1200&7002=1&7090=70&7007=2014&7093=levels](http://www.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=2#reqid=70&step=10&isuri=1\&7003=200&7035=-1&7004=naics&7005=1&7006=53000&7036=-1&7001=1200&7002=1&7090=70&7007=2014&7093=levels)

\(^{15}\) This data is obtained by summing the State and Local government revenues together (columns 3 and 4) in order to match the IMPLAN figures. This data may be downloaded at [https://www.census.gov/govs/local/](https://www.census.gov/govs/local/)
## Appendix 2: Description of the 11 Industrial Sectors

Three sectors: Processed foods, Services, and Manufacturing

<table>
<thead>
<tr>
<th>Table A.2: Sector Descriptions</th>
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<td>Secondary smelting and alloying of aluminium</td>
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<td>Aluminum sheet plate and foil manufacturing</td>
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<td>Nonferrous metal (ex aluminium) smelting and refining</td>
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<td>Crown and closure manufacturing and metal stamping</td>
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<td>Cutlery utensil and pan manufacturing</td>
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<td>Ornamental and architectural metal work manufacturing</td>
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Appendix 3: Parameters Initially calculated from the SAM

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Appendix 4: Code for Modeling Economic Shocks

* Set counterfactual

* YEAR 1 SCENARIOS
* (Iteration 1) this counterfactual is a 0.5% reduction in the sales tax paid by all sectors
tc(H,NSER) = -.005;
tc(H,'SER-C') = -.0015;

* (Iteration 2) this counterfactual reduces the IBT for manufacturing
tb('MAN-A') = .00158;

* (Iteration 3) this counterfactual adds a commodity fuel tax
tq(NAG,'FOSSIL-C') = .04561;
tq('AGR-A','FOSSIL-C') = .0019;

* (Iteration 4) this is the low income transfer payment
trans('HHD1') = 157.74

* YEAR 2 SCENARIOS
* (Iteration 1) this counterfactual is a 1% reduction in the sales tax paid by all sectors
tc(H,NSER) = -.01;
tc(H,'SER-C') = -.003;

* (Iteration 2) this counterfactual reduces the IBT for manufacturing*
tb('MAN-A') = .00158;

* (Iteration 3) this counterfactual adds a commodity fuel tax
tq(NAG,'FOSSIL-C') = .076;
tq('AGR-A','FOSSIL-C') = .0038;

* (Iteration 4) this is how we built in the low income carbon transfer payment
trans('HHD1') = 262.899