EXPLORING A WEIGHTED CARBON TAX POLICY FOR THE UNITED STATES

by

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Dr. Gregory Bothun

The average American emits more carbon dioxide than a citizen from the next top three emitting countries combined. Greenhouse gas emissions are steadily increasing with our use of fossil fuels and social damages from carbon dioxide are not accurately captured in fossil fuel prices. The purpose of this thesis is to develop a carbon tax model for the United States that generates revenue equal to ten percent of government spending. This particular model introduces three unique concepts to a carbon tax design: individual weightings for fuels, a floor pricing concept for carbon that determines the tax rate, and a hybrid taxation structure wherein national production of fossil fuels will be taxed alongside regional consumption of carbon dioxide. On both a national and regional scale, a weighted tax achieves more revenues and reduces emissions faster and more effectively than a flat tax. The weighted national tax on production is expected to raise roughly $116 billion in its first year of enactment and reduce emissions by 82% by 2030 while the weighted regional consumption tax will raise $13.63 billion its first year and reduce emissions by 15% by 2030 in the California region.

Acknowledgements

This thesis would not exist without the support and guidance of Professor Gregory Bothun. Thank you for your patience and encouragement, especially when I did not know what I was doing. Learning about the impending future of our planet because of greenhouse gas emissions was difficult at times – and I probably emitted my fair share of greenhouse gases from the electricity that went into writing this thesis over countless nights – but I am thankful that you have given me an opportunity to experience the work that go into researching decisions that affect our entire country. Thank you also to the rest of my committee – Professor Ryan Wilson for his continued support over the years even if it meant last minute independent research class requests, and to Professor Prazniak for her valuable insight into this project.

Thank you to my sisters and boyfriend for having continually cheered me on throughout this thesis journey. And of course, the best for last, a huge thank you to my parents for motivating me from afar. You work so hard so that my sisters and I can have an education. This Honors degree is for you.

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List of Commonly Used Acronyms

AEO: Annual Energy Outlook

BAU: Business-As-Usual

BC: British Columbia

CO_2: Carbon Dioxide

CH_4: Methane

EIA: Energy Information Administration

EPA: Environmental Protection Energy

GHG: Greenhouse gas emissions

MAC: Marginal Abatement Cost

N_2O: Nitrous Oxide

Introduction

> *"Human beings and the natural world are on a collision course. Human activities inflict harsh and often irreversible damage on the environment and on critical resources. If not checked, many of our current practices put at serious risk the future that we wish for human society and the plant and animal kingdoms, and may so alter the living world that it will be unable to sustain life in the manner that we know. Fundamental changes are urgent if we are to avoid the collision our present course will bring about."*
>
> *-1992 World Scientists' Warning to Humanity*[1]

1,700 of the world's leading scientists issued the statement above in November 1992, the same year that the international community established the United Nations Framework Convention on Climate Change (UNFCCC) to examine policy options to curb greenhouse gas emissions. We have yet to see society take their warning seriously.

Numerous opportunities for significant changes in climate policy have presented themselves in the last two decades, but none have gained traction in American legislation. In 1997, for example, the Kyoto Protocol was signed, mandating industrialized nations to reduce their emissions with specific targets by 2012. The Clinton Administration signed the Kyoto Protocol, but resistance from Congress prevented the United States from completing the ratification process. Other developed countries followed the U.S.'s example and in essence, decommissioned the Kyoto Protocol in reducing global greenhouse gas emissions. The G.W. Bush Administration did not take major action to curb emissions and the Obama Administration have tried, but have been largely unsuccessful, in developing renewable energy sources. Perhaps most telling of the government priorities is where it spends its money. Environmental

[1] Quoted from the 1992 World Scientists' Warning to Humanity. See bibliography for full citation.

policies only occupied 3.5% of federal discretionary spending in 2015 compared to more than 50% of the discretionary fund going to the military (Federal Spending, 2015).

Twenty-three years later, the United States has once again taken a step – albeit small – in making "fundamental changes" to its environmental policy: it signed the Paris Agreement for Climate Action on April 22, 2016. The Paris Deal, as it has become known, requires each signatory state to help bring global temperatures to well below 2 degrees Celsius above pre-industrial levels. China and the United States, whose combined emissions account for more than a third of global greenhouse gas (GHG) emissions, will formally adopt the Paris deal by the end of the year (Nichols).

The United States has seen some success in state-led initiatives to reduce greenhouse gases within their own borders or regions, but no such action has taken place on a national scale.[2] The Paris deal is one of many promising steps that our country is taking towards a nationwide pricing on carbon emissions. Businesses have been preparing for such costs in their forecasted financials and the Big Four accounting firms have released publications on how to prepare for such legislation. However, a carbon tax policy still remains one of the most contested issues of our day.

Because of the controversial nature of a carbon tax, the literature on this particular topic is vast. Leading carbon tax proponents such as Gilbert Metcalf (Tufts University) and William Nordhaus (Yale University) have discussed important considerations for a carbon tax on a national scale. Other studies have analyzed the

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[2] Some states have developed GHG emissions regulations for new fossil fuel-fired power plants and/or GHG emission reduction targets for 2020. More than half of U.S. states have established their own renewable energy or energy efficiency resource standards. The Regional Greenhouse Gas Initiative is a cap-and-trade program for the electric sector in nine northeastern U.S. States and the Air Resources Board in California currently runs a cap-and-trade program for its top 500 carbon emitting entities. (Damassa, Bianco, Fransen & Hatch, 2012)

effectiveness of carbon tax proposals that have tried to pass through U.S. Congress in years past (Nystrom & Luckow, 2014). And countless reports by government, agencies, and consulting firms have also been issued about the social cost of carbon, abatement costs of greenhouse gas mitigation, and the incidence of such taxes.

While this thesis could have gone a number of different ways, it has developed into a project where I piece together what I have learned about climate change policies in order to produce a model of a carbon tax levied on fossil fuel production nationwide and carbon dioxide consumption on a regional basis. Research on actual models of a carbon tax are relatively modest. While carbon tax research itself is plentiful, a vast majority do not actually generate models but instead focus on recommendations and considerations should a carbon tax ever be modeled (what I call pre-model literature) or analyzing the impact of already enacted carbon taxes (post-legislation literature).

Pre-model literature includes theoretical considerations and recommendations for a carbon tax without modelling actual numbers that go alongside the theoretical framework. Carbon tax proponents in the academic fields of economics or law mainly write this literature.[3] Metcalf and Weisbach (2009) created perhaps the most comprehensive research paper on the design and infrastructure considerations of a national carbon tax, which I attempt to integrate into this thesis. Post-legislation literature evaluates already enacted carbon taxes on grounds of effectiveness and impact on greenhouse gas reductions and economic implications. Because of its relative and

[3] Most of the research related to carbon tax modeling are done by economists or lawyers as accounting research is usually concentrated in the impacts of already existing tax laws. However, a carbon tax will significantly affect the financial statements and positions of businesses in every point of the supply chain. Filing taxes and auditing financial statements for the fossil fuel industry will be significantly affected by a carbon tax.

recent success, or at least acclaimed success, a large body of literature exists for the carbon tax levied in British Columbia (BC carbon tax) in 2008 as well as the European Union's Emission Trading System (ETS) and Australia's brief stint with carbon taxes. More recent literature include post-legislation evaluations for California's cap-and-trade program, however, research only comes out as quickly as data emerges. Data is currently limited as the program was only established in 2013.

The few carbon tax models[4] available are: Keibun Mori's (2011) open-source Carbon Tax Analysis Model (C-TAM) for the state of Washington which is similar to the BC carbon tax on carbon dioxide consumption; the Carbon Tax Center's spreadsheet model of carbon taxes as outlined in proposed carbon tax legislation under the McDermott tax and the Whitehouse-Schatz tax; William Nordhaus' Dynamic Integrated Climate-Economy (DICE) model which estimates the optimal path of reductions of GHGs (1992); and Rausch, Metcalf, and Reilly's (2011) U.S. Regional Policy (USREP) model which tracks nine different income groups and twelve geographic regions within the United States. This thesis attempts to add another possibility of a carbon tax model to the list: a carbon tax model that taxes fossil fuel production nationwide and carbon dioxide consumption on a regional basis with weighted tax rates. A weighted tax allows tax levying bodies to place heavier taxes on certain activities or fuels to achieve certain amounts of tax revenues. Because of limited time and technical skill in advanced modeling, I only developed a consumption model for the State of California, one of six regions in the United States, because of its

[4] These are models that are available to the general public and did not require purchase from a private firm. Models created by companies included IAMS which could be purchased by government entities to model potential taxes.

similarities in nationwide energy consumption and its diversity of fossil fuel use and renewable energy sources.

The basis of my model is adapted from Keibun Mori's Carbon Tax Analysis Model (C-TAM) for Washington State because its open-source format was understandable and easily imitable for my limited programming capabilities. C-TAM was developed at the request of the Washington Department of Commerce as the state underwent research into implementing a carbon tax policy similar to the carbon tax implemented by British Columbia in July 2008 (Mori, 2011, p. 4).

Though my model follows Mori's design and base formulas, it does introduce three unique concepts. First, my model is a hybrid model, taxing production on a national scale and consumption on a regional scale. Other tax models do one or the other, but not both. Second, the user can choose between two tax pricing structures for carbon at the regional level: 1) a tax rate that will gradually increase by a set increment over every year, or 2) the tax rate equal to the difference between average energy prices and a carbon price set by the user. And finally, this model allows the user to assign individual weights to certain fuels and sectors to create a differential tax on carbon. Current carbon tax models assign equal weights to fossil fuel emissions, following a straightforward approach of targeting fossil fuels with greater carbon content. However, as will be explained later, taxing based on carbon content may not necessarily capture the full social cost of a specific fuel or sector or create changes in consumption behavior for significant carbon dioxide emitters who are inelastic. A weighted carbon tax can help overcome barriers from inelastic fuels and to capture compounded effects of carbon dioxide.

The tax rates, tax base, and structure of this national and regional tax model will make up the bulk of this paper. Further discussion will be offered on the weighted tax rate concept that seeks to tax sectors differently based on behavior modification and marginal abatement costs. While this thesis explains in detail what a potential carbon tax model may look like, I do not offer extensive discussion on the political climate that impedes such legislation from being passed as it would be too extensive for my research and is irrelevant to the goals of this thesis. Nevertheless, I pursue this work because "a model tax can serve as a baseline from which the political process can do its work" (Metcalf & Weisbach, 2009, p. 503).

The sections of this thesis are as follows: Part I will discuss the need for climate change policies and give a general background on the emissions of the United States and California. Part II will discuss some of the theories that go into my carbon tax model. Part III will describe the national carbon production tax model. Part IV will discuss the regional carbon consumption tax model for California. Part V will discuss the results of the model. Part VI will conclude.

Part I: The Need for a Climate Policy in the United States

Fossil fuels – coal, natural gas, and petroleum oil – are the backbone of energy production for the United States, meeting 82% of our energy demands (U.S. Energy Information Administration, April 2016). Fossil fuels came about as a way to replace other sources of energy (Institute of Energy Research). Coal was first used widely in the U.S. for home heating as a cheaper substitute for wood. Easy access to large amounts of coal on American soil eventually sparked the U.S. industrial revolution in the late nineteenth century. Natural gas was briefly used in the U.S. for lighting fuel only to be replaced by the electric light bulb. Today, natural gas largely powers electricity generation, which in turn now powers the electric light bulb. Petroleum oil took off in the early 1900s when it became the preferred means of powering the automobile.

Modern society runs on fossil fuels. Petroleum oil is the currency of globalization, transporting people and goods around the world. Oil powers trucks, ships, and airplanes but it is also found in numerous consumer products ranging from plastic to crayons to tires to dishwashing detergent to clothing. Coal and natural gas are heavily used for energy production. American coal production is the second highest in the world, only after China and the U.S. leads in natural gas production. The abundance of these two fossil fuels has led to their extensive use in electricity production: coal generates 40 percent of U.S. electricity and natural gas 30 percent (Institute of Energy Research).

While fossil fuels have modernized and industrialized our world, it has also altered our environment. Extraction of these fossil fuels through hydraulic fracturing (fracking), oil drilling, and mining have damaged natural landscapes while consuming and contaminating bodies of water. The burning of these fossil fuels – a process called combustion – produces energy alongside water and carbon dioxide. During combustion, carbon dioxide is absorbed into the environment (endothermic reaction) or released into the environment (exothermic reaction) (Petro Industry News). Exothermic and endothermic reactions are a natural part of the carbon cycle, but anthropogenic activities – fossil fuel combustion being the main driver – have altered the balance between the two.

Fossil fuel combustion in industry, mainly driven by our consumption of goods, is the leading exothermic reaction emitting carbon dioxide into the atmosphere over the last decade. Endothermic processes, mostly from plant photosynthesis, now remove carbon dioxide from the atmosphere at a rate slower than carbon dioxide is released resulting in net atmospheric growth of about 16 gigatons of carbon over the last decade (see Appendix A).[5] Therefore, when these carbon-based fuels are not taxed, environmental effects of production and consumption result in market externalities in the form of GHGs (Sodero, 2011).

Atmospheric CO_2 observed at Mauna Loa Observatory indicate increasing carbon dioxide levels over the last six decades (Figure 1), as well as an annual mean growth of CO_2 (Figure 2). So not only is there more carbon dioxide now than before, the amount is growing quickly and steadily every year.

[5] One gigaton of carbon is weighted at one billion tons, or over one hundred million African elephants. Close to 1.6 billion African elephants worth of carbon has stayed in the atmosphere in the last decade. See Appendix A.

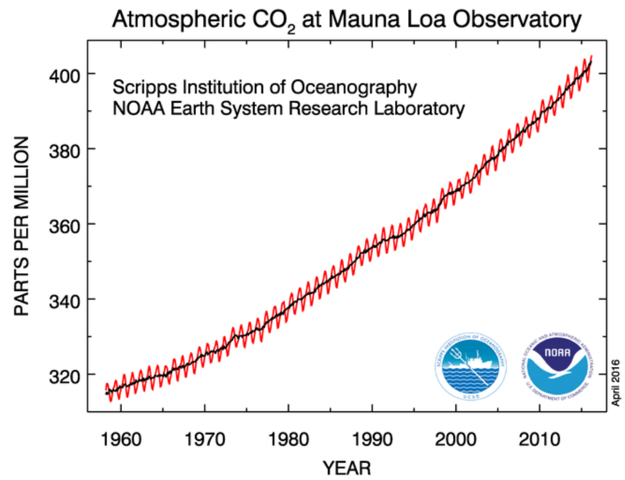


Figure 1: Atmospheric CO_2 observed at the Mauna Loa Observatory.
Caption: Reprinted from the National Oceanic & Atmospheric Administration by Earth System Research Laboratory, n.d., Retrieved May 2016, from http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo.png

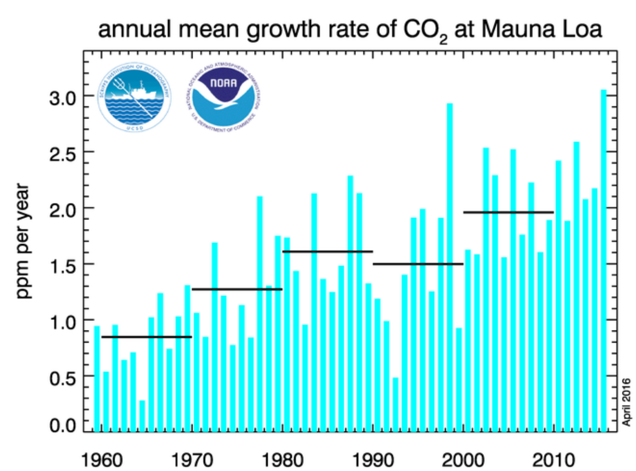


Figure 2: Annual mean growth of CO_2 at Mauna Loa.
Caption: Reprinted from the National Oceanic & Atmospheric Administration by Earth System Research Laboratory, n.d., Retrieved May 2016, from http://www.esrl.noaa.gov/gmd/webdata/ccgg/trends/co2_data_mlo_anngr.png

Although the United States has not been the top greenhouse gas emitting country in the world for the last several years, we are the world leader in the highest concentration of GHG emissions per capita. Figure 3, mapped by the Global Carbon Project, shows that an American living in the United States emits nearly 2 more tons of CO_2 per year than the per capita emissions of the next top three emitting countries combined.

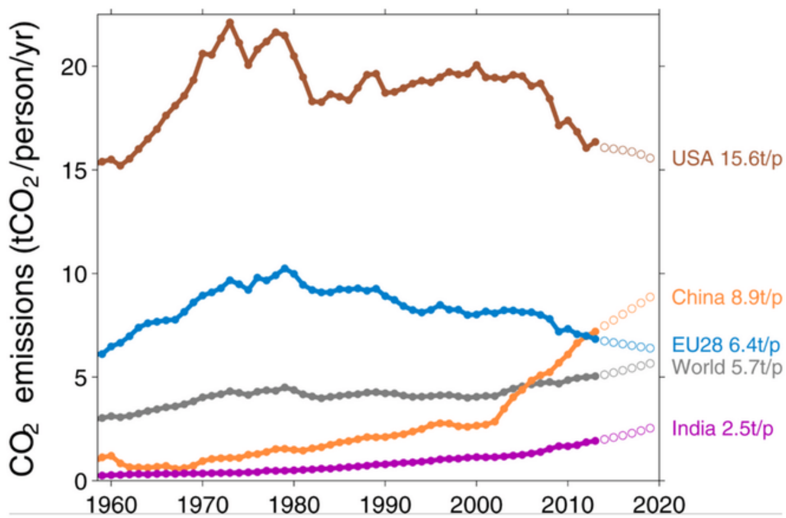


Figure 3: Top fossil fuel emitters (per capita), 2014.

Caption: Reprinted from the Global Carbon Project 2014, Retrieved May 2016, from www.globalcarbonproject.org/carbonbudget/15/files/GCP_budget_2015_v1.pdf

A carbon tax provides economic incentive for fossil-fuel use reduction by pricing carbon across the market. Unpriced emissions create distortions in the economy by failing to inform the public about where our consumption causes the most harm. By pricing carbon, the environmental costs associated with these fuels' GHG emissions can be internalized, encouraging behavioral changes across supply and consumption chains.

Hsu (2011) argues that a carbon tax imposes a price on carbon more efficiently than government subsidies, command-and-control environmental regulation, and cap-and-trade because a carbon tax prices carbon dioxide emissions directly. Government subsidies lower prices of low-carbon technologies and practices, not actual emissions. Command-and-sort environmental regulation places administrative price, not market price, on high emitters of carbon dioxide. And cap-and-trade prices tradable emissions allowances, not the carbon itself. Only a carbon tax directly prices carbon dioxide emissions.

Hsu further argues that a carbon price can sort industries by their energy efficiency by aggregating disparate pieces of information carbon intensity and transmitting a highly visible price signal at every stage in which there is a fossil fuel usage from production to consumption. Furthermore, fossil fuels are non-renewable resources. Only a finite amount exists and one day, they will run out. A carbon tax can accelerate the weaning process from our heavy dependence on fossil fuels and encourage investment in more sustainable and renewable sources of energy.

Emissions (United States)

To understand the design of an effective carbon tax, we look to the plethora of information collected by the Environmental Protection Agency (EPA) and the Energy Information Administration (EIA) as they help us to understand the emissions behavior of our nation (Metcalf & Weisbach, p. 503). In 2014, the United States emitted close to 6.9 billion metric tons of carbon dioxide equivalents. Carbon dioxide from fossil fuel combustion accounted for approximately 76% of these emissions: 24% from coal, 21%

from natural and 31% from petroleum (Environmental Protection Agency, 2016, p. 2-1, 2-2; Table 3-5, p. 3-5). Coal has the highest carbon content per unit of energy, followed by petroleum. Natural gas is considered the cleanest burning of the three major fossil fuels because it emits half the amount of carbon dioxide for the same amount of energy as coal. We have seen some decline in CO_2 emissions over the last ten years, however, this may be due to the fact that we have increased our use of natural gas for energy generation as opposed to coal. Our behavior has not changed when it comes to consumption of fossil fuels.

Important carbon-emitting activities need to be identified in order to understand what items should be included in the tax base. The following table lists major sources of GHG emissions in the United States comparing 2006 emission levels to 2014. Table 1 shows that fossil fuel combustion, agricultural soil management, and landfills have remained the top three sources of greenhouse gas emissions over the last eight years and contribute about 80% of carbon emissions nationwide. Other activities such as coal mining, cement production, and iron and steel production contribute less than one percent of all emissions individually, but the aggregate of these smaller, non-combustion emissions make up 20% of U.S. emissions.

Table 1: A comparison of GHG sources above 20 million metric tons of CO_2E

GHG Sources Above 20 MMT CO_2E: Comparison between 2006 and 2014[6]								
					2006		2014	
2006 Rank	**2014 Rank**	**Source**	**Gas**	**Primary Sector**	**MMT CO2e**	**% of Total**	**MMT CO2e**	**% of Total**
1	1	Fossil Fuel Combustion	CO_2	Energy	5,747.1	77.4%	5,208.7	75.8%
2	2	Agricultural Soil Management	N_2O	Agriculture	296.7	4.0%	318.5	4.6%
3	3	Landfills	CH_4	Waste	187.3	2.5%	181.8	2.6%
7	4	Substitution of Ozone Depleting Substances	HFC	Industrial	113.0	1.5%	171.4	2.5%
6	5	Enteric Fermentation	CH_4	Agriculture	168.9	2.3%	164.3	2.4%
4	6	Natural Gas Systems (CH_4)	CH_4	Energy	176.3	2.4%	157.4	2.3%
6	7	Non-Energy Use of Fuels	CO_2	Energy	138.9	1.9%	114.3	1.7%
9	8	Coal Mining	CH_4	Energy	64.1	0.9%	64.6	0.9%
10	9	Manure Management	CH_4	Agriculture	56.3	0.8%	61.2	0.9%
8	10	Iron and Steel Production	CO_2	Industrial	66.5	0.9%	55.4	0.8%
11	11	Cement Production	CO_2	Industrial	45.9	0.6%	38.8	0.6%
13	12	Natural Gas Systems (CO_2)	CO_2	Energy	30.0	0.4%	37.8	0.6%
14	13	Petrochemical Production	CO_2	Industrial	27.4	0.4%	26.5	0.4%
15	14	Petroleum Systems	CH_4	Energy	23.5	0.3%	25.2	0.4%
16	15	Stationary Combustion	N_2O	Energy	20.2	0.3%	23.4	0.3%
		Total			7,162.1		6,649.3	
		U.S. Total			7,428.8	96.4%	6,872.6	96.8%

Equally important to the amount of carbon dioxide emitted from a particular activity is the marginal abatement cost of curtailing carbon emissions from that activity. The marginal abatement cost curve (MAC) shows, for every emissions level, a firm or industry's marginal cost (foregone profits) of reducing emissions, or equivalently, its marginal willingness to pay for the right to emit one additional unit of pollution. Although an activity may produce a smaller percentage of emissions, if its marginal

[6] Adapted from Metcalf and Weisbach (2009), with data from EPA 2016 GHG Inventory 2014 with figures from Table ES-2 and Table ES-4.

abatement cost is low, it should also be included in the tax base (Metcalf & Weisbach, 521). A global abatement cost curve made by McKinsey & Company maps opportunities to reduce emissions of greenhouse gases across regions and sectors (Figure 4).

McKinsey & Company's analysis conclude that there is potential by 2030 to reduce GHG emissions by 35% compared with 1990 levels, or by 70% compared to future 2030 levels if the world collectively attempted to curb current and future emissions (Naucler & Enkvist, 2009, p. 8). Global abatement cost curves work in a way that the activities listed to the furthest left cost the least amount of money to reduce an emission of carbon dioxide. Likewise, abatement activities listed to the right are the most costly to implement. The activities to the furthest left of McKinsey & Company's study how that personal consumption/behaviors may be the least costly abatement activities. McKinsey & Company label this as energy efficiency and low carbon energy supply (Naucler & Enkvist, 2009, p. 11). Marginal abatement cost curves can provide an indicator of where revenues can be directed towards in a carbon tax model as well as provide some baseline as to where certain sectors may have ability to reduce their greenhouse gas emissions for relatively low prices.

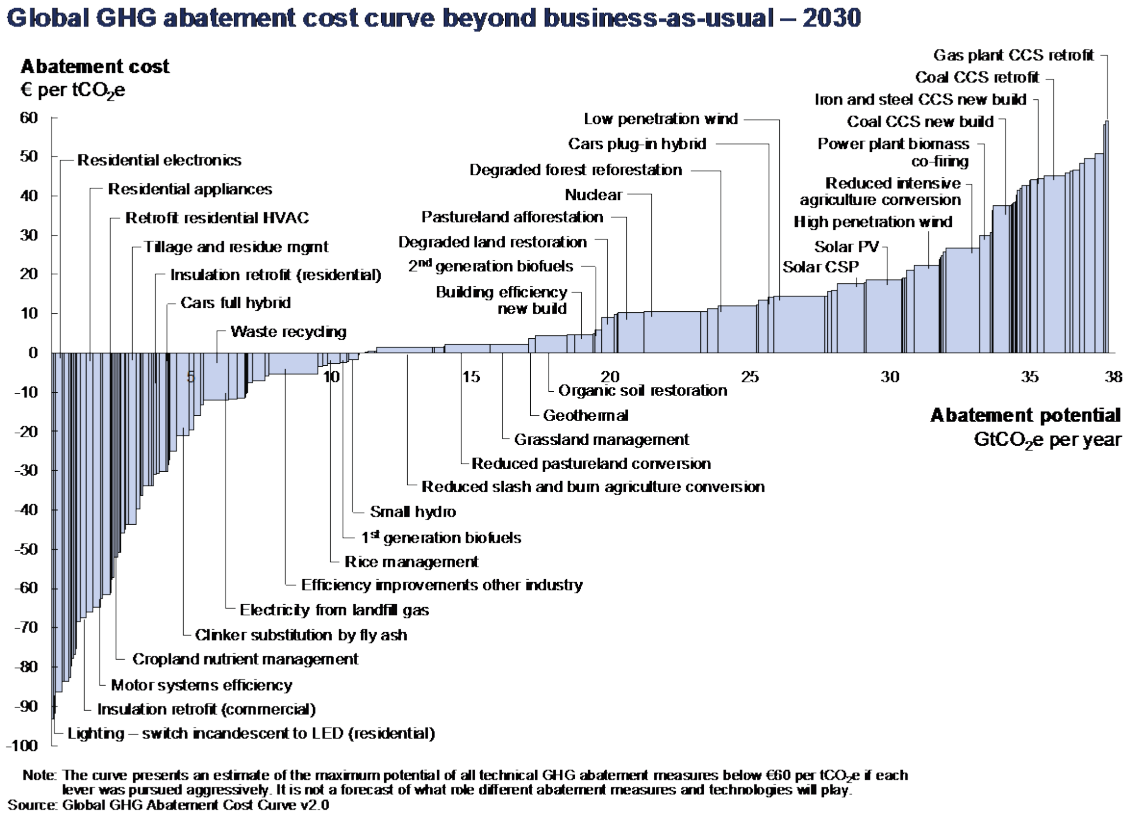


Figure 4: Global abatement cost curve for greenhouse gases beyond 2030 BAU.

Caption: Reprinted from Pathways to a low-carbon economy by Naucler & Enkvist from McKinsey & Company (2009), p. 7, Exhibit 1. Retrieved April 2016.

In addition to specific sources of greenhouse gases and activities that drive these sources, we must also consider the end-use of these emissions: industrial, commercial, residential, and transportation. Knowing the end-users of greenhouse gas emissions helps to set the stage of several considerations when it comes to the design of a regional, weighted carbon tax. Not only does it help us understand the tax base, it also provides a sense of where differential taxes can come in to alter behaviors and fuel use in specific sectors. Electric power generation has the most emissions of the listed sectors. Electricity, however, is an intermediary because electricity generation produces emissions while also providing energy that creates emissions when used by the other four sectors. Coal and natural gas are heavily used in generating electricity. When electricity use is distributed to its end-use sectors, we see that industry and transportation produces the most CO_2 emissions, followed by commercial and residential, and finally agriculture (Figure 5).

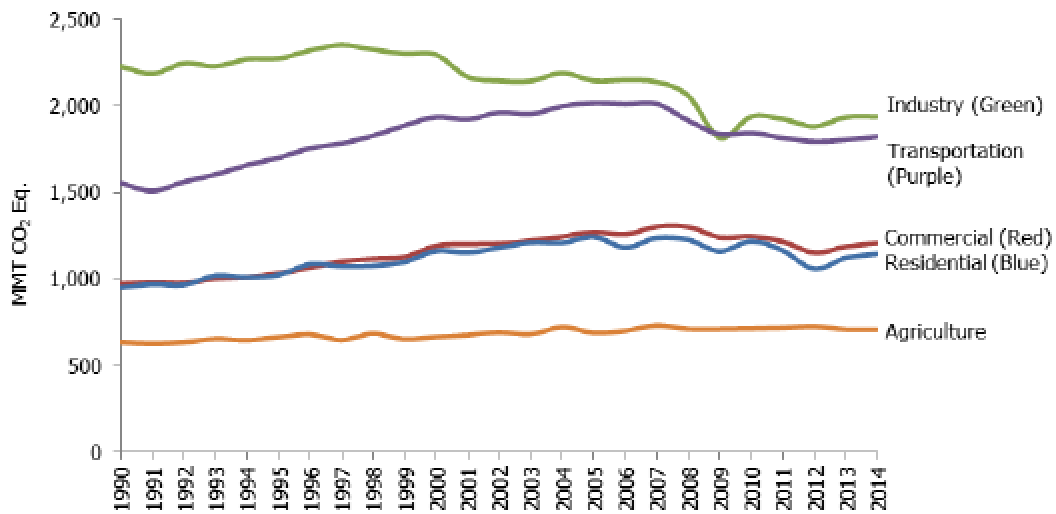


Figure 5: Emissions with electricity distributed to economic sectors (MMT CO_2 Eq.)

Caption: Reprinted from EPA GHG Inventory (2016), Figure 2-13. Retrieved May 10, 2016.

Industry produces GHG emissions from fossil fuel combustions in manufacturing facilities nationwide, which include methane emissions from petroleum and natural gas systems, fugitive CH_4 emissions from coal mining, by-product CO_2 emissions from cement manufacture, and ODS (ozone depleting substances) byproduct emissions from semiconductor manufacture. In general, emissions from industry have declined, not so much from lower output but the "shift from energy-intensive manufacturing products to less energy-intensive products (e.g. from steel to computer equipment)" (EPA, 2016, p. 2-29).

Transportation accounts for a little under a third of U.S. GHG emissions in 2014, with the largest source by far passenger cars coming in almost at half of the transportation emissions. This is followed by freight trucks at almost a quarter, light-duty trucks at almost a fifth, and then commercial aircraft, rail, pipelines, and ships and boats adding up to a little over a tenth (EPA, 2016, p. 2-29). Petroleum fuels a large portion of the transportation and industrial sectors (Figure 6). As result, combustion of petroleum-based products such as gasoline, diesel, and jet fuel, has increased CO_2 emissions by 16% from 1990 to 2014 (EPA, 2016, p. 2-30). The commercial and residential sectors primarily rely on electricity for lighting, heating, air conditioning, and operating appliances. Much of these energy needs are met with direct consumption of natural gas and petroleum products for heating and cooking as well as indirect consumption of coal through electricity usage (EPA, 2016, p. 2-31).

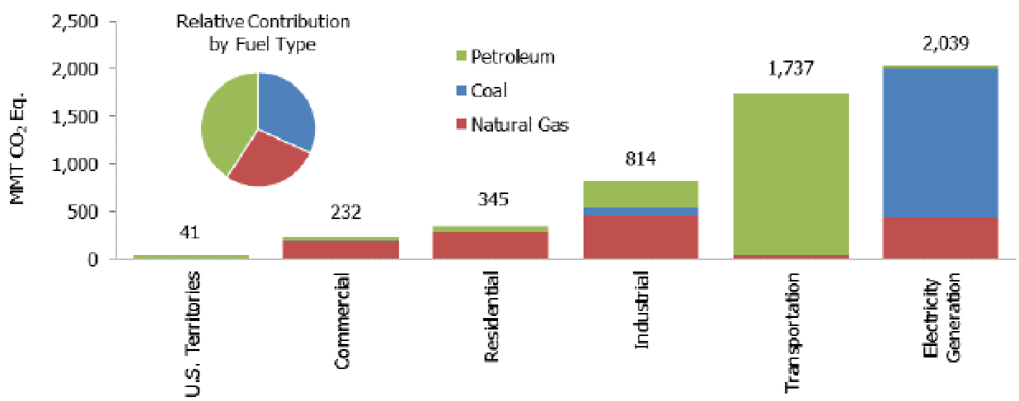


Figure 6: 2014 CO2 emissions from fossil fuel combustion by sector and fuel type (MMT CO2 Eq.)

Caption: Reprinted from EPA Inventory (2016), Figure 3-5.

Emissions (California)

In a way, California serves as a microcosm of national environmental conditions which is why this became the region of choice to begin the consumption tax model. For example, greenhouse gas emissions by type were fairly similar between California and the United States as a whole. A comparison of California and U.S. GHG emissions by type of gas reveal similar percentages, only differing greatly in the smaller gases such as nitrous oxide and fluorinated gases (Table 2).

Table 2: 2013 Total California vs U.S. Greenhouse Gas Emissions by Gas

Greenhouse Gas Emissions by Type	California	U.S.
Carbon Dioxide	84%	82.5%
Methane	9%	9.5%
Nitrous Oxide	3%	5.3%
Fluorinated Gases	4%	2.6%

Table Caption: Information from the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2013 (https://www3.epa.gov/climatechange/ghgemissions/inventoryexplorer/#allsectors/allgas/econsect/current,) and the California Air Resources Board with data from http://www.arb.ca.gov/cc/inventory/background/hgwp.htm.

Furthermore, emissions by end-use sector were also pretty similar between the United States and California (Table 3). The only areas of major difference were electricity generation and transportation, the reason being that California has a diverse renewable energy source for electricity generation thereby lowering electricity generation emissions and a large freight fleet, thus increasing transportation emissions.

Greenhouse Gas Emissions by Type	California	U.S.
Electricity Generation	20%	31.3%
Transportation	37%	27.2%
Industry	23%	21%
Agriculture	8%	8.8%
Commercial	5%	6.0%
Residential	7%	5.6%
Not Specified	<1%	0%

Table 3: 2013 Total California vs U.S. Greenhouse Gas Emissions by Economic Sector

Table Caption: Information from the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2013 (http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html) and the California Greenhouse Gas Emission Inventory - 2015 Edition, http://www.arb.ca.gov/cc/inventory/data/data.htm.

And finally, California, like a mini-United States, has a diverse population and economy. Economic sectors include industry, manufacturing, technology, and agriculture. Its demographic is also diverse and has clear distinctions between rural and urban centers. California therefore, is like a microcosm of the United States as a whole.

However, California is the only state in the country that has a statewide cap-and-trade program for carbon for greenhouse gas emitting entities.[7] In addition, California also has access to a variety of renewable energy sources which are not as prevalent in other regions. Because the model for California only serves as a base model for the United States, I did not take into account the cap-and-trade emissions in California in order to remove that from the analysis of the United States a whole since the United States does not yet have a carbon pricing system.

[7] Several Northeastern states in the U.S. have developed a cap-and-trade program for carbon but it only affects utility companies. It is not as comprehensive as the California cap-and-trade program. .

Part II: Carbon Tax Theory

If there is overwhelming need to regulate greenhouse gas emissions from our consumption and production activities, why has it been difficult to enact such a tax? This section attempts to answer this question while also explaining underlying theories in the design of my carbon tax model.

Several factors need to be considered with designing an effective carbon tax, which can make the task challenging. Metcalf and Gilbert (2009) mention three general areas in their publication: the tax rate, tax base, and international trade concerns. Sumner, Bird, and Smith (2009), in addition to the design considerations mentioned by Metcalf and Gilbert, also looked at how to use the tax revenues, the tax's impact on the consumers, and evaluation of achieving emissions reductions goals for carbon tax policies around the world. Further design issues put forth by the Center for Climate and Energy Solutions (2013) include discussions on political considerations into the tax and who administers, monitors, and enforces such a tax. This thesis shows that designing a carbon tax model can be relatively straightforward given the amount of data and research that is available on this topic.

Political concessions and compromises that are necessary for lawmaking prove the most challenging aspect of this endeavor. Fossil fuel companies have the financial backing and advocacy willpower to lobby for their benefits. In fact, the a report from Oil Change International and the Overseas Development Institute show that national subsidies to oil, gas and coal producers amount to $20.5 billion every year in the form of tax or royalty breaks (Pandey). Political impediments aside, a carbon tax can be quite effective in regulating a market where fossil fuels and the externalities that come with it currently dominate the supply.

Another major concern with the carbon tax, in addition to resistance from the fossil fuel industry, is its incidence. Most post-legislation literature on carbon taxes assume that the burden of carbon taxes is shifted forward to consumers in the form of higher energy prices and higher prices for energy-intensive goods and services. Whether this burden will fall on poorer households is a major concern for policymakers and economists.

Empirical evidence exists that the direct incidence of a carbon tax is regressive. Wier *et al.* (2005) proves this in his case study about Denmark's carbon tax while Poterba (1991) and Hassett, Mathur, and Metcalf (2011) demonstrate this same concept for fuel taxes in the United States. However, Hassett, Mathur, and Metcalf (2007) found that when carbon tax incidence is measured on a lifetime income framework, rather than current or lifetime consumption, the taxes are more progressive. In the same study, the direct component of a carbon tax (household burdens from direct consumption of fuels) is more regressive than the indirect component of a carbon tax (increase in cost of other goods from higher fuel costs in production). In fact, in certain years, the indirect component were also mildly progressive. Hassett *et al.* (2007) also found that variation in carbon taxes paid by households across U.S. regions are relatively modest, with the variations usually related to climate variations or driving patterns.

As a result of these findings, my model is designed to be a hybrid carbon tax on national production of fossil fuels as well as regional carbon consumption in order to balance regressivity. As the amount of carbon taxes owed will not necessarily vary between regions, the regional consumption tax can encourage competitive pricing structures amongst regions wherein more efficient and low-carbon sources of extracting, producing, and transmitting fossil fuels and renewable energy will remain.

The rest of this section will briefly discuss the design considerations of this tax model, addressing the following areas: a hybrid tax, the tax rate, the tax base, tax weighting, and revenues.

A Hybrid Tax

This model is unique because of its hybrid nature. Upstream taxes on fossil fuels are argued to have very little visibility to downstream consumers and therefore, a tax would not necessarily alter consumer behaviors. A hybrid model strengthens the visibility of the tax because gasoline prices and electricity bills will include the costs of carbon dioxide emissions. Furthermore, a regional division for carbon dioxide taxation groups together states with similar consumption patterns as well as energy dependencies so that each region can tailor their specific baselines for taxable emissions. Unique carbon tax weightings for each region depending on their fuel and energy mix can also help facilitate market competition amongst energy providers to ensure the most carbon-efficient (and therefore less costly) energy sources outweigh the benefits of fossil fuels.

Figure 7 depicts the six regions of my model and each region is described briefly by information on the U.S. of Energy website (http://usofenergy.com/overview/):

- **Southern**: Texas to Florida and all the way up to West Virginia. This region contains a majority of petroleum refineries and coal mines.

- **Northeast**: Wisconsin and Illinois and eastward towards Maine through Delaware. This region is known for their natural gas deposits and a developing mix of renewable energy sources like wind and solar power.

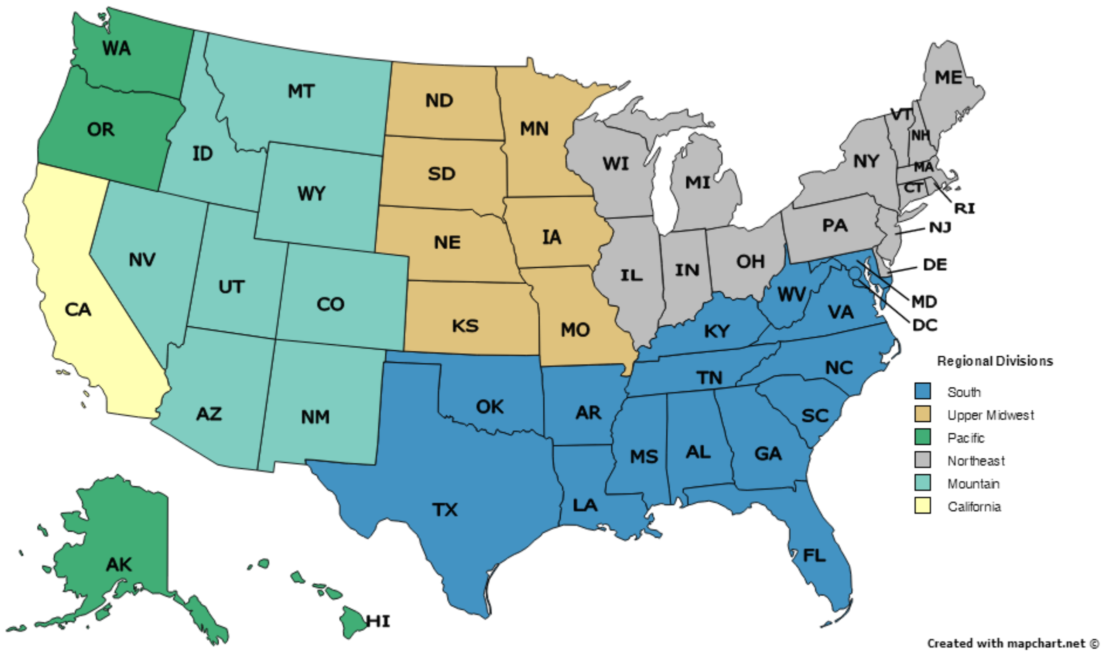


Figure 7: Regional divisions for the regional carbon consumption tax model.

Caption: Six regions will make up the United States carbon consumption tax model. Regions are divided similarly to the EIA's regional divisions for easier data collection.

- **Upper Midwest**: North Dakota and Minnesota through Kansas and Missouri. This region has a mix of coal in its northeastern parts and coal deposits in the west, but also has wind energy and biofuel production.
- **Mountain**: Idaho and Montana through Nevada and New Mexico. This region is rich in resources including natural gas, oil, and coal deposits. However, the region also houses solar energy and some nuclear plants.

- **Pacific**: Washington, Oregon, Alaska, and Hawaii. Washington and Oregon are two of the largest hydroelectric power-producing states in the country. Alaska has vast oil, coal, and natural gas deposits but also some geothermal sources, wind energy, and hydroelectric plants. Hawaii has no fossil fuel deposits and thus imports petroleum and coal, but also has solar power, wind, biomass, and geothermal generators.
- **California**: California's energy production portfolio from oil, natural gas, wind, solar, hydropower, biofuels and nuclear power, making it one of the most energy-diverse areas in the country.

Tax Rate

Determining a tax rate for carbon is difficult because of the many assumptions that go into its calculation, which include predictions of economic and technological developments and the forecast of the effects of climate change (Metcalf & Weisbach, p. 511). One way to tax carbon could be to find its social cost – or the price at which "the social marginal damages from producing an additional unit of emissions equals or the social marginal benefit from abating a unit of emissions" (Metcalf & Weisbach, p. 523). Social damages according to the Environmental Protection Agency can be characterized as changes in important social metrics such as agricultural productivity, human health, property damages from natural disasters, and changes in energy system costs – but even the EPA acknowledges that this does not capture all important damages. A large part of determining the value of social damages is the extent of carbon dioxide's role in the net changes of these social metrics. Increasing social costs of carbon overtime indicate that the impact of carbon dioxide in social wellbeing is actually more significant that we realize. Various organizations have attempted to price carbon in this way but even their estimates vary. According to the Intergovernmental Panel on Climate Change (IPCC), the social cost of carbon in 2005 was an average value of $12 per ton of carbon dioxide, but the range from a survey of 100 estimates varied between $3 to $95 per ton of CO_2 (Intergovernmental Panel on Climate Change, 2007). Even the EPA sees a range of estimates for the social cost of carbon in 2020 ($12 to $123 per ton of carbon dioxide) depending on the discount rate used (Environmental Protection Agency, 2015).

Another alternative to pinpointing the optimal carbon cost would be to set a rate of taxes overtime to achieve target emissions reductions and/or temperature change limitations. According to Metcalf and Weisbach (2009), this approach tends to produce a range of tax rates equal to those generated from deriving carbon's social cost (p. 512). One such goal has been to limit global warming to 2 degrees Celsius by 2030. The IPCC concludes that to do so, a global average carbon price has to be between $80 to $120 US dollars per ton of CO2 (Clarke *et al.*, 2014). In August 2015, the World Bank found that prices for carbon from around the world ranged from $1 to $130 per ton of carbon dioxide with little movement over the past year. 99% of emissions worldwide were priced less than $30 per ton of carbon dioxide and 85% were priced less than $10 per ton (Kossoy *et al.*, 2015, p. 24). These prices are barely effective in reducing emissions based on the IPCC's estimate of an effective carbon price.

My tax model allows the user to try between the two different pricing structures mentioned above. The first pricing structure (Value A) follows the setting of prices overtime to achieve target emissions reductions. It introduces an initial rate, an amount that it increases by every year, and then caps it at a specified rate. The second pricing structure (Value B) follows a floor pricing strategy at the social cost of carbon, where a floor price is set (equal to a social cost of carbon) and the tax is equivalent to the difference between average fuel prices and the price set.

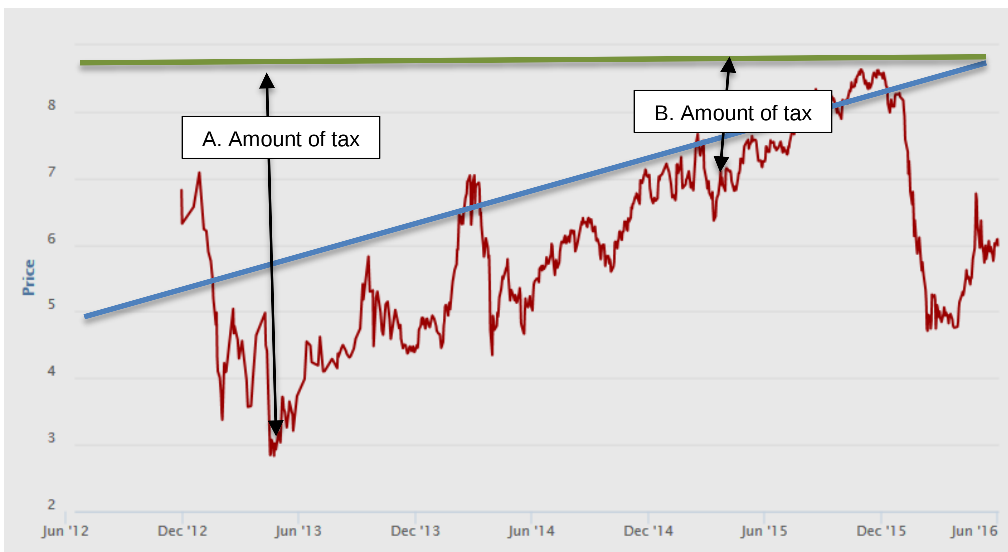
The default setting for pricing structure A is an initial rate of $35/ton of CO2, increasing $2 every year, and capped at $50/ton of CO2. I use $35 because a majority of carbon prices in the world fall below this threshold. This ramp-up method allows for business to slowly transition into the carbon tax program and allowing society to make steady changes to the eventual social cost of carbon.

The second pricing structure (Value B) defaults the cost of carbon to $50/ton of CO2 and the tax is the automatically calculated depending on the average cost of fossil fuels that year. This pricing structure allows for the cost of the tax to fluctuate depending on the cost of fossil fuels. In years where fossil fuels are relatively inexpensive, the cost of the tax will be extremely high. In years where fossil fuels are expensive, the tax would adjust to a lower amount. This allows for a predictable price for fossil fuels and that it would remain a cost where it would make sense to faze them out of use.

Value B pricing, however, is only available for regional taxation because energy prices are too varied across the country to issue an average price. Furthermore, the purpose of taxing regional consumption is to promote competition amongst various energy sources on a grid across the United States. In a region where fossil fuels are abundant and therefore less expensive, energy suppliers can look to other regions that have more efficient and renewable sources to lower their taxes.

My model automatically places the rate on a linear up-ramp or automatically populates the difference between the floor price and the price of carbon based on dollar amounts that can be inputted into the model. However, knowing what rates to input can also be a logistical challenge. Questions around who determines the rates, how often the rates are updated, and what growth rate is used for the tax are valid administrative questions. Metcalf and Weisbach (2009) address options for such issues such as 1) delegating the responsibility for rate setting to an expert governmental agency, 2) having an agency recommend the rate but with procedural rules that forces Congress to consider or protect the recommendation, or 3) having Congress reconsider the rate at pre-scheduled intervals (p. 520). These logistical items are not the focus of my thesis and therefore will not be addressed, but nevertheless, these are important considerations when implementing a carbon tax in the United States.

The advantage of a carbon tax over other carbon pricing methods such as cap-and-trade is the ability for governing bodies to set a predictable tax rate. Consider the price of carbon under the European Union's ETS (in red below). Over the course of two years, prices have fluctuated between 3 and 8 euros per ton of carbon dioxide. Such a volatile carbon pricing system makes it difficult to have any lasting effects on green energy investments. In years when carbon emissions are relatively inexpensive (such as April through June 2013), there is little incentive to curb emissions or invest in green energy. A carbon tax (blue line) however, can set a linear price of carbon that increases overtime, therefore encouraging continued emissions reductions and investments in green energy. A weighted carbon tax (as will be discussed later) is even more effective because different weightings can result in the carbon tax being manipulated to create a constant price for carbon (green line). Even as the social cost of carbon fluctuates, the tax can be adjusted to be higher rates in periods of low social carbon cost (point A) and lower in periods of high social carbon cost (point B). Such a tax rate system can help encourage businesses to plan ahead for carbon emissions reduction plans as well as green energy investment strategies.



Tax Base

Determining the tax base can also be a challenge for a carbon tax law. This model taxes production of fossil fuels and emissions of landfills on a national scale as well as the regional consumption of fossil fuels in the industrial, commercial, and transportation end-use sectors. Despite a wider tax base than most carbon tax regimes, this model still rules out about 20% of other greenhouse gas emissions such as methane and nitrous oxide emissions from agriculture (i.e. enteric fermentation), carbon dioxide emissions from forestry activities, and emissions from international travel. Like British

Columbia's (BC) carbon tax, this model also exempts carbon dioxide emissions in industrial processes such as lime production in cement manufacture, methane emissions from natural gas extraction and transmission, and aviation and marine fuels used for international travel out of and into BC.

For my model, domestic production of crude oil, natural gas plant liquids, dry natural gas, coal, imports of crude oil, petroleum products, and natural gas, as well as non-combustion emissions of landfills are taxed. Taxing the carbon content of fossil fuels at the point of production can capture approximately 76% of US emissions in the United States. This is possible because a unit of fossil fuel will emit the same amount of carbon regardless of when or where it is burned. Carbon emissions from fossil fuel combustion have an almost perfect correspondence between input and output (Metcalf & Weisbach, p. 523). As 76% of U.S. GHG emissions are from fossil fuel combustion, taxing the fossil fuel input can effectively tax 76% of emission sources, and taxing landfills can also capture an additional 2.5% of U.S. greenhouse gas emissions (Metcalf & Weisbach (2009); EPA Inventory (2016), p. ES.2, Table Es-2, ES-3, & ES – 4). Furthermore, the amount of taxed entities on the production level will be fairly lean. In 2007, the top 500 operators controlled about 95% of proved natural gas wells and more than 93% of natural gas production in 2006 (Metcalf & Weisbach, p. 524). Coal mines numbered about 1,916 in 2014 (EIA Annual Coal Report). And petroleum can be taxed at the refinery, which numbered 140 in 2015 (EIA Number and Capacity of Petroleum Refineries). Taxing about 2,600 entities can virtually capture a little under two thirds of combusted greenhouse gas emissions.

Like the BC carbon tax, my model also exempts aviation and marine fuel for international travel. However, this model taxes imports of fossil fuels should they come from a country that currently does not price carbon, which allows for these fossil fuels to be captured in the tax base. Data on fossil fuel imports can be broken down by country and I took the average percentage of imports for crude oil, petroleum and other liquids, and natural gas over the last decade that came from countries without a carbon tax. This percentage is visible in the model and can be changed by the user should import data change.

While production of fossil fuels are taxed on a national level, there is also a more downstream tax on the consumption of these fossil fuels in the industrial, commercial, and transportation sectors of regional areas (discussed further in Section IV). British Columbia, Ireland, and the United Kingdom follow this tax model and the carbon tax appears in consumers' garbage fees, car payments, gasoline refueling, and their electricity bill. My regional model for the United States does not tax quite as downstream as these carbon taxes (as it does not tax the residential sector) because not only will taxing further downstream add more administrative costs to tax collection, it will increase the burden of individual taxpayers because industry and commercial businesses will likely pass on their increased tax expenses to the consumer. Instead, the regional consumption tax is only imposed on industrial and commercial sectors as well as on motor gasoline and diesel fuel in the transportation sectors.

A majority of the commercial sector will see their taxes on their consumption of natural gas and electricity which relates largely to their heating and power needs. The industrial sector will see a majority of their taxes in natural gas and lease and plant fuels that go into industrial processes. Industrial processes such as clinker production from cement manufacture and production of metallurgical coke and pig iron in the steel and iron manufacturing, however, are not taxed under this model.

Notable Exemptions

Following some of the BC carbon tax's most notable exemptions, my model also exempts the following carbon-emitting activities (Murray & Rivers, 2015):

- Fuels exported from the United States
- Fuels used by planes and ships travelling to or from BC
- Greenhouse operations and fuel used in agriculture
- Non-fossil fuel greenhouse gas emissions from forestry and agriculture

Weighted Tax Rates

A carbon tax will not affect every activity in the tax base equally and therefore weighting fuels and activities differently is a key component of both the national and regional carbon tax model. Recall that certain fuels are much more involved with certain end uses than others. Transportation and industry primarily consume petroleum, while electricity generation pulls from coal, natural gas, and nuclear power. Natural gas is perhaps the most versatile, consumed in electricity generation, residential, commercial, and industrial activities. Because each activity and use for fossil fuels are different, taxing them at different weights can be much more effective in manipulating the demand for fossil fuels.

A certain fossil fuel or activity may have compounding effects of carbon dioxide emissions that are not captured with a flat carbon tax. For example, natural gas is known to be a "cleaner" burning fuel than coal because it emits half the amount of carbon dioxide. However, natural gas is primarily made out of methane gas and its transmission via pipelines results in a 3% leakage rate of methane into the atmosphere. Methane has 34 times the global warming potential than carbon dioxide. Natural gas, therefore, has the potential to be of greater contributor to climate change because of pipeline leakage. Placing a heavier weighting on the natural gas tax rate can, in essence, "equalize" the carbon dioxide emissions of natural gas and coal that would otherwise not be captured from a flat carbon tax.

Furthermore, certain activities may not necessarily contribute large amounts of carbon dioxide into the atmosphere, but their marginal abatement costs are low enough to reduce emissions at a reasonable scale. Landfills for example, would normally be exempt from such a tax because they release methane, not carbon dioxide. However, being able to convert the methane emissions factors into a common global warming potential (GWP) to carbon dioxide as well as weighting it above the baseline of carbon dioxide tax rates because of its relatively low marginal abatement costs can be beneficial to altering landfill management behaviors.

A weighted carbon tax can also effectively tax relatively inelastic fuels. On a national scale, fuels used in the transportation section, for example, are relatively inelastic and carbon taxes in this sector may raise revenue but not necessarily encourage emissions reductions, except maybe in the socioeconomic class and region (i.e. rural communities and suburban areas dependent on commuting) most impacted by higher motor gasoline taxes. By weighting transportation fuels heavier than other sector fuels, change in consumption and therefore emissions from them gain more traction.

Similarly, certain regions are more dependent on some fossil fuel sources resulting in relatively sensitive elasticities. California, for example, depends heavily on natural gas for power generation while mid and eastern regions of the United States depend on coal. A tax on carbon dioxide will affect these regions differently. A study by the Electric Power Research Institute (2006) concluded that a carbon tax would affect coal-dependent regions differently from natural gas-dependent regions (pp. 3-6 through 4-8). The following figures are graphs the marginal cost of generating certain amounts of energy. Fuel types with the lengthiest portion of the line is the dominant fuel source for power generation in that particular region.

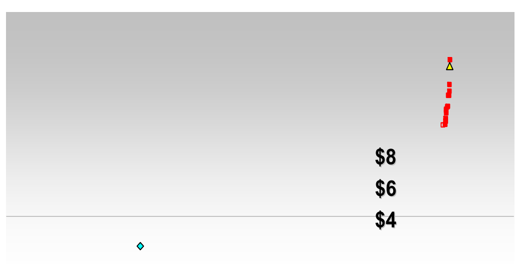


Figure 8: Marginal costs of natural gas in comparison to the generation supply stack.

Caption: Natural gas is highly sensitive to fluctuations in natural gas prices. Higher natural gas costs, the higher the marginal cost per watt hour. Reprinted from Electric Power Institute (2006), Figure 2-21, p. 2-23.

Marginal cost in a region dependent on natural gas is highly sensitive to natural gas prices, therefore a carbon tax (which will increase prices for natural gas) will significantly increase the marginal cost of natural gas (Figure 8). Contrast this to a coal-dependent region such as the ECAR-MAIN sector of the US electricity grid (Figure 9). A carbon tax hardly affects marginal costs for coal in coal-dependent regions, therefore it would make sense to weight the carbon tax on coal more heavily in these areas in order to effectively impact their usage and price elasticity. The default weights assigned to each sector will be discussed further in Part IV and V.

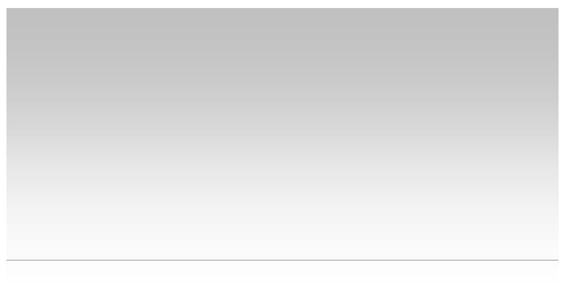


Figure 9: Net revenue distribution with CO_2 priced at $25/ton.

Caption: A carbon price alone does not cause much decrease in revenue as it would if there were also generation of additional nuclear power to provide energy supply. Reprinted from Electric Power Institute (2006), Figure 3-6, p. 3-7.

Revenues and Credits

The goal of my carbon tax model is to be able to generate revenues equivalent to a percentage of the government budget. Taxation from national production of fossil fuels should raise 10% of federal discretionary spending. Taxation from regional consumption should raise 10% of state spending within that region. Default tax rates and their weightings were selected in order to achieve these goals.

Revenues for my model will be distributed in two parts. Tax collected from production nationwide will be re-invested into low-carbon infrastructure and temporary transition assistance for fossil fuel industry workers while tax collected through regional consumption are redistributed back to citizens in the form of tax rebates.

Metcalf and Weisbach (2009) recommend that carbon tax revenue remain neutral (i.e. the size of government should be maintained, not enlarged or decreased as a result of the tax) and should be used to offset other taxes rather than through adjustments to the design of the carbon tax itself (p. 513). However, the nature of this particular carbon tax will generate decreasing carbon tax revenue overtime as the economy shifts away from fossil fuels (discussed more in Part V) and therefore adjustments to its design can be beneficial to reduce economic hardship for businesses and individuals.

Similar to the R&D tax credit, producers of fossil fuels can take a credit against their carbon tax liability equivalent to 20% of their current year's qualified renewable energy or carbon capture expenditures in excess of some base amount. This tax credit ensures that businesses are increasing their investment in low-carbon projects every year. Commercial and industrial businesses can receive carbon tax credits equivalent to the amount they spend on energy through renewable energy. Because commercial and industrial businesses will essentially bear the compounding burden of a national and regional tax on carbon, their tax credits have less limitations. A business could potentially receive a tax credit on their full electricity bill if their electricity is completely sourced from renewable energy.

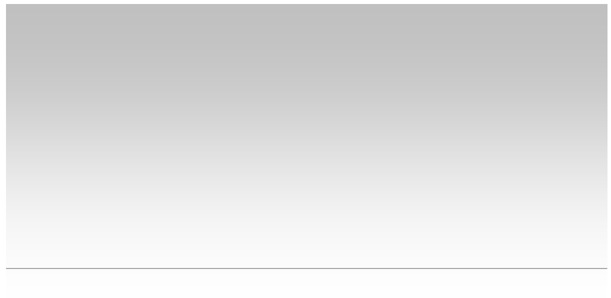


Figure 10: The combined effect of a \$10/ton CO_2 price and adding 19,000 MW of new nuclear generation in the ECAR-MAIN Net Revenue Distribution.

Caption: The combination of a carbon tax and the introduction of other sources of power significantly reduces the net revenues of coal. Reprinted from Electric Power Institute (2006), Figure 4-6, p. 4-6.

The combination of a carbon tax and investment in low-carbon energy production has significant impact on the usage of fossil fuels. Recall that an unweighted carbon tax on coal slightly decreased net revenues for coal-fired plants. Figure 10 graphs the combined effect of a carbon tax and the addition of energy from nuclear power plants resulting in a significant decrease of net revenues. Nuclear power may not necessarily be the best source of low-carbon energy source, nevertheless, the combined effect of a carbon tax and the addition of more power from renewable sources could have the same effect on the usage of fossil fuels (Figure 11).

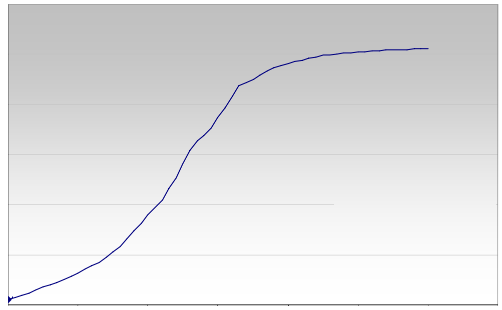


Figure 11: Equilibrium additions of new nuclear generation and regional CO_2 emission by CO_2 price are inversely related to each other.

Caption: As price of carbon increases and wattage available increases, carbon emissions decrease. Therefore a carbon price and new generation of renewable energy reduces CO_2 emissions. Reprinted from Electric Power Institute (2006), Figure 4-8, p. 4-8.

As discussed earlier, carbon taxes do have the potential to be regressive as a larger portion of lower-income families are spent on gasoline and electricity prices. To combat this, several options are suggested here:

1. Personal income taxes can be offset to accommodate a rise in prices and energy expenditures.
2. If personal income taxes are not adjusted, the standard tax deduction could be increased to include a base amount of annual electricity and gasoline expenditures for an average American. Essentially, this would lower the taxable income of individuals resulting in less taxes payable. Regions that experience higher mileage (i.e. rural and farming communities) or adverse weather that require more heating or cooling can choose to include additional tax credits for their constituency regarding gasoline and tax expenses in these areas.

3. Introduce a Green Credit for individuals similar to the Earned Income Tax Credit so that individuals who do not need to pay taxes can still receive the benefits taxpayers have with a greater standard deduction. Essentially, about 50% of Americans do not pay taxes but they would still be affected by a carbon tax. Other taxpayers are given the benefit of taking higher standard deductions. The Green Credit can allow individuals to receive those benefits in the form of cash instead of a lower taxable income.

Part III: National Tax Model

Overview

This section details the mechanics of the production tax model for the whole United States, which estimates the impacts of a potential carbon tax on national GHG emissions and revenues. This model is adapted from Keibun Mori's (2011) Carbon Tax Analysis Model (C-TAM) that estimates the potential carbon tax on GHG emissions and revenues for Washington State. Major determinants of the model's behavior are weighted carbon tax rates, price elasticity of demand by fuel sources, and energy prices and amount of production forecasted by the EIA. Monetary values in the model are in 2013 nominal dollars.

Concept

The basic concept of the national production model is based on Mori's C-TAM which depends on price elasticity of demand to forecast a change in price for fuels and therefore the change in quantity demanded. Mori's conceptual equation which predicts the adjusted demand is:

Adjusted Demand =

Baseline Demand * (1 + % Price Change * Price Elasticity of Demand)

Mori explains that though the equation is simplistic, the complex dynamics in actual energy demand are already addressed in the EIA baseline forecast. In the national model, the basic premise of the equation is to calculate adjusted production as a result of price changes from the carbon tax. I also incorporate the option to weight certain fuels differently. I maintain price elasticity of demand as a factor since demand ultimately affects the supply of these fossil fuels upstream. As a result, Mori's equation has adapted into the following equation for my model:

Adjusted Production Demand =

Baseline Production * (1 + % Price Change * Tax Weight * Price Elasticity)

Baseline Energy Price and Demand Forecast

Baseline fossil fuel prices and production quantity is based on the EIA's Annual Energy Outlook 2015 (AEO 2015). Data is generated through the National Energy Modeling System (NEMS), an energy-economy equilibrium model developed by the EIA that predicts energy price and quantity demanded by fuel source, for each year to 2040. The latest edition came out in 2015 with historical data from 2013. Each fuel source falls into three major categories: crude oil, natural gas, and coal. Furthermore, imports of crude oil, petroleum, and natural gas are also accounted for as they are part of the tax base in my model.

GHG Emissions

With the baseline and adjusted production capacities, the GHG emissions are estimated by multiplying the demand of each fuel by the respective emission factors for each fuel. The EIA classifies the emission factors of each fuel and this model uses a single emission factor for each fuel source for convenience, as the differences by use are minimal. The model assumes the emission factor to be zero for the following fuel sources: renewable energy, nuclear power, and hydropower. These renewable sources are not part of the tax base and the EIA does not provide emission factors for these fuel sources as the emissions occur only at the time of construction for renewable energy, nuclear power, and hydropower, and the projected level of demand is minimal for the rest of these fuel sources.

Carbon Tax Rate and Weights

The default rate to run the national production carbon tax model starts at $35/ton of carbon in 2017, increasing at $2/ per year, capped at $50/ton of carbon. Multiplying these base rates by emission factors used to calculate the baseline GHG emissions yields the individual tax rates for each fuel per million Btu.

Tax rates are also subject to a weight because of unaccounted factors in carbon dioxide emissions. Some of these factors include inelastic prices, lower marginal abatement costs, and intensity of use of the fuel in energy generation. Weights were also manipulated to achieve the revenue goals of 10% of federal discretionary spending.

Table 4: Tax weights assigned to each fossil fuel source and its respective price per million Btu.

Fuel Source	Tax Weight	Price/MMBtu
Production		
Coal	5.53	$24
Natural gas	7.85	$24
Oil	3.86	$24
Imported		
Natural gas	15.00	$37
Crude Oil	10.50	$44
Petroleum and Other Products	11.50	$42
Other Sources		
Landfills	45.00	$73

Weights are selected in order to produce similar costs between the fossil fuels. Under the tax weights selected above, national production of the three fossil fuels cost around $24 per million Btu. Extracted oil has the lowest weight (3.60) oil costs the most per million Btu. However, it should not be taxed at a base rate of 1.0 because it is used in mainly inelastic sectors such as transportation and industry. Because the United States imports three-quarters of its oil supply, I suggest weighting imported crude oil and petroleum at the respective rates of 10.00 and 11.50 in order to capture emissions from the transport of oil from other countries as well as to discourage the U.S. dependency on oil outside of the United States. The model only taxes the imports that come from countries without a carbon pricing system.

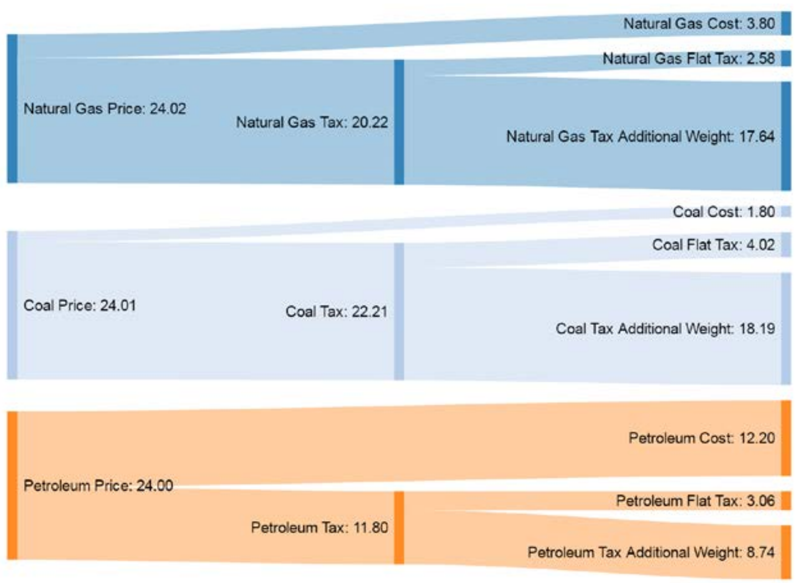


Figure 12: Components of natural gas, coal, and petroleum prices after a weighted tax.

Coal and natural gas generate a large portion of electricity production because they are relatively cheap compared to oil. When coal is taxed 5.50 times the tax rate and natural gas taxed at 8.00 times the tax rate, the price coal and the price for natural gas is about $24 per million Btu. Without weighted tax rates, natural gas can cost more than coal and therefore shift the marginal cost of electricity to the price of coal. Imported natural gas is weighted at 15.00 times the rate of the tax to capture fugitive emissions of methane from pipeline leakage. Imported coal produces less than 1% of the emissions from imports and therefore are excluded from this model.

Finally, landfills are taxed at the greatest amount more than the other tax weights because landfills have extremely low marginal abatement costs. Technology already exists for landfills to capture methane gas emissions to generate power. A high tax on landfill emissions will likely encourage widespread use and further development of this technology.

Price Elasticity of Demand

Another important aspect of the model are the price elasticities of each fossil fuel that predict prices changes and therefore demand for certain fossil fuels. As a majority of produced fossil fuels in the United States are used for electricity generation, the price elasticities I used came from the EIA's publication on fuel elasticities of different power regions. Alongside these elasticities are the "stickiness", or the length of time in which the full elasticity is recognized for the fossil fuel. For simplicity purposes, I assumed that imported fossil fuels will have similar elasticities to the elasticity of domestic production of fossil fuels. Landfill price elasticity of demand was an average of elasticities of solid municipal waste in a study by Kinnaman and Fullerton (1999). The elasticities and stickiness I used for the national model are as follows:

Table 5: Elasticities and stickiness factors used in the national production tax model

Fuel	E	Stickiness
Natural Gas	-0.29	20
Coal	-0.11	20
Petroleum (Oil)	-1.26	20
Landfills	-0.16	20

Impact Estimation and Renewable Energy

With the adjusted production amounts, the model can project the adjusted GHG emissions from national production by multiplying the emission factors by the production. Carbon tax revenues are the multiple of the carbon tax rates for each fuel by the amount of carbon dioxide emitted from national production. In theory, a carbon tax should change the fuel mix for electricity generation as it disproportionately alters the fuel price in favor of untaxed non-fossil fuel or renewable sources such as hydropower and nuclear power. However, power generation normally involves a large sum of capital costs to build power plants, and the lifetime of these plants typically stretches over half a year or longer. This is particularly the case for hydprower and nuclear power, and their operating costs to produce additional output are relatively low. For these reasons, the model assumes that the carbon tax does not affect the output of nuclear power and renewable energy.

Limitations

Elasticity estimates used in the national production carbon tax model are based on the assumption that electricity price elasticities will drive the demand for fossil fuel production. It is a simple price elasticity to use but may not necessarily capture the nuances associated with the demand of fossil fuel production. Other assumptions in this model that may affect results greatly include the percentage of imports that come from countries without a carbon tax, the “optimal” social cost of carbon, and the prices of fossil fuels that are more specific grades (i.e. anthracite coal versus lignite coal). This model also does not take into account the change in demand or capacity of nonrenewable energy as it is not taxed and therefore cannot predict the effect of tax credits on the overall carbon tax revenue. Industrial processes are also not a part of the emissions taxed in the national production section and may produce inaccurate estimates of impact for industry emissions.

Part IV: California Tax Model

Overview

This section details the mechanics of the regional consumption tax model, which estimates the impacts of a potential carbon tax on GHG emissions and revenues in one of the six regions of the United States (California). The structure of the model can be easily expanded to incorporate data from other regions, but for the sake of length and time, I focused on developing the regional tax model with data from the California region. This model is similar in concept and structure as Mori's C-TAM and my national production tax model, with the exception that data in this model are based on the *consumption* of fossil fuels in three end-sectors: commercial, industry, and transportation. Major determinants of the model's behavior are weighted carbon tax rates, price elasticity of demand by fuel sources, and energy prices and consumption forecasted by the EIA. Monetary values in the model are also in 2013 nominal dollars.

Concept

The underlying equation for the regional consumption tax model is similar to that of the national production model wherein price elasticities alongside the calculated price change and tax weight will equal adjusted demand:

Adjusted Demand =

Baseline Demand * (1 + % Price Change * <u>Tax Weight</u> * Price Elasticity of Demand)

Baseline Energy Price and Demand Forecast

Baseline energy price and consumption quantity demanded is based on EIA's Annual Energy Outlook 2015 (AEO 2015). Each fuel source and demand is reported in four major sectors: residential, commercial, industrial, and transportation. Electricity is allocated to each sector. Like Mori's C-TAM, fuels used to generate electricity are accounted for on a production basis so imported electricity to California is not included in the forecast. The AEO's finest level of geographical resolution is at a regional level. In this case, California belongs to the Pacific region, which also includes Oregon, Alaska, Hawaii, and Washington. Following Mori's C-TAM, California's consumption is prorated according to data reports from the EIA's State Energy Database System (SEDS).

GHG Emissions

GHG emissions are estimated by multiplying the demand of each fuel by the respective emission factors for each fuel. Again, the EIA does not provide emission factors for these fuel sources as the emissions occur only at the time of construction for renewable energy, nuclear power, and hydropower, and the projected level of demand is minimal for the rest of these fuel sources.

The baseline emissions computed using these methods is also substantially lower than the GHG emissions inventory compiled by the California Air Resources Board, for two reasons. The first reason is that the baseline emissions in this model do not cover emissions from non-fossil fuel sources such as cement production, waste management, and agriculture. The other reason is that the AEO accounts for electricity on a production basis while the state inventory accounts for it on a demand basis.

Carbon Tax Rate and Weights

As mentioned in Part II, the regional tax model allows the user to select between two different pricing structures (Table 6).

Table 6: Pricing structures implemented for the regional carbon consumption tax model

1. Define the carbon tax				
parameter description	default Value A	Price Value A	default Value B	Price Value B
Set price of ton CO2	-	-	$ 50.00	
First year of model	2017		2017	
Initial ton of CO2 tax rate	$ 35.00		$ 26.68	$ -
Annual increment	$ 2.00		-	-
Maximum rate	$ 50.00		-	-

Value A pricing follows the same trajectory as the national production tax model starting at $35/ton of carbon in 2017, increasing at $2/year, and then capped at $50/ton of carbon. Value B pricing assigns a tax through a floor pricing strategy at the social cost of carbon, where a floor price is set and the tax is equivalent to the difference between the set amount and average fuel prices. The default floor price is $50, setting the tax rate in 2017 to $26.68 per ton of CO_2.

Multiplying the base rates by emission factors used to calculate the baseline GHG emissions yields the individual tax rates for each fuel. The tax rates also include a second option that uses a rate equivalent to the difference between fuel's average cost in the market and the price set by government.

Weights by sector and fuel are also incorporated into the regional consumption tax model in order to accommodate inelastic fuels and to be able to achieve revenue goals of 10% of the state's expenditures. These weights are much smaller than that of the national production tax in order to minimize the tax burden since fossil fuels have already been subject to a tax during production. Table 7 summarizes the weights involved in regional consumption:

Table 7: Default tax weights used in the regional carbon consumption tax model

parameter description	default tax rate weight
Residential sector	
natural gas	0.00
electricity	0.00
Commercial sector	
natural gas	1.50
electricity	0.50
Industrial sector	
natural gas	1.50
petroleum	1.00
coal	1.00
electricity	0.70
Transportation	
gasoline	1.00
diesel	4.00

The commercial and industrial sector are primarily taxed on their electricity usage and any consumption of fossil fuels for industrial processes. Electricity for commercial businesses and industrial entities are taxed below the base rates to compensate for increased electricity prices from the national production carbon tax. However, any fossil fuels they consume beyond electricity is also taxed. Natural gas is taxed the highest because the abundance of natural gas in California makes it a preferred fossil fuel and as mentioned previously, natural gas transmission includes fugitive emissions from pipeline leakage. The 1.50 weight on natural gas also includes the social cost of transporting natural gas to commercial businesses and industry.

Transportation presents the greatest area of taxation as it is a leading cause of emissions in California. Motor gasoline is taxed at base rate to encourage more sustainable alternatives to driving. However, diesel is taxed at four times the base rate to curb emissions from heavy-duty trucks and freight transport. This area has the potential to become more efficient as vehicles do not just emit carbon dioxide. They also emit nitrous oxide gases that are harmful to the environment.

Finally, the default tax weight for the residential sector is 0 in order eliminate double taxation for households. As costs for businesses and industry go up, these costs are likely to be passed on to the consumers.

Price Elasticity of Demand

Price elasticity figures are used to gauge consumer reactions to fossil fuel prices. Mori (2011) did an extensive study on price elasticity for different fuel sources which I utilized for my model. Some important takeaways from his study include:

- Using long-term elasticity which represents more fundamental changes such as capital replacement and land use change because the model needs to find the long-term effects of the carbon tax;
- Using studies on elasticity that are published after 1900 in order to control temporal change in elasticity;

- Focusing on state-level and regional-level elasticity estimates because price elasticity of demand are different between countries;
- Separating meta-analysis elasticity data from individual studies because these are derived from large data pools. Fuels subject to a meta-analysis are doubled the weight in a weighted average of the meta-analysis figures and the individual studies;
- Elasticity is 0 for the following fossil fuel sources: kerosene, coal (residential and commercial), motor gasoline (commercial and industrial), petrochemical feedstock, other petroleum, and biofuels and heat coproducts.
- Minor fuels also follow the same elasticity as the following fuels:
  - Gasoline: liquefied natural gas (LPG), compressed natural gas, pipeline fuel natural gas, and ethanol (E85),
  - Residential natural gas: LPG and distillate fuel oil,
  - Commercial natural gas: LPG, residual fuel, distillate fuel oil,
  - Industrial electricity: LPG, residual fuel, distillate fuel oil, natural gas, and coal.

To see the complete table of elasticities that Mori used to calculate his weighted average elasticities, see Appendix B.

Impact Estimation

With the adjusted energy demand, the model can easily project the adjusted GHG emissions for California by multiplying the emission factors by the new energy demand. Carbon tax revenues are the multiple of the carbon tax rates for each fuel by the amount of carbon dioxide emitted from national production or regional consumption.

The revenues from regional consumption are meant to be revenue-neutral in that the taxes raised will go back to citizens in the form of cash rebates. However, the user also has the ability to select other ways to utilize the revenues including income tax or sales tax offsets. The model assumes that the other tax rates and structure are static.

Electric Sector

Mori (2011) explains that electricity is modeled differently in C-TAM because 1) consumers pay for electricity, not fuel; 2) electricity is an intermediary so it produces emissions while also providing energy that creates emissions when used by other four sectors; 3) each industry has different baseline prices for electricity; and 4) each industry has different price elasticity of demand for electricity. For these reasons, Mori models the electric sector by allocating it to their end-use sector by first aggregating the electric sector to create a total for all fuels, and the total is then allocated to other sectors based on the sectors' forecasted share of the electric consumption each year. The electricity price change caused by the carbon tax is the weighted average of price increases of each fuel source. The adjusted demands are aggregated to find the adjusted energy demand for the electric sector. The regional carbon consumption model follows this structure.

Summary of Limitations

Based on fuel mix disclosures made available by states, the model has the ability to allocate a percentage of the emissions to the correct fuel source. A carbon tax should change the fuel mix as it disproportionately alters the fuel price in favor of non-fossil fuel sources such as hydropower and nuclear power, however, the model currently does not include a way to measure this. As a result, I also have not designed the model to take into account some of the tax credits for individuals that were discussed in Part II. There is also some disconnect between the national and regional models as the regional model currently does not have baseline prices that are dependent on the increase in fossil fuel prices from a carbon tax.

Part V: Analysis and Results of the Models

Overview

This section reports the revenue breakdown of the carbon tax in 2017, 2020, and 2030 as well as the emissions reductions as compared to business-as-usual emissions in 2020 and 2030.

Goals for Revenue

The goal of the model was to develop tax weightings that would raise 10% of the federal discretionary spending through the national production tax in the first year and 10% of state expenditures in California through the consumption tax in that region for the first year.

Weighting Scenarios

Different scenarios are presented for this analysis which include the following:

- National production tax –
    - Scenario 1: Value A pricing at flat tax.
    - Scenario 2: Value A pricing at differential weights.
- Regional consumption tax –
    - Scenario 1a: Value A pricing at flat tax.
    - Scenario 1b: Value A pricing at differential weights.
    - Scenario 2a: Value B pricing at flat tax.

- Scenario 2b: Value B pricing at differential weights.

Scenario results for National Carbon Production Tax

Table 8: Results from Scenario 1 – Price Scheme A, flat tax

Carbon Tax Revenues (billions)			
	2017	2020	2030
Federal Spending	$1,198.0	$1,248.0	$1,429.0
Revenue as % of Federal Spending	1%	2%	2%
	2017	2020	2030
fuel type	$	$	$
Natural Gas	$ 3.45	$ 4.20	$ 5.32
Coal	$ 6.38	$ 7.72	$ 8.45
Petroleum	$ 4.01	$ 4.75	$ 4.59
Imports	$ 3.50	$ 3.92	$ 4.10
Landfills	$ 0.22	$ 0.25	$ 0.30
TOTALS	$ 17.56	$ 20.83	$ 22.75

Table 9: Results from Scenario 2 – Price Scheme A, differential weights

Carbon Tax Revenues (billions)			
	2017	2020	2030
Federal Spending	$1,198.0	$1,248.0	$1,429.0
Revenue as % of Federal Spending	10%	8%	1%
	2017	2020	2030
fuel type	$	$	$
Natural Gas	$ 25.68	$ 26.71	$ 9.59
Coal	$ 33.65	$ 33.42	$ 0.89
Petroleum	$ 14.87	$ 14.93	$ 5.28
Imports	$ 32.70	$ 17.35	$ -
Landfills	$ 9.72	$ 8.32	$ -
TOTALS	$ 116.63	$ 100.73	$ 15.76

Discussion on scenario results for National Carbon Production Tax

Revenue from differential taxes, 115.96 billion, are almost 560% larger than revenue from the flat tax, 17.56 billion, in 2017. By weighting the tax, the sources of revenue are evened out, scaling back taxes from coal and petroleum in order to capture more taxes from imports, landfills, and natural gas (Figure 13). There is a decrease in petroleum's share of tax revenue, however, much of that loss is recovered from the weighted tax on imported crude oil and petroleum products. By equalizing sources of revenue between each fossil fuel, it will be unlikely that one fossil fuel will substitute for another and therefore encourage producers to turn to low-carbon sources for energy needs.

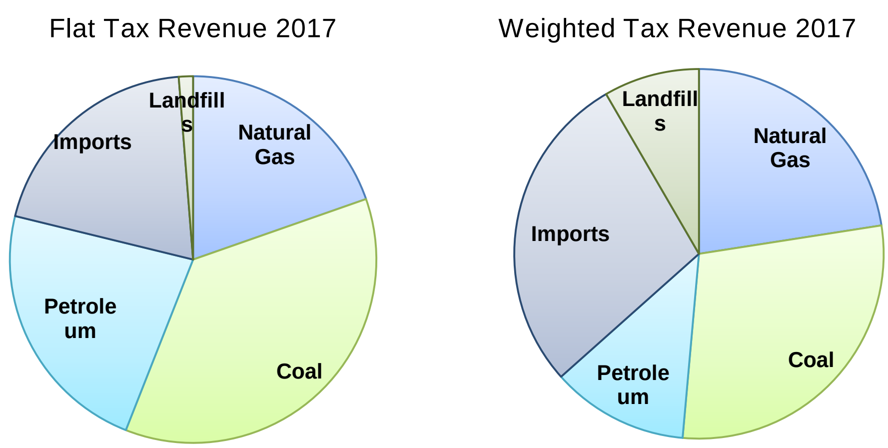


Figure 13: Comparison of the tax revenues from a flat tax versus a weighted tax on national production in 2017.

The drawback to the weighted tax model, however, is the steep adoption rate of the tax leading to declining revenue overtime. Whereas the flat tax maintains a mostly linear and positive revenue stream even through 2034, revenues from the weighted production tax model decreases significantly between 2020 and 2040 (see Figure 14). This will require significant overhaul within the American economy over a shorter period of time. However, this may be necessary and the most incentivizing market activity to meet global greenhouse gas emission abatement goals by 2030. A weighted carbon tax decreases overall 2030 business-as-usual projected emissions by 82% versus a flat tax which decreases business-as-usual projected emissions by 15%.

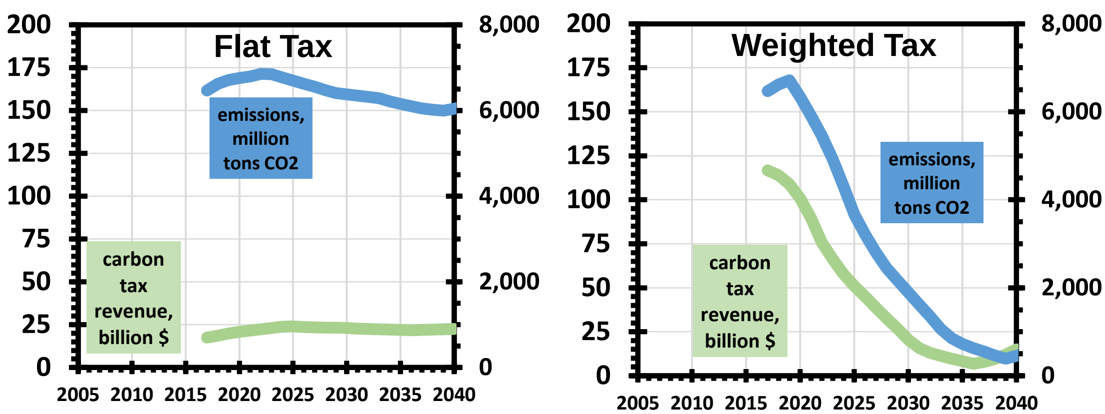


Figure 14: Differences between a flat carbon tax versus a weighted one in revenues (green line) and emissions (blue line).

Over the next decade, a weighted tax will significantly reduce demand for fossil fuels, particularly coal because it is currently the most inexpensive of the three fuels and therefore, weighted the most. Revenues from coal production are projected to make up about a third of the revenue amounts collected annually, amounting to about $34 billion every year through 2020. Potential losses to labor in the coal industry amount to $5.5 billion annually which can be leveraged by transition assistance from the coal portion of the tax revenues (Metcalf & Weisbach, 2009, p. 515).

Furthermore, these revenues can be used as upfront costs for shifting to a low-carbon economy. The US spent $39.1 billion in energy and environmental efforts in 2015 (*ibid*). The revenue from this carbon tax can easily produce nearly twice that amount for energy and environmental efforts through 2030. Studies have shown that even doubling our environmental investments can be spent productively (Newell 2008; Furman 2007). By bolstering renewable energy infrastructure and carbon capture and storage, firms will seek out renewable substitutes, make energy production more efficient, and cause further development in this market.

Scenario results for Regional Carbon Consumption Tax

Table 10: Scenario 1a – Value A pricing, flat tax

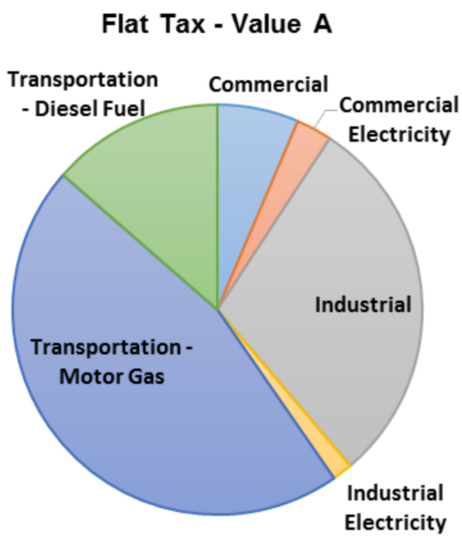
***Output:* carbon tax revenue ($ bil)**			
California Budget	**2017**	**2020**	**2030**
State Spending	$123.8	$130.6	$143.6
Tax Revenue as % of Spending	7%	7%	7%
	2017	**2020**	**2030**
sector group	**$**	**$**	**$**
Residential	$ -	$ -	$ -
Commercial	$ 0.82	$ 0.94	$ 1.04
Industrial	$ 2.76	$ 3.36	$ 3.54
Transportation	$ 5.55	$ 5.16	$ 5.34
TOTALS	$ 9.13	$ 9.47	$ 9.93
(individual)	$ 4.09	$ 3.31	$ 3.02
(business)	$ 5.04	$ 6.15	$ 6.90

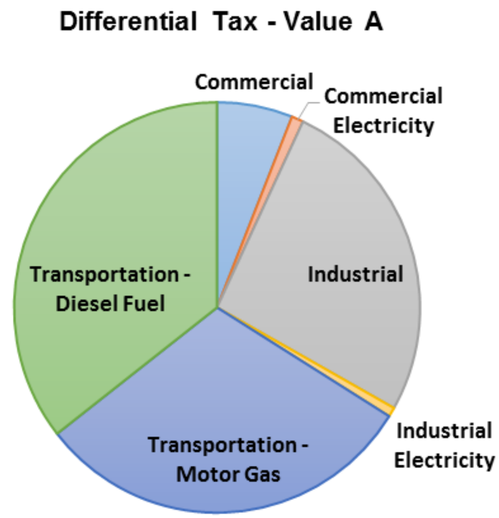
Table 11: Scenario 1b – Value A pricing, weighted rates

Output: **carbon tax revenue ($ bil)**			
California Budget	**2017**	**2020**	**2030**
State Spending	$123.8	$130.6	$143.6
Tax Revenue as % of Spending	11%	11%	10%
	2017	**2020**	**2030**
sector group	**$**	**$**	**$**
Residential	$ -	$ -	$ -
Commercial	$ 0.93	$ 1.09	$ 1.27
Industrial	$ 3.60	$ 4.15	$ 3.93
Transportation	$ 9.09	$ 9.03	$ 9.46
TOTALS	$ 13.63	$ 14.27	$ 14.67
(individual)	$ 4.09	$ 3.31	$ 3.02
(business)	$ 9.54	$ 10.96	$ 11.64

For both Value A pricing and Value B pricing, weighted taxes produce 49% more revenues than a flat tax. Transportation also remains the largest source of revenue for both carbon pricing methods. However, the weighted tax increases the tax burden on diesel fuel consumers while decreasing the tax burden on electricity for commercial and industrial sectors. Diesel is weighted particularly heavily because it is the main fuel used in the freighting industry. About 40% of the country's containerized goods enter or exit California's ports and these goods are transported via an inefficient fleet of trucks (American Association of Port Authorities, 2013). Nationwide, diesel-reliant trucks emit 75% of greenhouse gas emission from freight transportation (U.S. Department of Transportation).

Figure 15: Comparison of tax revenues from a flat tax versus weight tax, Value A pricing regional consumption, 2017.





By imposing a weighted tax on diesel, the California region can better capture the cost of social cost of nitrous oxide, air pollutants, and greenhouse gases emitted by a relatively inefficient trucking fleet. The trucking industry in California also has the opportunity to lower their taxable emissions by investing in carbon-capture technologies on freight vehicles, developing more energy-efficient vehicles, and expanding rain infrastructure as a means of transporting goods. Diesel locomotives could reduce greenhouse gas emission by 84% and an electrical rail line could bring total emissions reductions of ~94-99% in the freight transportation industry (California Cleaner Freight Coalition, 2014, p.8).

Value B pricing produces somewhat lower tax revenues than Value A pricing and has more volatility in revenue over the decade. Value A pricing is somewhat constant in its tax revenues, only fluctuating by 1 or so percent every few years. However, Value B pricing decreases about 2% every five years because it relies on changing average prices of energy to calculate the tax rate for carbon.

Table 12: Results from Scenario 2a: Value B pricing, flat tax.

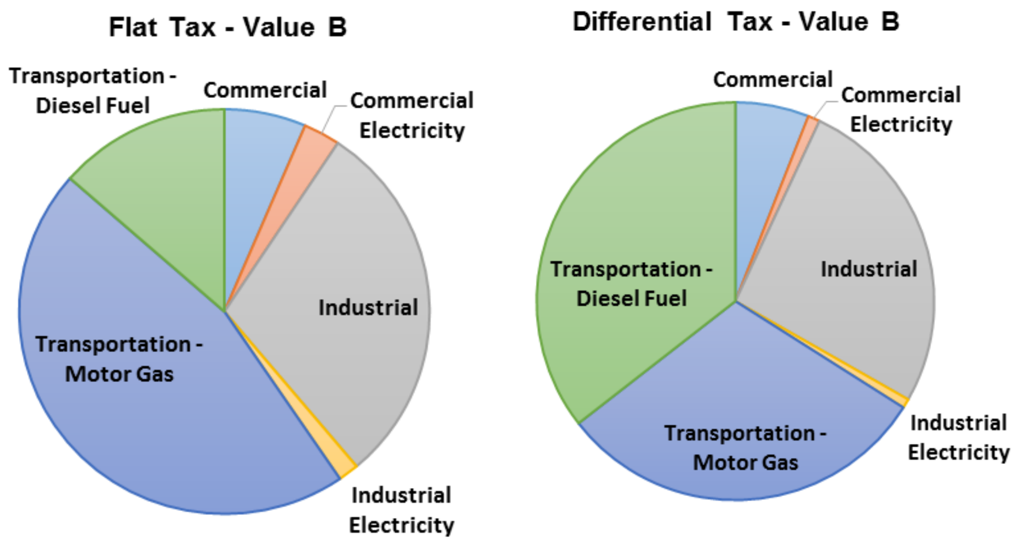
***Output:* carbon tax revenue ($ bil)**			
California Budget	**2017**	**2020**	**2030**
State Spending	**$123.8**	**$130.6**	**$143.6**
Tax Revenue as % of Spending	**7%**	**6%**	**4%**
	2017	**2020**	**2030**
sector group	**$**	**$**	**$**
Residential	**$ -**	**$ -**	**$ -**
Commercial	**$ 0.73**	**$ 0.72**	**$ 0.65**
Industrial	**$ 2.44**	**$ 2.61**	**$ 2.35**
Transportation	**$ 4.89**	**$ 3.88**	**$ 3.17**
TOTALS	**$ 8.06**	**$ 7.22**	**$ 6.18**
(individual)	**$ 3.60**	**$ 2.49**	**$ 1.80**
(business)	**$ 4.46**	**$ 4.73**	**$ 4.38**

Table 13: Results from Scenario 2b: Value B pricing, differential weights.

***Output:* carbon tax revenue ($ bil)**			
California Budget	**2017**	**2020**	**2030**
State Spending	**$123.8**	**$130.6**	**$143.6**
Tax Revenue as % of Spending	**10%**	**8%**	**7%**
	2017	**2020**	**2030**
sector group	**$**	**$**	**$**
Residential	**$ -**	**$ -**	**$ -**
Commercial	**$ 0.82**	**$ 0.83**	**$ 0.78**
Industrial	**$ 3.19**	**$ 3.25**	**$ 2.82**
Transportation	**$ 8.02**	**$ 6.85**	**$ 5.91**
TOTALS	**$ 12.03**	**$ 10.93**	**$ 9.51**

(individual)	$ 3.60	$ 2.49	$ 1.80
(business)	$ 8.43	$ 8.44	$ 7.72

Figure 16: Comparison of tax revenues from a flat tax versus weight tax, Value B pricing regional consumption, 2017.



Part VI: Conclusion

I began this thesis wanting to piece together what I had learned about climate change policy and incorporating economic and tax principles to develop a model that taxes carbon dioxide emissions from fossil fuel production and consumption.

This study has shown that a weighted national tax on fossil fuel production and a weighted regional tax on carbon consumption can indeed raise revenues equivalent to 10% of federal discretionary spending and 10% of state spending in California. The distributed nature of this tax, allocated on the basis of differential sector contribution to carbon emissions, is sufficiently broad that no one industry or sector would be overly penalized. Furthermore, contribution from all sectors represents that the national nature of these emissions and revenue return at the level of 10% of federal discretionary spending is quite significant. In turn this revenue could be re-invested in the green energy rising economy (infrastructure and jobs) as well as offering various energy savings incentive based tax credits to the American taxpayer. Indeed, the entire nature of this study was to simply determine if such a weighted approach to a national (or regional) carbon tax was feasible. We have demonstrated the feasibility which should then initiate a broader discussion of this concept.

In context, a carbon tax may be the most straightforward tool to help regulate our society moderate its fossil fuel addiction as now more of the true cost of carbon pollution is now taken into account. Perhaps the most trusted source on global emissions is the annual audit and score card provided by the Global Carbon Project. Their report released at the end of 2014 (Friedlingstein *et al*. 2014) reveals the following:

Global emissions, mostly from fossil fuel burning but supplanted by increased cement production (primarily used in the increasing urbanization of China), reached a new high of 36 billion emitted tons in 2013. Simple growth models predict an additional 2.5% increase in 2014. The most recent Mauna Kea measurements (April 2016) reveal an atmospheric CO2 concentration of 407.57 ppm up an astounding and alarming 4.12 ppm from April of 2015. Thus, there is no doubt that CO2 emissions are accelerating on a global basis and any mechanism to curtail this activity should be hailed. If no curtailment is possible, the Global Carbon Project offers this waveform for our near term future:

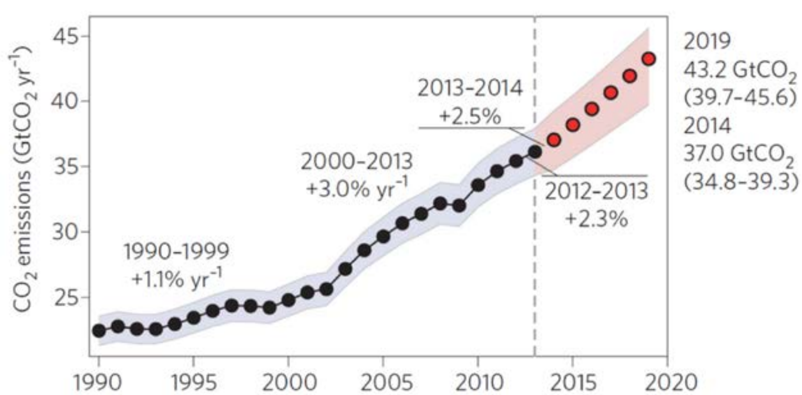


Figure 17: Global carbon dioxide emissions from fossil fuel and cement production.

Caption: Global emissions are expected to increase steadily over the coming four years through 2020 due to forecasted growth in gross domestic product (GDP). Reprinted from Global Carbon Project 2014 and Friedlingstein *et al*. 2014, Figure 1.

The figures below show the projected emissions and emissions per capita. We note here that US emission and emissions per capita are mostly flat out to 2020:

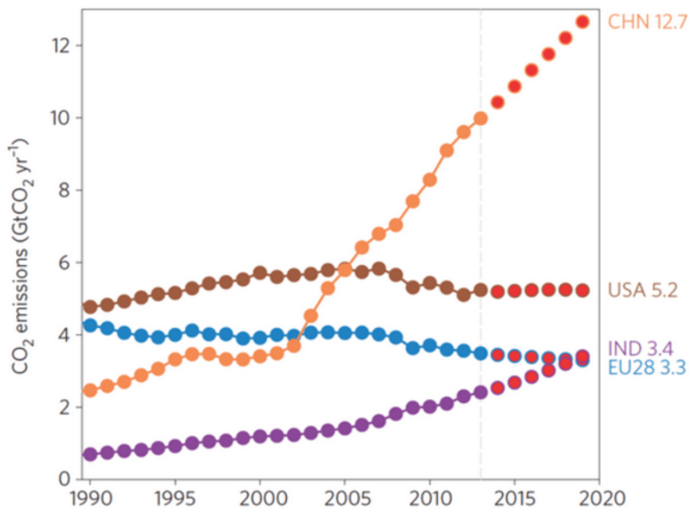
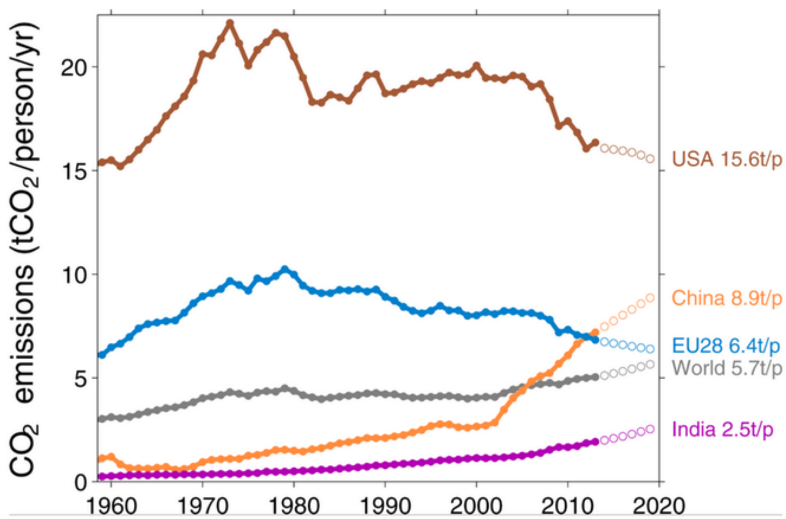


Figure 18: 2014 carbon dioxide emissions per top emitting country with forecasts to 2020.

Caption: Reprinted from Global Carbon Project 2014 (Friedlingstein *et al.* 2014, Figure 2).



Reference to Figure 3: Reprinted from Global Carbon Project 2014.

These emissions are large dominated by fossil fuel electricity generation and fossil based transportation systems. For the US, in the year 2015, 66% of our total electricity use was provided equally by coal and natural gas (the latter due to our current fracking fetish). When considering transportation and space heating, our total energy use portfolio increases to 82% from fossil fuels (EIA 2015). If left unregulated, the United States will continue business as usual (BAU), exhausting our resources of coal, oil, and natural gas in the next few decades. We therefore need some form of incentive to curtail our BAU trajectory.

Unlike other models, this particular carbon tax design imposes a tax on production of fossil fuels on a national scale while also taxing consumption of fossil fuels and the energy they can generate in six regions of the United States at a rate of $35 to $50 per ton of carbon. The major uncertainty in our model, which we directly treat as an adjustable parameter, is the price of carbon. To date, that price is not well determined. According to a recent report by the Sightline Institute (Eberhard 2014) there are 39 different programs that price 12% of the global greenhouse gas emissions. The bulk of this comes from the EU Emission Trading System which covers about 45% of EU emissions and Japan, which has recently priced carbon to cover 70% of their emissions. Among these 39 different structures, prices range from $1 to $168 per ton though most prices are in the range $10-30 per ton; still that is a factor of 3 range in price. For example, California's program price is currently $13 per ton while British Columbia's is $28 per ton. According to our approach, a low price of carbon naturally requires a large carbon tax revenue while a high price of Carbon would lower the required revenue because our model targets a 10% federal R&D expenditure. The likely trend, especially as China emerges in to this market, is that the price of carbon will increase thus reducing the severity of our proposed differential carbon tax.

For one specific example, at $35 per ton our Model returns the following

- The first year of the tax will raise $115 billion.
- Since individual gasoline consumption is not taxed, this revenue comes from the weighted tax applied to approximately 2/3 of all US greenhouse gas emissions.
- Over the next decade, a weighted tax will significantly reduce demand for fossil fuels, particularly coal because it is currently the most inexpensive of the three fuels and therefore, weighted the most. Under various financial models, this would lead directly to a significant reduction in coal emission in the very near term.

In sum, we have offered a simple spreadsheet model that centers on the concept of a differential carbon tax. We have shown the model can potentially raise significant tax revenue. This model could be applied nationally as well as on a regional scale. Improvements to the model would result from price of carbon and/or carbon emissions that has low regional variance. Further improvement could occur through a more rigorous consideration of the monetary value of tax credits and renewable energy investments that could result directly from this raised revenue. This latter part, however, is critically dependent on the actual price of carbon.

As an example of a direct investment of this tax revenue of $100 billion per year in to green energy infrastructure to replace fossil fuel infrastructure, consider the following: The current capital price of wind energy is in the range $1.5 -2 per watt (Bothun and Bekker 2015). An example is provided by the Horse Hollow wind farm in TX which now has 800 MW of capacity – at $1.5 per watt the total cost would be $1.2 billion, similar to what the reported costs have been since an investment of $100 billion would build 80 equivalent facilities for a total capacity of 64000 MW (64 Gigawatts) . Since the operating efficient 88 of wind are about 1/3 compared to the 90% for coal, then 64 GW of name plate capacity is equivalent to 64/3/.9 = 24 GW of coal power. But this is just for one year of revenue! While coal plants are being retired (supplanted mostly by natural gas), the total generating capacity is currently around 300 GW. Clearly, a steady 10 year investment from this carbon tax revenue would essentially eliminate the need for any coal fired electricity,

Our simple spreadsheet model shows that a carbon tax design is achievable in public policy and generates a significant amount of tax revenue. It taxes approximately two-thirds of all greenhouse gas emissions and with weights placed on certain items, federal revenues can amount to $116 billion in the first year of the tax while decreasing carbon dioxide emissions by 82% in 2030. Of that $116 billion, $34 billion will come from coal mines, $26 billion from natural gas wells, and about $15 billion from petroleum (along with an additional $32 billion from mostly imported natural gas and petroleum). A flat tax on the other hand, only raises $18 billion in revenue, with a majority of the burden on the coal industry alone, and only reduces emissions by 15% in 2030. Regional weighted taxes can also raise an additional $13.63 billion and lower emissions by 25% in 2030 as opposed to a flat tax raising $9 billion in revenue and reduce emissions only by 9% in 2030. On both a national and regional scale, a weighted tax achieves more revenues and reduces emissions faster and more effectively than a flat tax. A weighted tax rate therefore will incentivize green energy investment much more effectively than a flat tax because more revenue can be raised to be funneled back in green energy research as well as more companies will be much more proactive in creating more efficient energy processes, pursue carbon capture technologies, and change the way they consume energy – all necessary changes to create a low-carbon society.

This model, however, does have some limitations and further areas of work including 1) more closely linking the national tax and the regional tax so prices from the national tax flow into the prices for the regional model, and 2) embedding the effects of tax credits by placing a monetary value on renewable energy investments. Another area of further research could be other weighting strategies such as differential taxes by consumption (i.e. taxing more "luxurious" carbon activities more than necessary ones) rather than on the inelasticity of certain fossil fuels.

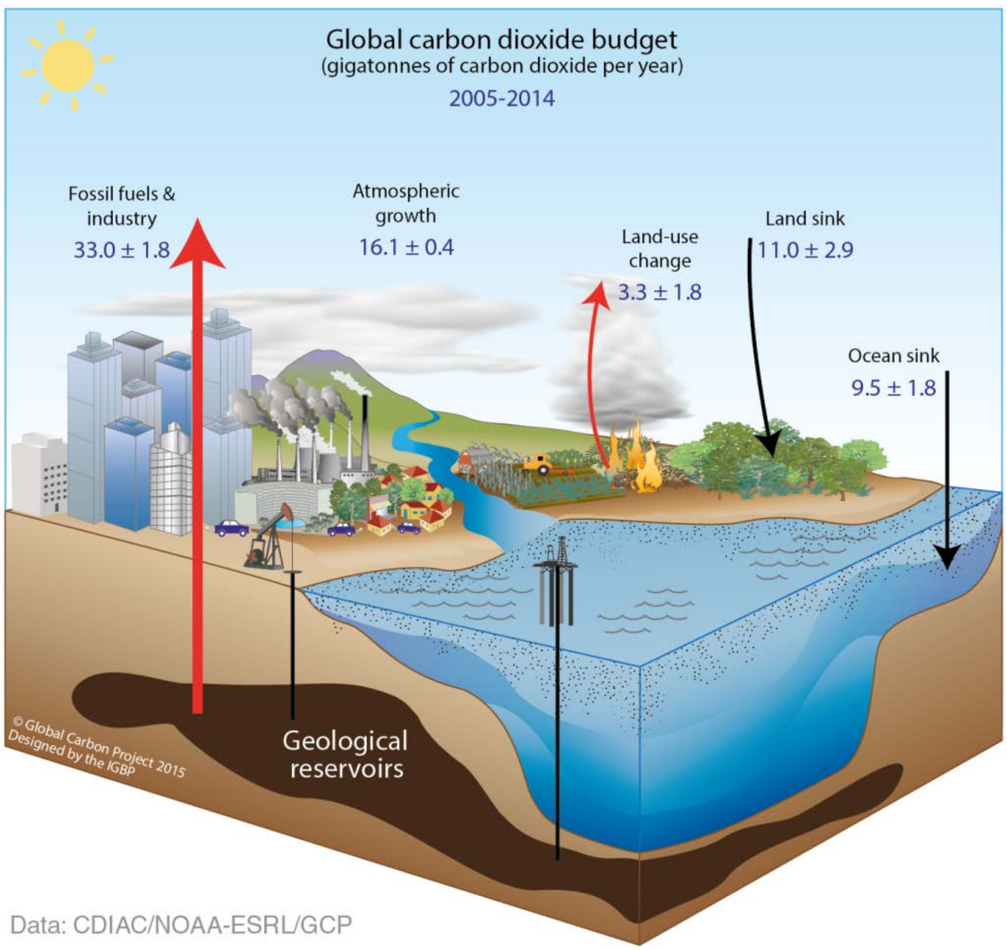
To conclude, this research has taught me that the question with a carbon tax is not "*how do we create a structure for it?*" If I as an undergraduate can make sense of and piece together greenhouse gas emissions inventory data, dollars, and elasticities into an Excel spreadsheet that produces a revenue estimation, a carbon tax design should be achievable in public policy, an arena with access to professional economists, scientists, lawyers, and financial advisers who can take this simple model and refine it to be more economically and politically feasible. The real question in implementing a carbon is, *"do we actually want to put in the effort to implement such a tax?"* The United States has taken a stance to curb its greenhouse gas emissions by promising to adopt the conditions of the Paris deal by the end of this year. Perhaps the warnings of the scientists from 1992 will finally be heeded.

Appendices

Appendix A

Perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2005-2014 (gigatons CO2 per year). Reprinted from

http://www.globalcarbonproject.org/carbonbudget/15/files/GCP_budget_2015_v1.02.pdf.



Appendix B

Elasticity study conducted by Keibun Mori for the Carbon Tax Analysis Model (C-TAM) he created and which my models are based off.

Type	Author	Year	Transportation Fuels				Electricity			Natural Gas		
			Gasoline	Diesel Fuel	Jet Fuel	Residual Fuel	Res.	Com.	Ind.	Res.	Com.	Ind.
Meta-Analysis	EIA[42]	2003					-0.49	-0.45		-0.41	-0.40	
	Goodwin[43]	2004	-0.64									
	Espey[44]	1996	-0.58									
	Brons[45]	2006	-0.53									
	AVG		-0.58				-0.49	-0.45		-0.41	-0.40	
Individual Studies	Council[46]	1982					-0.40	-0.53	-0.22			
	WSU[47]	1982					-0.09	-0.32	-0.82			
	BPA[48]	1982					-0.28	-0.42	-0.93			
	Dahl[49]	1991	-0.86									
	Greene[50]	1984		-0.47								
	Bernstein[51]	2006					-0.25	-1.37		-0.45		
	Small[52]	2007	-0.40									
	Agras[53]	1999	-0.92									
	Maddala[54]	1997						-0.23			-0.20	
	Maddala[55]	1997						-0.26			-0.28	
	Azevedo[56]	2011					-0.25					
	Sipes[57]	2001	-0.60									
	Sterner[58]	2006	-0.80									
	Goodwin[59]	1992	-0.71									
	Hewlett[60]	1980				-0.43						
	Hagler Baily[61]	1999	-0.60	-0.40	-0.30	-0.30						
	Silk[62]	1997					-0.60					
	Gately[63]	1988			-0.15							
	AVG		-0.70	-0.44	-0.23	-0.37	-0.30	-0.52	-0.49	-0.31	-0.24	
Weighted AVG			-0.62	-0.44	-0.23	-0.37	-0.43	-0.47	-0.49	-0.38	-0.35	

Appendix C

Screenshot of the front page of the national model

1. Define the carbon tax

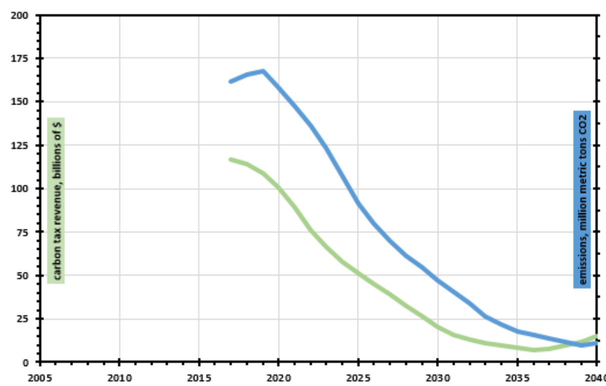
parameter description	default Value A	Price Value A
set price of carbon (per ton)		
First year of model	2017	
Initial carbon tax rate (per ton)	$ 35.00	
Annual increment	$ 2.00	
Maximum rate	$ 50.00	

2. Specify model behavior

parameter description	default	your value
Include Landfill Gas emissions	Yes	No
Pricing scenario	Value A	Value A

3. Assign weights to sectors — 2020

parameter description	default tax rate weight	your value	tax (per MMBtu)	change in price after tax (per MMBtu)
Production				
Coal	5.53		$ 22.21	1273%
Natural gas	7.85		$ 20.22	414%
Petroleum Oil	3.86		$ 11.80	93%
Imported				
Natural gas	15.00		$ 32.64	669%
Crude Oil	10.50		$ 32.09	244%
Petroleum and Other Products	11.50		$ 30.54	232%
Other Sources				
Landfills	45.00		$ 73.17	1876%



Output: **energy related emissions, million metric tons CO2**

fuel type	2020 baseline	2020 adjusted	2020 change	2030 baseline	2030 adjusted	2030 change
Natural Gas	1,916.28	1,513.89	-21%	2,158.72	503.32	-77%
Coal	2,068.12	1,544.84	-25%	2,150.60	145.33	-93%
Petroleum	1,652.97	1,265.64	-23%	1,571.80	418.77	-73%
Imports	1,289.64	544.28	-58%	1,289.64	-	-100%
Landfills	148.62	59.40	-60%	149.67	-	-100%
TOTALS	7,075.63	4,928.04	-30%	5,881.12	1,067.42	-82%

**Electricity is included in each sector's emissions forecast above

Output: **carbon tax revenue ($ bil)**

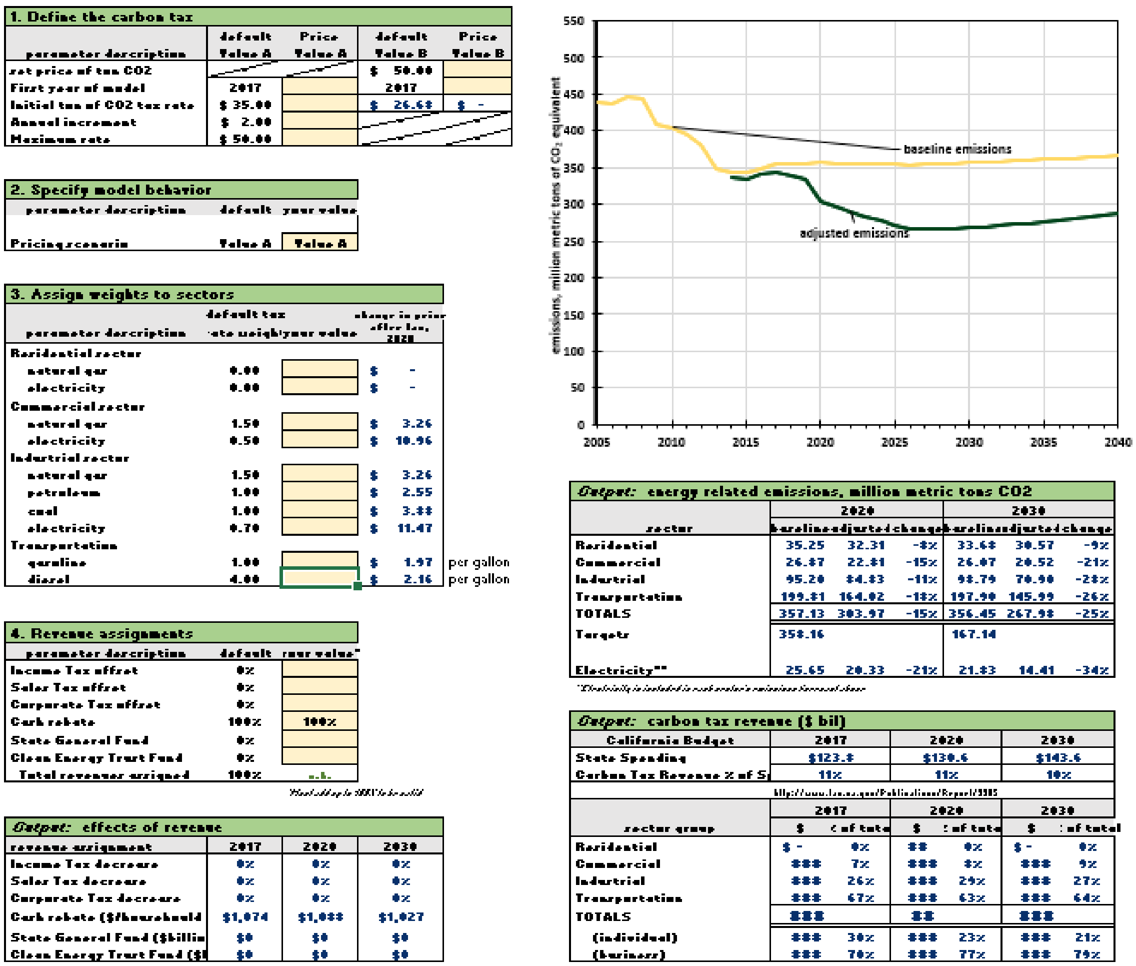
Federal Budget	2017	2020	2030
Federal Spending	$1,198.0	$1,248.0	$1,429.0
Carbon Tax Revenue % of Spend	10%	8%	1%

http://www.lao.ca.gov/reports/2015/3305/fiscal-outlook-111815.pdf

fuel type	2017 $	2017 % of total	2020 $	2020 % of total	2030 $	2030 % of total
Natural Gas	$ 25.68	22%	$ 26.71	27%	$ 9.59	61%
Coal	$ 33.65	29%	$ 33.42	33%	$ 0.89	6%
Petroleum	$ 14.87	13%	$ 14.93	15%	$ 5.28	33%
Imports	$ 32.70	28%	$ 17.35	17%	$ -	0%
Landfills	$ 9.72	8%	$ 8.32	8%	$ -	0%
TOTALS	$ 116.63		$ 100.73		$ 15.76	

Appendix D

Screenshot of the first page of the regional model



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