THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ECONOMICS

CAPPING CARBON: A SURVEY OF CARBON PRICING MECHANISMS AND THEIR EFFICACY

MARIA COSMA
SPRING 2016

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Economics
with honors in Economics

Reviewed and approved* by the following:

Ronald Gallant
Professor of Economics
Thesis Supervisor

Russell Chuderewicz
Senior Lecturer of Economics
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

Carbon dioxide is arguably the most complex externality problem faced by today's markets. Economic theory dictates that a social cost must be applied to this pollutant to bring markets to their true equilibrium and discourage further emissions that lead to climate change. This paper takes a look at various carbon pricing experiments at all levels of government and in private markets as well. It begins by defining the carbon problem in terms of disproportionate emissions, disproportionate effects, and uncertainty. Then, a survey of estimates of the social cost of carbon shows how different approaches to the same variables, such as the discount rate and uncertainty, lead to large differences in the final estimates. A discussion on mandate markets, specifically carbon taxes and trading schemes, identifies common factors for successes and failures. Finally, an analysis of the carbon offset market considers the validity of a voluntary market for carbon pricing. The paper concludes with suggestions for carbon pricing policies in the United States.

TABLE OF CONTENTS

LIST OF FIGURES iii

LIST OF TABLES iv

Chapter 1 Introduction 1

Chapter 2 The Carbon Problem 3

2.1 Greenhouse Effects 3
2.2 Disproportionate Emissions 5
2.3 Regions Affected 6
2.4 Uncertainty 7
2.5 Carbon Dioxide as a Negative Externality 8

Chapter 3 The Social Cost of Carbon 11

3.1 Defining the Social Cost of Carbon 11
3.2 Calculating SCC 12
3.3 The Discount Rate 13
3.4 Uncertainty 15
3.5 Regional Variation 16
3.6 Widely Used SCC Models 16
DICE Model 17
FUND Model 18
PAGE Model 18
DSICE Model 19
3.7 Takeaways 19

Chapter 4 Carbon Taxes 21

4.1 How a Carbon Tax Works 21
4.2 Case Studies 24
Sweden 24
British Columbia 26
Ireland 29
Australia 31
United States 33
4.3 Carbon Tax Conclusions 35

Chapter 5 Trading Schemes 39

5.1 How a Trading Scheme Works 39
5.2 Case Studies 42
The Clean Air Act 42
European Union Emissions Trading System 46

Regional Greenhouse Gas Initiative 50
Western Climate Initiative 54
California Trading Scheme 54
5.3 Trading Scheme Conclusions 56

Chapter 6 Voluntary Markets 60

6.1 Carbon Offsetting 60
6.2 Defining the Voluntary Market 61
6.3 Offset Prices 62
6.4 Voluntary Market Trends 64
6.5 Environmental Impact of Carbon Offsets 66

Chapter 7 Analysis and Conclusions 67

7.1 Mandate Markets vs. Voluntary Markets 67
7.2 Tax or Trade? 68
7.3 Carbon Pricing in the United States 69
7.4 An International Solution 69
7.5 Areas for Further Research 70
7.6 Final Remarks 72

REFERENCES 73

LIST OF FIGURES

Figure 1: Anthropogenic GHG Emissions by Gases 1970-2010 4

Figure 2: A Market with a Negative Externality..9

Figure 3: Sweden's Decoupling of GDP and GHG Emissions 25

Figure 4: British Columbia and Canada GDP per capita 28

Figure 5: GHG Emissions by Australia's Power Sector in Tons of Carbon Dioxide Equivalent 33

Figure 6: Sulfur Dioxide Caps and Emissions (1988-2010) 44

Figure 7: Sulfur Dioxide Allowance Prices (1994-2012) 45

Figure 8: Historical EUA Prices (2007-2011) 47

Figure 9: Historical EUA Prices (2008-2013) 49

Figure 10: EU-28 Historic GHG Emissions Data (1990-2013) 50

Figure 11: RGGI Observed Emissions and Emissions Cap 52

Figure 12: RGGI Allowance Demand and Prices (2008-2011) 53

Figure 13: California Carbon Allowance Futures Prices 56

Figure 14: Carbon Offset Buyers by Region 61

Figure 15: Voluntary Carbon Market Prices 2005-2014...63

Figure 16: Historical Market-Wide Voluntary Transaction Volumes 65

LIST OF TABLES

Table 1: Distribution of Social Cost of Carbon Estimates for Different Discount Rates 13

Table 2: A Survey of Notable Social Cost of Carbon Estimates 20

Table 3: Summary of Carbon Tax Case Studies 36

Chapter 1

Introduction

On March 29th, 1997, five economists from leading American universities[1] released the Economists' Statement on Climate Change. This statement, which received the endorsement of over 2,500 economists, including nine Nobel laureates[2], was comprised of three simple ideas: human activity has negatively impacted the global climate, there are numerous economic policies that can reduce greenhouse gas emissions, and the most efficient approach to mitigating climate change is through market-based policies (Redefining Progress, n.d.). The statement was released in support of the upcoming meeting of the United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, Japan. Several months later, the Kyoto Protocol was adopted and lauded as one of the greatest international treaties since the Universal Declaration of Human Rights (Rosenthal, 2009).

Unfortunately, climate change remains an unsolved problem. The Kyoto Protocol was never ratified by the United States, and only a handful of the countries that adopted it met their reduced emissions targets (Rosenthal, 2009). Greenhouses gases continue to serve as a battleground for economists and politicians alike, with much debate, many proposals, and very limited action. The global recession of 2008 put climate talks on the backburner just as fledgling carbon pricing programs were starting to see results. Since then, the debate has blossomed once

[1] The authors of the Economists' Statement on Climate Change are Kenneth Arrow from Stanford University, Dale Jorgenson from Harvard University; William Nordhaus from Yale University, and Paul Krugman and Robert Solow from MIT.

[2] The nine Nobel laureates who endorsed the statement are Kenneth Arrow, Gerard Debreu, John Harsanyi, Lawrence Klein, Wassily Leontief, Franco Modigliani, Robert Solow, Joseph Stiglitz, and James Tobin.

more, with 2015 marking the passage of the first national carbon mitigation policy in the United States, the Clean Power Plan, and the 21st Conference of the Parties by the UNFCCC.

Economists have played an integral role in the development of climate change solutions. On the theoretical side, they have used comprehensive climate-economy models to find the societal cost of carbon. On the policy side, they have counseled politicians on the best market-based approaches. After passage of these policies, economists have assessed their efficacy to give way to further improvement. This paper seeks to build on their work by tying the theoretical to the actual, and provide a big picture overview with lessons for the future.

By surveying existing social cost estimates, carbon pricing mechanisms, and policy results, I hope to identify common attributes of successful emissions reductions at the lowest economic costs. I will begin by outlining the carbon problem in terms of climate impacts, regional impacts, and uncertainty in Chapter 2. Then, Chapter 3 will define the social cost of carbon (SCC) and provide a survey of SCC estimates using the most popular models and outlining some of their most contentious parameters. Chapters 4 and 5 will use case studies to determine the efficacy of mandate pricing schemes, looking at carbon taxes and trading schemes, respectively. Chapter 6 will elaborate on the recent growth of a voluntary market for carbon pricing, the offset market. Finally, Chapter 7 will compare and contrast these three pricing mechanisms and provide policy suggestions for the United States. As an economist and concerned citizen, I hope this paper will provide policy makers with an extra tool to make informed decisions.

Chapter 2

The Carbon Problem

2.1 Greenhouse Effects

The Intergovernmental Panel on Climate Change (IPCC) estimates that the average global temperature on both land and ocean surfaces has warmed by 0.85°C (1.53°F) from 1880 to 2012. The past three decades have seen the warmest temperatures in the Northern Hemisphere in the past 800 years (IPCC, 2014) and nine of the ten warmest years on record have occurred since 2000 (NASA, 2016). Most of this increased energy in the climate system, more than 90% of the energy accumulated between 1971 and 2010, has been the result of ocean warming (IPCC, 2014). Consequently, the global average sea level has risen 178 mm (nearly 7 inches) over the past 100 years alone (NASA, 2016). These climate statistics are astounding and point to a serious problem: the global climate is changing.

Human activity has been the driving cause of the rise in global temperatures, specifically through the emission of greenhouse gases (GHGs) resulting from economic and population growth. Concentrations of these gases, notably carbon dioxide, methane, and nitrous oxide have increased by 40%, 150%, and 20% respectively since 1750. In fact, the current atmospheric concentrations of GHGs are at levels unprecedented in the past 800,000 years (IPCC, 2014). Figure 1 shows how these gases have been building up in our atmosphere:

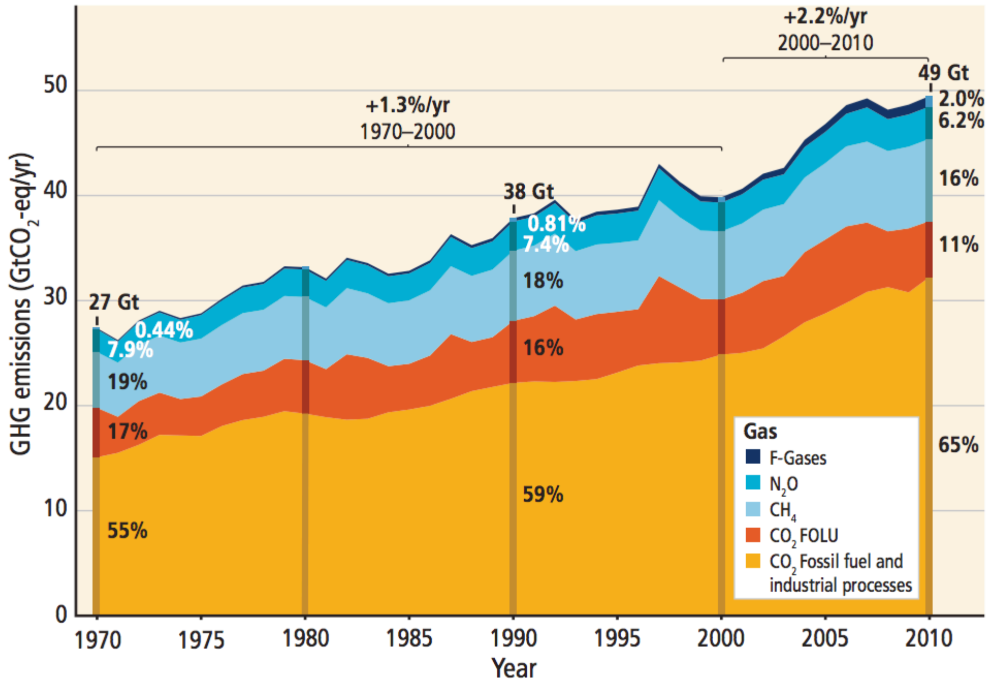

Figure 1: Anthropogenic GHG Emissions by Gases 1970-2010[3]

Source: IPCC (2014)

Most of these emissions have occurred in the late 20th and 21st centuries, just as global warming trends have shown the sharpest increases in temperature during that time.

Though far from the most potent GHG, carbon dioxide was the largest single contributor to anthropogenic global warming from 1750 to 2011. This is because carbon dioxide has the highest atmospheric concentrations of all GHGs, both naturally and as a result of human activity. Of the total GHG emissions in 2010, 76% were carbon dioxide, compared to 16% methane and 6% nitrous oxide (IPCC, 2014). Carbon dioxide levels currently stand at 403.19 parts per million, the highest level in 650,000 years (NASA, 2016). Consequently, reducing carbon dioxide emissions has become an international priority, though solving this problem is not without its challenges.

[3] Note: FOLU stands for Forestry and Other Land Use

2.2 Disproportionate Emissions

One of the biggest challenges to carbon dioxide mitigation is that emissions are disproportionate. The top carbon dioxide emitters in 2011[4] were China (28%), the United States (16%), the European Union (10%), India (6%), the Russian Federation (6%), and Japan (4%) (Boden et al., 2015). These large economies produced 70% of global emissions; however only the European Union, Japan, and the United States have displayed plateaued or declining emissions levels.

Economists and politicians alike argue that a homogenous international solution to emissions reduction would be inequitable, since it would put developing economies at a disadvantage. Developed countries like the United States achieved economic growth by using cheap fossil fuels, mostly coal and oil, for centuries. As their economies developed, they were able to invest in alternative forms of energy and can now limit their emissions without causing too much damage to their economies. Countries like India and China have only been developing their economies for a half a century and argue that they still need cheap fossil fuels to meet their energy demands without harming their industries (Ravindranath & Sathaye, 2002). Unfortunately, as these populous countries continue to grow, and as their energy demand rises, their emissions are also rising exponentially. Developing countries currently produce more than half of global GHG emissions, and they are projected to produce more than 70% of emissions by 2035 (Markandya et al., 2015). If this trend continues, even if developed countries limit their emissions, global temperatures will continue to rise.

[4] It is important to note that these figures were calculated using only data from fossil fuel combustion and some industrial processes. Taking into account changes in land use could alter these numbers, though areas such as the United States and Europe typically have the net effect of absorbing carbon dioxide (EPA).

At the World Summit in 2002, the United Nations Convention on Climate Change (UNFCCC) introduced the principle of Common But Differentiated Responsibilities (CBDR). This principle acknowledges the different needs and different capacities of developed and developing countries to reduce carbon emissions. CBDR places a heavier burden on developed countries[5], allowing developing countries more leeway for economic growth (Markandya et al., 2015). There is still a lot of debate over what is the most equitable approach. Should developing countries risk economic growth or risk climate change? Are developed economies doing enough already to curb emissions or should they do more?

2.3 Regions Affected

Another challenge to carbon dioxide mitigation is that regions are disproportionately affected. Perhaps the greatest irony of the carbon problem is that developing countries, who need to consume cheap fossil fuels for economic growth, are also the most heavily affected by climate change. Ravindranath and Sathaye (2002) explain that developing countries are typically located in regions that are most at risk to suffer the consequences of rising global temperatures, such as tropical and coastal regions. Developing countries are also the most reliant on the agricultural sector (which is tied directly to climate conditions) and have the lowest adaptive capacities due to poor infrastructure and limited access to technology and investment. The projected warming patterns of 1.4 to 5.8° C by 2100 will cause changes in rainfall patterns, rises in sea levels, and increased frequencies of extreme events (drought, hurricanes, storms, etc.). For developing countries, this will threaten food security, increase fresh water scarcity, lead to decline in biodiversity, and cause flooding of coastal settlements, among many more problems.

---

[5] Chapters 4 and 5 of this paper will only contain case studies on carbon pricing policies from developed contries due to data availability and easier comparison.

In contrast, some countries will not face such disastrous effects if the climate keeps changing, and others may yet benefit from warmer temperatures. Countries close to the poles may see a rise in arable land, and countries far inland will not have to worry about rising sea levels. As such, while climate change is a global problem, the incentives to reduce emissions are not equally dispersed.

2.4 Uncertainty

The running theme of the carbon problem is that it is riddled with uncertainty. We are only now starting to see the effects of global warming, and we just don’t know how they will develop in the long-run. Perhaps the past two centuries of carbon gluttony will lead to disaster scenarios such as extremely low or high temperatures, changes in ocean currents, the complete melting of ice caps, exceptional rises in sea levels, acidification of the oceans, and increased frequencies of extreme weather events (Tol, 2013). Or perhaps the disaster scenarios are unlikely and the global climate is more resilient than we think.

Yale University’s William Nordhaus (2008) humorously states, “If global warming is the mother of all public goods, it may also be the father of decision making under uncertainty.” The uncertainty of global warming has led to inaction in some cases, random policy experiments in others, and endless debate throughout. Economists are equally torn on the subject, and typically split up into two camps: the abaters and the adapters. Abaters favor cutting emissions now rather than facing a different climate in the future. Adapters favor a “business as usual” approach now and then adapting to a new climate in the future (Pielke, 1998).

For the purposes of this paper, we will assume that the abatement view is correct. General consensus among the more than 1,300 scientists in the IPCC is that the current rate of warming has already led to the loss of sea ice, accelerated sea level rise, more droughts and heat waves, changes in precipitation patterns, and stronger and more intense hurricanes (NASA, 2016). These effects threaten global agriculture, biodiversity, and coastal areas. In the United States alone, climate disasters over the past decade alone have killed, harmed, or displaced Americans across the country. Examples of this include the current drought in California, Hurricane Katrina in 2005, and the Washington D.C. snowstorm that happened just earlier this year (January of 2016). The IPCC estimates that all of these effects will continue and worsen even if emissions are brought under control. As such, carbon dioxide emissions need to be limited as soon as possible to prevent any further damage for generations to come.

2.5 Carbon Dioxide as a Negative Externality

In economic terms, the carbon dioxide problem can be considered a negative externality, which is a type of market failure. When markets work properly, they align private costs and benefits with social costs and benefits. Negative externalities occur when private costs and benefits differ from social costs and benefits, or in other words, when the actions of economic actors impose costs on third parties that are not reflected in market transactions (Oskar, 2016). On a traditional supply and demand graph, a negative externality can be seen in the form of two differing “supply” curves: marginal social cost (MSC) and marginal private cost (MPC). This relationship can be seen in Figure 2 on the following page.

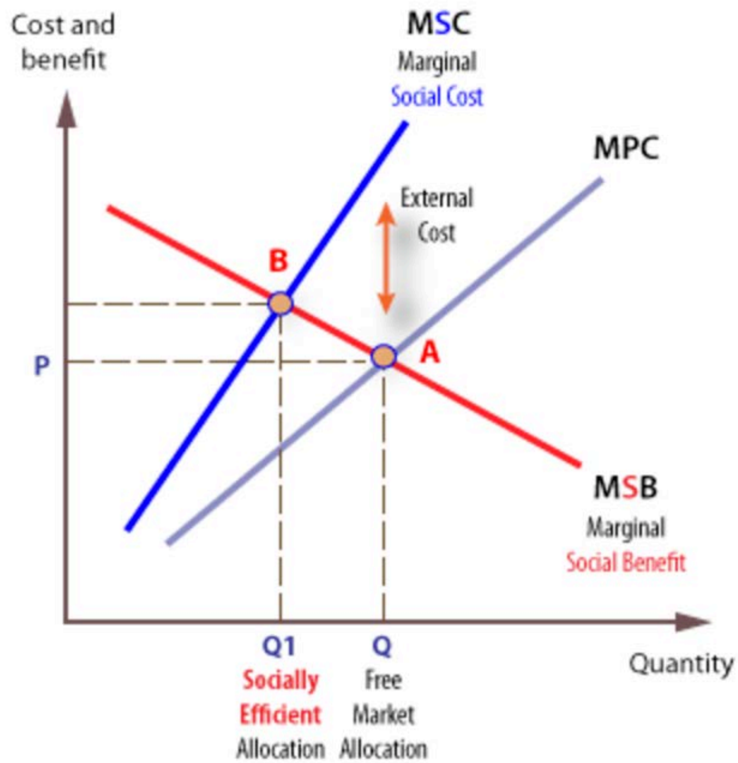

Figure 2: A Market with a Negative Externality

Source: Economics Online (n.d.)

Figure 2 shows that free markets with externalities result in too much of an activity, or overproduction in socially efficient terms (point A). Therefore, negative externalities require the involvement of a third party, usually the government, to re-align markets to the socially efficient equilibrium (point B) (Helbling, 2012). With its global causes, global effects, and uncertainty, carbon dioxide is arguably the most complex externality problem faced by today's markets.

When the government is tasked with solving a negative externality problem, it can apply three policy solutions: command and control, a Pigouvian tax, or a Coasian approach. Command and control is a form of quantity regulation: The government imposes a production quota that firms and industries cannot exceed. For carbon dioxide, an example of this type of policy would be the United States government setting an emissions cap of 50,000 metric tons per year (an arbitrary number) for all coal-fired power plants. Conversely, a Pigouvian tax, named after the economist who pioneered the theory in 1920, Arthur Pigou, is a form of price regulation: The government taxes production to shift the MPC curve to the MSC curve. Carbon taxes are Pigouvian taxes for carbon dioxide. Finally, the Coasian approach, also named after the economist who developed it in 1960, Ronald Coase, assigns property rights to the externality, creating a market where parties can bargain. The Coasian approach to carbon dioxide is a cap-and-trade market, also known as a trading scheme (Helbling, 2012).

Pigouvian taxes and Coasian trading schemes are considered market-based solutions to carbon dioxide because they price carbon to achieve the true social cost. The former approach directly prices the external cost, while the latter creates a market that determines the external cost. This paper will only focus on price regulation (Carbon Taxes in Chapter 4 and Trading Schemes in Chapter 5) because this approach has been generally favored by economists, as indicated by the writers and signatories of the Economists' Statement on Climate Change. Furthermore, command and control policies for carbon dioxide in both the United States and abroad only exist in limited forms, such as car emissions standards. Carbon taxes and trading schemes have been applied to entire regions, countries, and even across borders, providing for more significant comparison and analysis.

In order to price carbon, the social cost of carbon must first be determined. Referring again to Figure 2, the social cost of carbon is the difference between the MPC and the MSC at points A and B. Chapter 3 takes a closer look at the theoretical work of many economists in determining this figure in terms of cost per ton of carbon dioxide emitted. It will also provide some much-needed economic context for evaluating existing carbon pricing mechanisms.

Chapter 3

The Social Cost of Carbon

3.1 Defining the Social Cost of Carbon

Over the past two decades, economists and politicians have been focusing on a new estimate to serve as a guidepost for climate-change policies and carbon markets. Known as the “social cost of carbon,” or SCC, this estimate represents the societal cost of each additional ton of carbon dioxide emitted (Van den Bergh & Botzen, 2015). More specifically, Nordhaus describes the SCC as, “the change in the discounted value of the utility of consumption denominated in terms of current consumption per unit of additional emissions” (2011). The SCC thus links the environmental damages of climate change to their economic effects across the globe.

SCC estimates are a powerful tool for policy-makers. Using cost-benefit analysis, they can determine the most economically efficient policy investments for climate change mitigation. For example, if the SCC is estimated to be $10, then it would be in the government’s interest to spend at most $10 to prevent the emission from occurring (Van den Bergh & Botzen, 2015). Nordhaus (2011) explains, “the US government has undertaken rulemaking proceedings to determine the SCC for use in such areas as subsidies for the installation of low carbon energy sources, regulations requiring energy efficiency standards in buildings and motor vehicles, and rebates for home insulation materials.” As estimates increase, so do the expected policy investments, thus these estimates have a large impact on policy development.

Furthermore, SCC estimates can serve as targets for carbon pricing. In the case of a carbon tax, policy-makers aim for tax rates equivalent to SCC estimates, such that all prices in the economy will internalize the SCC of all greenhouse gas emissions (Van den Bergh & Botzen, 2015). For cap and trade markets, policy-makers will adjust the quotas and offset constraints to align the price of carbon permits with an SCC estimate. Meanwhile, carbon offset companies can likewise aim for offset prices equivalent to SCC estimates. Using our previous example of an SCC of $10, a carbon tax will effectively charge citizens $10 per ton of carbon dioxide emitted, while both cap-and-trade and carbon offset markets will price carbon permits at $10 per ton.

There is much disagreement between economists about what the true SCC is. According to a 2013 study by Richard Tol from the University of Sussex, there are currently 75 academic peer reviewed and non-peer reviewed studies of the SCC, with 588 estimates. These estimates differ because they use different parameters or give the same parameters different values. Furthermore, because climate change is a long-term issue, SCC models typically measure the damages caused by rising global temperatures over a period of 100 or 200 years or longer, and then attempt to quantify them into a present cost (Van den Bergh & Botzen, 2015). With so much extrapolation, there is a lot of room for variation and error, creating further disagreement on the accuracy of estimates.

3.2 Calculating SCC

SCC estimates are calculated using Integrated Assessment Models (IAMs) of greenhouse gas damages to both climate and the economy (Van den Bergh and Botzen, 2015). The typical parameters of IAMs include projections of carbon dioxide emissions and rates of warming, the impact of climate change on total welfare, the rate of pure time preference, the growth rate of per capita consumption, and the elasticity of marginal utility of consumption (Tol, 2013). Practically every single IAM parameter has been contested and altered from study to study, resulting in very different SCC estimates. Rather than going through each one, I will discuss three of the most contested parameters, the discount rate, uncertainty, and regional variation, to show how different approaches can affect estimates.

3.3 The Discount Rate

In cost-benefit analysis, the discount rate compares money values over time. IAMs typically use a positive discount rate to show how climate change negatively impacts both the economy and the environment. However, the value of a discount rate in an IAM has a strong impact on the resulting SCC estimate. A higher discount rate minimizes future climate damage, leading to lower estimates, while a lower discount rate implies higher future damage values, leading to higher estimates (Van den Bergh & Botzen, 2015). A 2009 study by Tol demonstrated this relationship by comparing the distributions of SCCs with different discount rates, summarized in Table 1 below[6].

Table 1: Distribution of Social Cost of Carbon Estimates for Different Discount Rates

	Discount Rate		
	0%	**1%**	**3%**
Mean	$40	$33	$14
Median	$32	$25	$10
95th Percentile	$133	$112	$56

**Values are in 1995 dollars per ton of carbon dioxide*

Sources: Tol (2009), Van den Bergh and Botzen (2015)

These values clearly show the importance of the discount rate: For all measures of the distribution, moving from a discount rate of 3% to one of 0% nearly triples the SCC estimate.

Most IAMs employ a high discount rate because investments in renewable energy, carbon sequestration, and other mitigation technologies must be in line with historical and

[6] The values from Tol's study have been converted to reflect dollars per ton of carbon dioxide, rather than dollars per ton of carbon, by multiplication with the conversion factor 12/44.

current rates of market interest on capital. In other words, these investments must compete for financing with other areas, and thus their opportunity costs are determined by market interest rates, which are generally higher. However, this approach has been criticized for several reasons. Van de Bergh and Botzen (2015) explain:

> In the first place, [this approach] denies the variation in investment uncertainty and associated compensation (interest rates) in financial markets…Secondly, market interest rates vary over time, while empirical estimates of implicitly-used discount rates also vary quite a lot between individuals and categories (e.g., investing in energy-saving technology versus putting money in a savings account). Thirdly, the market interest rate is partly determined by the imperfections or even failure of financial markets, caused by among other things myopia, asymmetrical information, market power, externalities, herd behavior, etc.…And, finally, it should not be forgotten that market interest rates are based on activities with a high productivity which often also cause high environmental pressure, including global warming. In other words, high market interest rates reflect an unsustainable system, and thus are unsustainable themselves.

Additionally, Christian Gollier (2010) from the Toulouse School of Economics argues that a lower discount rate should be applied the loss of natural capital (e.g., biodiversity) as a result of climate change over the damage to economic capital. Furthermore, Gollier, in collaboration with Martin Weitzman from Harvard University (2010) theorize that if long-run discount rates are uncertain but have a permanent component, then they will fall over time to their lowest possible value.

Of course, some of the discount rate debate is also ethical. A lower discount rate inherently means a greater concern about a long-term problem like climate change. Tol (2013) explains, “Some authors argue, on ethical grounds, for a low discount rate. Other authors argue, on ethical grounds, that the will of the people should be respected and that all empirical evidence has that people discount future utility.” Thus, the discount rate debate is far from settled, and will continue to influence further disagreement in SCC estimates.

3.4 Uncertainty

Another important factor in both SCC estimates and cost-benefit analysis for policy development is the treatment of uncertainty. Unfortunately, this very factor is where most studies fall short. Uncertainty, as discussed in Chapter 2 (The Carbon Problem), refers to the possibility of disaster scenarios. For SCC models, Tol (2013) explains, “Uncertainty is vast and right-skewed. Undesirable surprises are more likely than desirable surprises.” Furthermore, Gollier and Weitzman (2010) list uncertainty as the driving factor for their theory on discount rates. They argue that if economic growth under climate change is uncertain, then the discount rate is not constant, but rather decreases over time.

Studies have usually taken three approaches to incorporate the risk of such catastrophes. The first approach uses the probability of a catastrophe as a discount rate, which is then included in the model’s overall discount rate, typically resulting in higher SCCs. In the second approach, the impact function of climate change is given a premium, such that rises in temperature beyond some critical value are deemed disastrous. This approach requires policy investment at all costs to avoid reaching that critical value. The third approach essentially ignores uncertainty, assuming that the net present impact of climate change is negligibly small (Tol, 2013). IAMs that follow this third approach typically have some parameters for adaptation and result in lower SCC estimates.

3.5 Regional Variation

As discussed in Chapter 2, the effects of climate change are disproportionate, causing greater harm to coastal areas and developing nations. Some IAMs make no geographical distinctions for both economic development and climate impacts, while others include regional assessments (Van den Bergh & Botzen, 2015). Interestingly enough, models that take on a regional approach result in higher SCC estimates. This is because climate change effects are skewed by regions that suffer greater damage as a result of rising temperatures, such as island nations that will flood as sea levels rise. Though this parameter is not nearly as contested as the discount rate or uncertainty, it nevertheless affects the resulting estimate. It should also be noted that SCC estimates of models with regional variation are nevertheless aggregate estimates of cost per ton of carbon dioxide emitted, regardless of who emits it and where the resulting effect occurs.

3.6 Widely Used SCC Models

The three most widely used models for calculating the SCC are the Dynamic Integrated Climate-Economy (DICE) model, the Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model, and the Policy Analysis of the Greenhouse Effect (PAGE) model. DICE, FUND, and PAGE are all IAMs that combine climate change, economic growth, and the effects of climate change on the economy. They are all characterized by extensive cost-benefit analysis, which makes them incredibly valuable for policy discussion and implementation (Van den Bergh & Botzen, 2015). Rather than explaining the complex details and equations behind these models, I will highlight some of their key characteristics and conclusions by looking at the notable studies that have developed or used these models.

DICE Model

The DICE model was developed by Nordhaus (2008) and assumes the perspective of neoclassical economic growth theory. It makes no distinction between climate effects and economic growth rates in different regions. DICE integrates the climate system as a “natural capital” input of the global economy. Carbon dioxide represents negative natural capital and emissions reductions are investments that raise the quality of natural capital (Nordhaus, 2008). The model assumes that technological development leads to a decrease in the carbon intensity of economic output over time (Van den Bergh & Botzen, 2015).

Like all other IAMs, DICE has a damage function that relates temperature increases to climate damage increases. Global temperatures in DICE are expected to grow by 1.9 to 4.0 degrees Celsius by the year 2100 (Nordhaus, 2008). The damage function represents the resulting sum of the damage to ecosystems, coastal areas, human health, cities, immaterial goods (recreation), the agricultural sector, and other market sectors (especially energy use). Additionally, the damage function assumes adaptation costs and accounts for only a small probability of a large climate catastrophe (Van den Bergh & Botzen, 2015).

In 2011, Nordhaus introduced a variation of DICE known as the Regional Integrated Climate-Economy (RICE) model that accounts for regional differences. RICE divides the world into 12 regions, which include large countries such as the US and China, and multi-country regions such as the European Union and Latin America (Nordhaus, 2011). The RICE model demonstrates that accounting for regional differences increases SCC estimates. DICE estimates the SCC to be $7.40 in 2005 (Nordhaus, 2008), while RICE estimates the SCC to be $11.31 in 2015 (Nordhaus, 2011). Both models employ an effective discount rate of 5.5% (Nordhaus, 2008, 2011).

FUND Model

The FUND model was originally developed by Tol. Like RICE, it divides the world into 16 major regions and runs in one-year time-steps from 1950 to 2300 (FUND, n.d.). FUND also assumes economic growth like the DICE model. The effects of climate change on the economy are calculated using damage functions for eight sectors: agriculture, forestry, water, energy, sea level rise, ecosystems, human health, and extreme weather (Tol 2002a, 2002b). Adaptation is only modeled for the agricultural sector and rising sea levels, and is implicitly included in the effects on the other six sectors (Van den Bergh & Botzen, 2015). The model runs sensitivity tests for each parameter to account for uncertainty, but does not include parameters for possible disaster scenarios. FUND uses a discount rate of 5% and estimates the SCC to be $7.17 (Tol, 2002a, 2002b). It has received a lot of criticism for being one of the IAMs with the lowest SCC.

PAGE Model

The PAGE model was developed by Chris Hope from the University of Cambridge and received international attention with the publication of the Stern Review in 2006. Like the previous models, a damage function combines the economic and non-economic effects of rising global temperatures. However, this IAM pays greater attention to disaster scenarios, and includes the consequences of catastrophe risks in the damage function. Rather than splitting the world into a certain number of regions, the PAGE model integrates regional differences in specific climate change effects, such as the effect of rising sea levels in coastal versus inland areas (Stern, 2006). Perhaps the most notable difference of the PAGE model is that it includes a specific adaptation function with a lower effectiveness. These characteristics, along with a comparatively low discount rate of 1.4%, result in one of the highest SCC estimates, $96.40 (Van den Bergh & Botzen, 2015).

DSICE Model

One final model is worth discussing because of its unique approach to uncertainty. A variation of the DICE Model, the Dynamic Stochastic Integration of Climate and the Economy (DSICE) Model was developed by Yongyang Cai and Kenneth Judd from Stanford University and Thomas Lontzek from the University of Zurich (2015). This model uses a stochastic variable in the damage function to represent the uncertainty of the effects of climate change. They explain, "DSICE [can] determine the stochastic features of the SCC process and shows that the SCC is approximately a random walk with substantial variance. For example, in our benchmark case the expected SCC is $286 in 2100 but with a 10% chance of exceeding $700 and a 1% chance of exceeding $1,200" (Cai et al., 2015). In this way, the function not only estimates possible damage values, but also the probabilities of these values occurring. Additionally, the DSICE models climate responses to GHGs differently from other studies, using recent literature on climate tipping elements. In this approach, emissions do not follow a predictable and reversible pattern for global warming, but rather exhibit a series of tipping points beyond which certain effects are triggered and cannot be reversed. Consequently, though the DSICE uses the same discount rate as the DICE model, Cai et al. (2015) arrive at a considerably larger estimate of the SCC of $34.06.

3.7 Takeaways

The goal of this chapter was not to identify one SCC estimate as the true SCC, but rather to highlight the many parameters that are used to calculate this value and point out some of the most contentious areas. Theoretically, the most effective carbon pricing initiatives result in investments or fees equal to the true SCC, thereby internalizing the carbon externality. While the true SCC is still unknown, a survey of SCC estimates can also offer a method of comparison for the current carbon pricing initiatives to measure their effectiveness.

Table 2 summarizes the models and studies discussed in this chapter. SCC estimates have been adjusted to 2005 dollars per ton of carbon dioxide and represent aggregate world values. Some studies present their findings in terms of cost per ton of carbon, rather than cost per ton of carbon dioxide, which are larger by a factor of 3.67 (Nordhaus, 2011). I have included both methods of measurement in the SCC estimates in the table.

Table 2: A Survey of Notable Social Cost of Carbon Estimates

Model	Study	SCC (t/CO_2)	SCC (t/C)	Discount Rate	Regional Assessment	Assessment of Uncertainty
DICE	Nordhaus (2008)	$7.40	$27.16	5.5%	No	Moderate (Premium added to impact of climate change)
RICE	Nordhaus (2011)	$11.31	$41.51	5.5%	Yes	Moderate (Premium added to impact of climate change)
FUND	Tol (2011)	$7.17	$22.68	5%	Yes	Low (Adaptation parameters)
PAGE	Stern (2006)	$96.40	$353.79	1.4%	Yes	High (Adjusted discount rate and premium added to impact of climate change)
DSICE	Cai et al. (2015)	$34.06	$125.00	5%	No	High (Represented by a stochastic variable)

The results of this table display some of the trends discussed in this chapter. Higher discount rates result in lower SCC values, while regional assessments result in higher values. SCC estimates also increase when studies pay greater attention to the uncertainty of climate change. As such, it makes sense that the highest SCC estimate, the 2006 Stern Review has the lowest discount rate, contains regional assessment, and has extra risk parameters.

Chapter 4

Carbon Taxes

4.1 How a Carbon Tax Works

Carbon taxes are the most direct and simplistic form of carbon pricing. When fossil fuels are burned, and carbon dioxide is released into the atmosphere, emitters are charged a rate proportional to the size of their emissions, such as $25 per ton of CO_2. As a result, emitters have a direct financial incentive to reduce emissions. These reductions can occur in a variety of ways, such as restricting fossil fuel use, investing in energy efficient technologies, and investing in renewable energy. As emitters shift away from high emissions technologies and fuel sources, they can ensure both short-term and long-term reductions (Burns, 2011).

Carbon taxes are advantageous because of their flexibility and simplicity. Burns (2011) explains, “Carbon taxes are easy to calculate because the precise carbon content of every form of fossil fuel is well known, and most fuels emit carbon dioxide in direct proportion to their carbon content.” Thus, for a given SCC, calculating the carbon tax would simply involve multiplying the SCC by the quantity of emissions. Additionally, carbon taxes can be levied at any level of fossil fuel use, from the point of ultimate fuel combustion (“downstream”) to the point of extraction (“upstream”). Some carbon tax advocates in the United States argue for the latter since it would cover all fossil fuel emissions by only taxing 3,000 entities (Burns, 2011).

Another advantage of a carbon tax is that it generates government revenue. Though most carbon taxes are designed to be revenue-neutral, meaning that they return revenues to the public to offset the resulting costs of the tax, some economists advocate using carbon tax revenues to offset budget deficits. Sebastian Rausch and John Reilly (2015) explain:

> Putting a price on carbon . . . has the potential to address two long-term problems. One is the problem of growing debt in the United States (and in many other countries) with potentially detrimental implications for economic growth. The revenue from a carbon tax could be used to reduce the deficit or to finance reductions in marginal rates of existing taxes while holding the deficit constant (or a combination of both). The other problem is the build-up of carbon dioxide in the atmosphere — the principal anthroprogenically-sourced GHG — contributing to global climate change.

Carbon taxes can therefore serve other purposes beyond climate change mitigation. Instead of harming the economy, they can provide economic benefits.

Of course, carbon taxes, like all carbon pricing mechanisms, have their drawbacks. Because carbon taxes affect emission quantities indirectly through price, they cannot guarantee a specific level of emissions reduction (Burns, 2011). Thus, it is crucially important that the carbon tax is high enough to result in meaningful reductions. At the same time, the carbon tax must be low enough to not harm emitters too much and maintain economic growth. Even if a carbon tax is designed to be revenue neutral, it can still ultimately harm the economy through production, consumption, or both. Unfortunately, as discussed in Chapter 3 (The Social Cost of Carbon), finding this middle ground has proved incredibly difficult.

Another big drawback of carbon taxes is that they affect economic sectors disproportionately. Taxing emissions directly hurts fossil fuel companies and energy-intensive industries a lot more than others. These industries include power generation, transportation, agriculture, forestry, and other land use (EPA). While environmentalists might say this is a good thing, firms can pass on these high costs to their consumers in the form of high electricity, heating, or fuel costs. These goods and services have inelastic short-term demand, and therefore require a gradual rise in prices as consumers invest in more energy-efficient or low-emission cars and appliances.

Carbon taxes also disproportionately affect low-income groups. Members of these groups do not have the money for significant investments like fuel-efficient cars, solar rooftop panels, or switching heating fuels. As such, when prices for these short-term inelastic goods rise (fuel, heating, and electricity), low-income families have no means to adjust their energy consumption habits and must therefore continue to pay the higher costs. This problem can be solved with low-income tax credits taken from the carbon tax revenue; however, this solution is not always implemented.

Perhaps the biggest drawback to carbon taxes is that carbon taxes require public support. Taxation in general is never a welcome subject in politics, and the handful of governments that successfully passed carbon tax legislation had significant public support. Furthermore, the very nature of carbon taxes requires rate increases with time in order to continue emissions reduction. Even with public support, these tax hikes have frequently been put on the back burner unless automatically included in the initial tax legislation.

This chapter will look at a few case studies of governments that have passed carbon tax legislation. I will specifically note their prices and effects on emissions, in addition to changes in GDP, consumption habits, and energy systems. A summary table at the end of the chapter will compare and contrast their successes and failures in order to determine the optimal approach to this carbon pricing mechanism.

4.2 Case Studies

Sweden

Sweden pioneered the carbon tax in 1991. At the time, the country had already established a system of energy taxes for all fossil fuels, which were reduced by 50% with the introduction of the carbon tax. Though the system has changed several times since then, a common feature is lower taxes for industry and no carbon or energy taxes on electricity and production (Johansson, 2000). Sweden has also expanded its exemptions to the carbon tax for participants of the European Union Emissions Trading Scheme (EU ETS) in order to promote this initiative (Andersson & Lovin, 2015). Additionally, the tax rate has grown as Sweden pursues increasingly aggressive environmental policies. In 1991, the tax rate was $41/t$CO_2$ (Johansson 2000), compared to $168/t$CO_2$ by 2014 (Andersson & Lövin, 2015). Notably, Sweden's current carbon tax rate is significantly higher than the Stern Review's generous SCC estimate ($96.40/t$CO_2$) discussed in Section 3 (The Social Cost of Carbon).

Though Sweden only accounts for less than 2% of global CO_2 emissions (Swedish Institute, 2015), the country's unique energy system has allowed it to pursue one of the most aggressive environmental policies in the world. Between one third (27% in 2000) (Johansson, 2000) and one half (52% in 2014) (Swedish Institute, 2016) of Swedish energy supply comes from renewables, particularly biomass and hydroelectric as a result of the country's extensive forests and rivers. Electricity generation is almost entirely fossil fuel free, and is instead based on nuclear and hydroelectric power. Sweden also has a very high per-capita electricity use, especially for space heating, which further reduces the need for fossil fuels to heat buildings. Overall, this means that the country has many options and alternatives to carbon-producing energy and traditional fossil fuels. Furthermore, Swedish public opinion continues to be very environmentally friendly. A 2015 Standard Eurobarometer survey showed that 26% of Swedes note the environment and climate change as main concerns, compared to the 6% EU average (Swedish Institute, 2016).

With strong public support and a flexible energy system, Sweden has seen positive effects as a result of its carbon tax. Carbon dioxide emissions per capita decreased by 8.3% within twenty years, from 6.0 metric tons in 1991 to 5.5 in 2011 (World Bank, 2012). Magdalena Andersson, the Swedish Minister for Finance, and Isabella Lövin, the Swedish Minister for International Development Cooperation, explain that Sweden has exhibited absolute decoupling between emissions reduction and GDP growth. In other words, "[carbon dioxide] emissions have decreased in absolute terms at the same time as GDP has increased" (2015). Figure 3 illustrates this emissions decoupling trend:

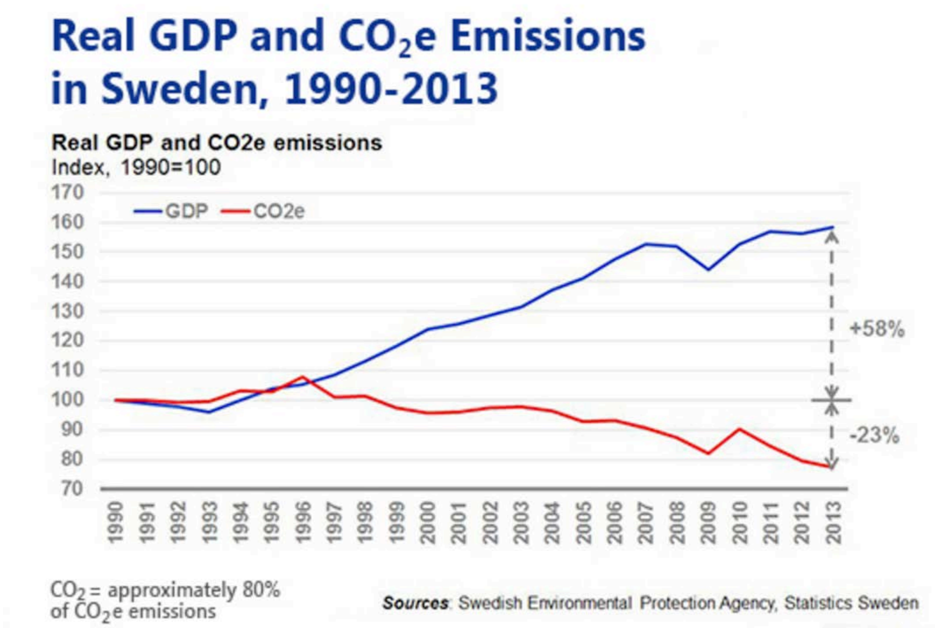

Figure 3: Sweden's Decoupling of GDP and GHG Emissions

Source: Andersson & Lövin (2015)

Additionally, environmental tax revenues in 2012 accounted for 2.52% of Sweden's GDP, compared to the OECD average of 1.54% (Swedish Institute, 2016).

Because electricity generation is exempt from the carbon tax, Swedes have not seen any tax-related increase in their electricity costs. However, the carbon tax has led to a new district heating system. Biofuels, which are exempt from the tax, have replaced coal and oil, which bear the full tax rate, as the main energy inputs for home heating (Fouché, 2008). In fact, biofuel use for heating jumped from 25% in 1990 to nearly 70% in 2012, contributing to Sweden's impressive renewable portfolio progress, though arguably not reducing emissions since biofuel consumption still produces CO_2 (Andersson & Lövin, 2015). The carbon tax also led to greater growth in non-energy-intensive industries, such as the service sector, compared to energy-intensive industries, such as paper mills. Swedish environmental minister Andreas Carlgren claims, "Our carbon emissions would have been 20% higher without the carbon tax" (Fouché, 2008).

British Columbia

On July 1st, 2008, British Columbia introduced a consumption tax on virtually all fossil fuels, including gasoline, diesel, natural gas, coal, propane, and home heating fuel (Fowlie & Anderson, 2008). The initial tax rate was C$10/ton of CO_2 (US$9), with yearly increases of C$5 scheduled until 2012. British Columbia's government has not hiked the tax rate since then, keeping it at C$30, or about US$22.20 with the February 2016 exchange rate (Foulis, 2014). The tax was designed to be revenue-neutral before it was even implemented. In June of 2008, the province's government issued a one-time C$100 payment to all residents to offset the costs. Since then, the tax has been used to offset income and corporate taxes and for low-income credits (Fowlie & Anderson, 2008).

Data from the Carbon Tax Center comparing pre-tax GHG emissions (2000-2007 average) to post-tax emissions (2008-2013 average) shows significant progress for the province compared to the nation. British Columbia saw a 6.1% drop in aggregate emissions, while Canada's emissions increased by 3.5%. Per capita, the province's emissions dropped by 12.9%, while Canada's only decreased by 3.7%. Still, British Columbia's emissions began to increase in 2012, and again in 2013, indicating that the government needs to continue price increments in order to maintain progress (Komanoff & Gordon, 2015).

For consumers, the tax has only affected their heating and transportation costs. Like Sweden, the province generates the majority of its electricity from hydroelectric power, so the tax did not significantly increase electricity prices. Conversely, heating costs rose for British Columbians. Coal is currently taxed at C$53.31 to $62.31 per ton depending on its heat value (British Columbia Ministry of Finance, 2012). As a result, public electricity and heat production saw a 29.9% drop in GHG emissions since the introduction of the tax (Komanoff & Gordon, 2015). In the transportation sector, consumers pay a different tax rate at the pump depending on the carbon content of the fuel. For example, gasoline is taxed at C¢6.67/liter, diesel is taxed C¢7.67/liter, and propane is taxed at C¢4.62/liter (British Columbia Ministry of Finance, 2012). These costs have led to a 16% drop in fuel consumption, compared to the rest of Canada, which saw a 3% increase (Beaty, Lipsey, & Elgie, 2014).

Manufacturing industries saw the greatest emissions decrease as a result of the tax, a 32.5% drop since its implementation (Komanoff & Gordon, 2015). This progress has not entirely been met with cheers and applause. The cement industry has been the loudest advocate of repealing the tax, estimating that they have lost a third of their market share to US and Asian imports (Foulis, 2014). Additionally, some industry sectors, such as heavy-duty diesel vehicles, mining and upstream oil and gas production, and domestic navigation, have actually seen GHG emissions increases since the introduction of the tax (Komanoff & Gordon, 2015).

Overall British Columbia's economy has been performing at the same pace as Canada's. Though growth was slightly slower during the global recession and the introduction of the tax, the province began outperforming the nation in 2011 (Foulis, 2014). Figure 4 below illustrates this trend:

BC and Canada GDP per capita

	2008	2009	2010	2011	2012	2013	2008-13 Total
BRITISH COLUMBIA	-0.39%	-3.93%	2.02%	1.85%	0.77%	1.15%	1.75%
REST OF CANADA	-0.02%	-3.93%	2.27%	1.71%	0.55%	.80%	1.28%

Figure 4: British Columbia and Canada GDP per capita

Source: Foulis (2014)

The carbon tax is partially responsible for this growth. 2014 estimates indicate that the carbon tax has generated nearly C$5 billion in revenue, of which $3 billion was returned as corporate tax cuts, $1 billion was returned as personal tax cuts, and $1 billion was returned as low-income credits of $115.50 for each parent and $34.50 per child annually (Beaty et al., 2014). British Columbia currently has one of the lowest corporate tax rates in North America, encouraging investment and further growth (Foulis, 2014).

Politically, the tax has also been a success. The Liberal Party, which devised and implemented the tax, won a rare third consecutive term as the leading party in 2009. Furthermore, opinion polling indicates that the percentage of residents opposing the tax has been shrinking over time. Komanoff and Gordon explain, "This mirrors the standard pattern for 'Pigouvian' taxes that 'internalize' the social or environmental costs of a process or commodity into its price: initial grumblings give way to broad acceptance" (2015). Still, if British Columbia wants to see continued progress, the province's government needs to continue the rate hikes, otherwise emissions will continue to increase.

Ireland

While British Columbia was developing its carbon tax in 2008, Ireland's economy took a plunge as a bursting real estate bubble decreased tax revenues by 25% (Rosenthal, 2012). In November of 2010, the Irish government reached an agreement with the European Central Bank, the European Commission, and the International Monetary Fund, "whereby the latter provided substantial financial support, on condition that a number of revenue raising and expenditure reduction targets were met" (Convery, Dunne, & Joyce, 2013). Ireland had just instituted a carbon tax of €15/ton CO_2 when it accepted "the Trioka's" deal. Within a few months of the bailout, the Irish government decided to adopt a novel strategy: use the carbon tax revenues to meet its bailout agreement (Rosenthal, 2012).

So far, this strategy has been working. In its first three years, the carbon tax raised nearly €1 billion ($1.3 million). For 2012, the €400 million of carbon tax revenue alone accounted for 25% of Ireland's required budget gap, allowing the government to avert a rise in income taxes (Rosenthal, 2012). Tax revenues have been decreasing slightly since, as consumers adjust their carbon consumption, with revenues of only €388 million in 2013 and €385 million in 2014 (Deegan, 2015). Nevertheless, the carbon tax continues to be a significant addition to the Irish government's efforts to balance their budget and meet their bailout requirements.

Ireland's carbon tax is currently levied on fossil fuels when they enter the country, and then passed on to consumers at the point of purchase. Consumers pay when they buy new cars, at the pump, and for home heating (Rosenthal, 2012). The current tax rate, which has not increased since 2012, is €20/ton CO_2, or about US$21.86/ton (Convery, 2012). In 2013, the Irish

Government began taxing coal and peat at €10/ton, and that price has risen to match the €20/ton price on other fuels (Office of the Revenue Commissioners, n.d.)

The carbon tax had several immediate effects on Ireland’s transportation and heating sectors. Between 2008 and 2011, gasoline consumption fell by 21% and diesel consumption fell by 13%. This was a significant change, considering that GDP only fell by 5% over the same period, suggesting a decoupling of emissions reduction and GDP growth (Convery, 2012). Car manufacturers responded with greener cars that were smaller or had higher fuel efficiencies (Rosenthal, 2012), and 90% of new car sales in 2011 were in the lowest emissions-producing brackets (Convery, 2012). Meanwhile, the taxes on fossil fuels for home heating made alternative energy sources more competitive, giving Ireland’s wind industry a much-needed boost (Rosenthal, 2012).

Because the tax has only been levied for the past 6 years, there is little data showing the effect on emissions. The World Bank’s World Development Indicators show a 15.8% decrease in per capita GHG emissions between 2008 and 2012 (2012). However, the Irish Environmental Protection Agency’s most recent projections show rising emissions levels starting in 2015. Furthermore, even in the agency’s best-case scenario, meaning with additional measures, total emissions will exceed their annual limit as part of the EU 2020 Effort Sharing Target in 2018 (Environmental Protection Agency, Ireland, 2016). This suggests that Ireland, like British Columbia, needs to raise the carbon tax rate or adopt additional carbon pricing mechanisms. Inaction will result in rising emissions levels and decreasing revenues, the latter of which Ireland desperately needs.

Australia

Australia seemed like a promising location for a carbon pricing experiment. Though the country accounts for less than 1.5% of global emissions, its extensive use of coal for electricity generation makes it one of the largest carbon polluters on a per capita basis (Schiermeier 2014). On July 1st, 2012, Australia's carbon tax went into effect, charging $22 per ton of carbon dioxide. The tax was scheduled to increase every year until 2015 when it would transform into a cap-and-trade scheme selling at market price (Robson, 2014). Unfortunately, the program never developed to that extent, and was repealed by the Senate on July 17th, 2014, only two short years after its implementation (Schiermeier 2014).

Australians regarded the carbon tax experiment as a political disaster, and public opinion was one of the major reasons for its eventual repeal. During the 2010 election campaign, the Labor Party promised not to enact a carbon tax if elected. However, just a few short weeks after winning the elections, Prime Minister Julia Gillard introduced a carbon tax that was passed by the Senate the following year. A Morgan poll from July 19th, 2011 found that 62% of Australians agreed that "The carbon tax will have no significant impact on reducing the total world-wide volume of carbon dioxide put into the atmosphere," and a majority agreed that, "We should not have carbon tax until China and the USA have a similar tax" (Robson, 2014). The Australian people considered the introduction of this tax by the Labor Party a betrayal of their votes, dooming the scheme before it even went into effect. By 2013, opposing parties were clamoring for control of the Parliament to repeal the unpopular tax. When Tony Abbott eventually replaced Gillard as Prime Minister, one of the first things he did was fulfill the centerpiece promise of his campaign and repeal the tax (Schiermeier 2014).

Politics aside, the Australian carbon tax had a mix of good and bad results. It achieved its goals of emissions reductions, raising $6.2 billion in its first year alone from almost 350 high-polluting companies. The tax also led to a 5% decrease in emissions from the coal-heavy power sector, and a 0.8% decrease in emissions economy-wide (Schiermeier 2014). However, the tax also resulted in 10% to 15% increase in household electricity prices. Affected producers also struggled against a 14.5% increase in their input costs as a result of the tax. In a survey conducted by the Australian Industry Group, 70% of businesses claimed they had not been able to pass on these costs to their customers. The scheme also failed at offsetting tax costs to households through income tax breaks. Though average income tax rates were lowered, marginal tax rates actually increased for 2 million Australians (Robson, 2014).

Where did Australia's carbon tax go wrong? One of the biggest criticisms was that the government's fixed cost rate of $22 per ton was too high and therefore hurt businesses too much. Another criticism was the government only allocated free emissions permits to certain emissions-intensive, trade-exposed industries, thereby hurting non-trade-exposed businesses that were unable to pass on their increased costs. The government also failed to implement a revenue-neutral policy, and as a result, costs to households were not mitigated or successfully offset. However, it is likely that the government's biggest failure was in not generating public support for the scheme, causing it to be repealed before any long-term effects could have been measured.

Figure 5 illustrates the effect of the repeal of the carbon tax on greenhouse gas emissions from Australia's power sector. The red line represents the date that the tax was repealed:

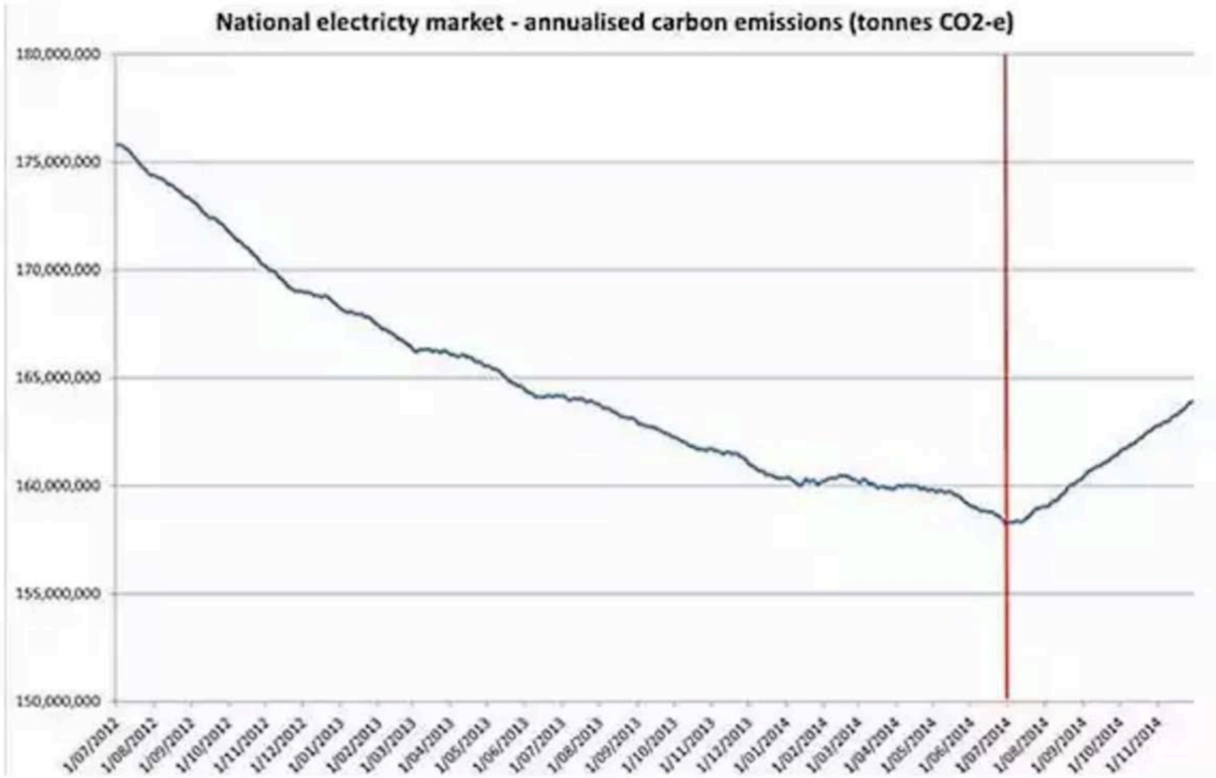

Figure 5: GHG Emissions by Australia's Power Sector in Tons of Carbon Dioxide Equivalent

Source: Taylor (2014)

Unsurprisingly, the decreasing emissions reversed their trend immediately following the repeal of the tax. This shows that, while unpopular and politically disastrous, Australia’s carbon tax was succeeding in its environmental purpose: to decrease the country’s greenhouse gas emissions.

United States

On April 1st, 2007, the city of Boulder, Colorado implemented the first carbon tax in the United States (Kelley, 2006). Starting at approximately $7/ton CO_2, the tax has since been renewed multiple times and raised to about $12 to $13 per ton according to estimates from the Center for Climate Energy Solutions (2013). This translates to an average annual tax rate is about $21 for residential households, $94 for businesses, and $9,600 for industries. Compared to the other case studies, this is by far the lowest tax rate. Still, Boulder estimates that it has avoided 50,000 tons of greenhouse gas emissions since the tax was implemented (City of Boulder, 2015). With a per capita estimate of 19 tons of GHG emissions per person, Boulder hopes this initiative will bring this figure down to only 3 tons by 2050.

The effectiveness of Boulder's tax is difficult to measure in terms of emissions for several reasons. First, the tax is only levied on electricity consumption, though Boulder estimates that this generates 53% of its GHG emissions (2015). Second, the city does not publish its emissions levels, making the reduction statistics, shown as aggregate totals rather than percent reductions, difficult to interpret. Perhaps the biggest challenge is that Boulder levies its tax in terms of kilowatt hours, rather than the standard dollars per tons of emissions, making it difficult to compare the tax rate to other case studies.

Still, Boulder has seen many changes in its electricity sector as a result of the tax. Between 2005 and 2012, coal use for power generation dropped from 64.7% to 57.7%. Natural gas use also decreased from 30.1% to 22.8%. Conversely, wind generation grew from 2.1% to 16.6%, while solar, hydroelectric, and other power sources remained the same. The tax has generated about $1.8 million each year, which Boulder has reinvested in further programs to reduce energy consumption and minimize further emissions (City of Boulder, 2015).

In 2010, Montgomery County, Maryland attempted to follow in Boulder's footsteps by passing a carbon tax on electricity generation. The \$5/tCO_2 tax was levied on "any stationary source emitting more than a million tons a carbon dioxide during a calendar year," and was expected to raise between $10 and $15 million annually (McGowan, 2010). The tax revenue would then be invested in programs to further reduce the county's carbon footprint, such as low interest loan program for improving residential energy efficiency.

Ultimately, this tax only applied to one coal-fired power plant in Dickerson, which released about 3 million tons of carbon dioxide per year (McGowan, 2010). Mirant Mid-Atlantic, the company in charge of the power plant, sued Montgomery County for the tax (Peterson, 2010). The case ultimately made its way to Maryland's Fourth Circuit Court of Appeals where it was ruled a punitive fee. Rather than risking further damage, the county repealed its tax and returned the $6 million of revenue it had generated back to Mirant, ending the short-lived carbon tax experiment (Baye, 2011).

4.3 Carbon Tax Conclusions

These case studies illustrate several important points about the efficacy of a carbon tax. While this mechanism is the most direct and simplistic form of carbon pricing, carbon taxes must nevertheless be very specifically tailored to their localities. Policy makers need to take into account the energy system and public opinion, while also designing the revenue and tax structure to walk that fine line between costs that are too high and continued emissions growth.

For easy comparison and analysis, I have summarized the main findings of the case studies in Table 3 on the next page. All of the source material for Table 3 is cited in the specific case study. The tax rates and emissions reduction statistics have been converted to the same units where possible for easy comparison. Dates for these figures have also been included for comparison. Additionally, the comments have been tailored to reflect the energy sector, public opinion, effect on costs, and use of revenues for each location where applicable.

Table 3: Summary of Carbon Tax Case Studies

Location	Duration	Price (USD/t)	Emissions Reduction	Comments
Sweden	1991-present	\$168/tCO_2 (2014)	8.33% per capita (1991-2011)	• Strong public support and flexible energy system • Absolute decoupling of GDP growth and emissions reduction • Electricity prices not affected • Led to expansion of biomass industry for heating
British Columbia	2008-present	\$22.20/tCO_2 (2016)	12.9% per capita (2008-2013)	• Scheduled tax increases of C\$5 from 2008-2012 • Tax revenue used to cut personal and corporate taxes and for low-income credits • GDP performance on par with Canada • Only applies to heating and transportation • Decrease in fuel consumption
Ireland	2010-present	\$21.86/tCO_2 (2016)	15.8% per capita (2008-2012)	• Revenue used to meet 2010 bailout requirements • Only applies to heating and transportation • Decrease in fuel consumption • Growth of wind power
Australia	2012-2014	\$22/tCO_2 (2014)	0.8% total (2012-2014)	• Was meant to phase into an emissions trading scheme with price determined by the market • Led to a 10-15% increase in household electricity prices • Lacked public support and politically unpopular • Repealed in 2014
Boulder, Colorado	2006-present	\$12-\$13/tCO_2 (2015)	50,000 tCO_2 (2007-2015)	• Tax only levied on electricity • Growth of wind generation • Revenues invested in further programs to reduce energy consumption
Montgomery County, Maryland	2010-2011	\$5/tCO_2	N/A	• Only affected one power plant • Repealed because of a lawsuit

The case studies show that locations with diversified energy portfolios can benefit the most from a carbon tax. Sweden, one of the first countries to institute a carbon tax, was already generating emissions-free electricity and had a budding biomass industry for heating and fuel, which was exempted from the tax. British Columbia was similarly generating its electricity from emissions-free hydroelectric power, so the carbon tax was only applied to fuel and heating. In contrast, Australia's carbon tax was largely levied on its coal-powered electricity sector, contributing to skyrocketing electricity costs that residents and industries were not prepared for. Similarly, Montgomery County's attempt at a carbon tax was only levied on one coal-powered plant, leading to a lawsuit that quickly ended the experiment. Unfortunately, the purpose of a carbon tax is to diversify the energy portfolio such that emissions-free or low-emission sources take up a larger proportion of energy production. Thus, carbon taxes should theoretically be levied the most heavily on fossil-fuel dependent countries, like Australia.

Another troubling paradox is that countries with successful carbon taxes also had an environmentally conscious public. With political support, policy makers could institute this pricing mechanism, and citizens were much more willing to pay the higher costs. Sweden, Ireland, British Columbia, and Boulder all illustrated this trend. Unfortunately, the purpose of a carbon tax is to punish emissions-producing consumption habits, which are typical of a public that is not environmentally conscious. Because democratic governments are fundamentally tied to the will of the people, a high-emitting populace that is unwilling to change their energy consumption habits will not support the passage of laws seeking to change those habits. Australia is the poster boy for this political failure.

Effective revenue use also led to successful carbon taxes. Ireland used the carbon tax to offset a budget crisis instead of raising taxes on its citizens, a strategy that continues to benefit the country today. Meanwhile, British Columbia's similar use of the revenue for income and corporate tax credits has contributed to the province having the lowest corporate tax rate in North America, thereby encouraging investment and economic growth. British Columbia also addressed the problem of carbon taxes disproportionately affecting low-income groups by using revenues for low-income tax credits. Though Australia also attempted a revenue-neutral approach, snowballing costs for end-users were still too high for the personal tax cuts to be effective.

As such, the most important issue, and certainly the most complex, is the actual price of carbon, or the tax rate. Effective carbon taxes were introduced at rates low enough for consumers and producers to adjust to the additional costs, giving them the time and the money to change their energy consumption habits. For example, while British Columbia's residents were able to adjust to higher fuel and heating costs, Australian industries struggled to pass on some of their high costs to customers. Additionally, these tax rates require gradual increments in order to continue decreasing emissions. Both British Columbia and Ireland saw their emissions rise when their scheduled tax increments expired. A well-priced tax requires constant government revision and supervision in order to walk this very fine line. Naturally, many economists believe that the free market can do a much better job than the government at achieving this price adjustment, and this belief is central to the pricing mechanism discussed in the following chapter: Trading Schemes.

Chapter 5

Trading Schemes

5.1 How a Trading Scheme Works

A trading scheme is the Coasian approach to carbon pricing. Trading schemes are also referred to as cap-and-trade because of their two-step process. First, the government imposes a quota of acceptable emissions, also known as the cap, which it can then monitor and change, typically reducing the cap over time. Then, the government assigns property rights to emissions by distributing emission permits, known as allowances. By trading these allowances, businesses establish a market price, and must then limit their emissions to the quantity covered by their permit purchases (Schmalensee & Stavins, 2012).

Like carbon taxes, this type of approach is merely an incentive to change consumer, business, and industry behaviors, rather than imposing specific changes in emission habits, or command-and-control (Burtraw & Evans, 2009). Also like carbon taxes, trading schemes provide this incentive by making it more expensive to produce emissions, and are levied in price per ton of carbon or price per ton of carbon dioxide. If the government is unhappy with the market price, they can shift supply by changing the cap or impose a price ceiling by adding a minimum trading price. Otherwise, the carbon market takes care of everything without intervention.

Trading schemes differ from carbon taxes in the way they impact end-users. Regular households and individuals do not participate in permit trading, only businesses, industries, and utilities. This allows the trading entities to choose how to pass on their additional costs to consumers (Sorrell & Sijm, 2003). While carbon taxes can also be levied in this manner, such as a tax on electricity generation, they have more flexibility to be directly levied on end-users, such as a fuel tax. The indirect approach of trading schemes can be a disadvantage if businesses and industries struggle to pass on their costs to end-users. Still, cap-and-trade advocates argue that businesses and industries benefit under this mechanism because they can choose how to pass on costs without further regulator intervention (Burtraw & Evans, 2009).

The biggest advantage to trading schemes is the certainty that emissions will fall under a set cap. Governments can use historical emissions data and climate models to set realistic emissions reduction goals (Burtraw & Evans, 2009). Unfortunately, this is easier said than done. Scientists, economists, and policymakers are frequently in disagreement on what that cap should be. Early trading schemes frequently chose this cap arbitrarily on estimates of the costs of abatement, rather than the social cost of emissions, and then attempted to adjust that cap in response to new information. Trading scheme legislation must therefore be flexible enough for such policy adjustment (Schmalensee & Stavins, 2012).

Another advantage of trading schemes is that they can develop into trans-national policies. As explained in Chapter 2, carbon dioxide pollution is a global problem with global effects, and the international community has been struggling to implement a long-term, trans-national solution. Trading schemes have greater potential than carbon taxes to be applied in this manner, since they have the flexibility of establishing different caps for different countries, while trading the same allowances across a global market. This is the major reason why the European Union chose to implement a trading scheme instead of a carbon tax to reduce emissions across borders. Alternately, trading schemes from different countries can come together in a bottom-up approach, allowing industries from one country to buy allowances from another country (Sorrell & Sijm, 2003).

The biggest difficulty with trading schemes is deciding whether to allocate or auction allowances. In the first approach, the government gives allowances to regulated industries, and those industries trade among themselves to establish a market equilibrium, absorbing all the costs and benefits of the allowance market. In the second approach, the government auctions allowances, thus generating additional revenue which it can return to end-users in the form of tax credits (a revenue-neutral trading scheme) (Schmalensee & Stavins, 2012). Most trading schemes employ a combination of the two, which then results in equity debates about who should receive allowances and who should buy them (Burtraw & Evans, 2009). Furthermore, allocating allowances reduces costs for industries, which is good for the economy, while auctioning allowances increases costs for industries, which has stronger emissions reduction results.

Trading schemes also allow regulated entities to meet their compliance requirements by purchasing carbon offset credits. Carbon offsetting, discussed in greater detail in Chapter 6, is financial investment in renewable energy, reforestation, and emissions reduction technologies. By purchasing a carbon offset credit, a regulated entity can offset its emissions elsewhere, while theoretically still having the same net emissions impact as reducing their own emissions. All current trading schemes have provisions for carbon offsetting. Unfortunately, carbon offset prices may differ from a scheme's allowance prices, creating room for arbitrage. For this reason, some trading schemes put limits on how many carbon offset credits regulated entities can buy (Center for Climate and Energy Solutions).

Historically, trading schemes were used to limit greenhouse gas emissions in the United States, excluding carbon dioxide. These emissions include sulfur dioxide and nitrous oxides and were covered under the Clean Air Act of 1990 (Burtraw & Evans, 2009). In 2005, the European Union established the largest trading scheme in the world for carbon dioxide emissions. Since then, trading schemes have been popping up in the United States at the regional level, some even trading carbon permits with Canadian provinces. Several efforts were made by Congress during the first term of President Obama to pass a national trading scheme for carbon dioxide, but these efforts never amounted to legislation (Erickson, Lazarus, & Kelly, 2011). The following case studies take a deeper look at the trading schemes mentioned.

5.2 Case Studies

The Clean Air Act

In 1990, President George W. Bush signed into law the Clean Air Act Amendments, creating a trading scheme for sulfur dioxide emissions and, to a lesser extent, nitrogen oxide emissions. These chemical emissions primarily came from coal-fired power plants, and reacted in the atmosphere to produce sulfuric and nitric acids, which then fell as acid rain precipitation, damaging forests and aquatic ecosystems in the United States and southern Canada. At the time, assigning property rights to air pollution was a novel idea; previous pollution regulations typically took the prescriptive command-and-control approach (Schmalensee & Stavins, 2012). Still, for the first two decades, the policy experiment proved successful, encouraging policymakers to adopt the same approach to carbon dioxide emissions. Unfortunately, the policy came to an end in 2010 when the allowance markets collapsed.

The goal of the Clean Air Act was to reduce sulfur dioxide (SO_2) emissions by 10 million tons relative to 1980[7]. The trading program had two phases: Phase I (1995-1999) limited the allowance market to the 263 most-polluting coal-fired power plants; Phase II (2000-2010) placed an aggregate national emissions cap on nearly 3,200 electric generating units, essentially the entire fleet of fossil-fueled plants in the continental United States. The Environmental Protection

[7] The main market created under the Clean Air Act was the sulfur dioxide allowance market, so I will focus my analysis on this market alone for clarity and simplicity.

Agency (EPA) was the government body tasked with issuing allowances and monitoring the market. Each year, the EPA issued allowances valid only for that year, with scheduled decreases of allowances for each successive year (Schmalensee & Stavins, 2012).

An interesting caveat of this trading scheme is that the government *gave* allowances rather than auctioning them. As such, the power companies in the market absorbed all of the potential costs and benefits resulting from the sale of allowances. In most trading schemes today, the government auctions off a proportion of allowances, creating additional revenue that can be returned to taxpayers to offset their costs. Unfortunately, efficiency arguments for such revenue-neutral policies were not yet developed, so the Clean Air Act did not have this additional policy measure (Schmalensee & Stavins, 2012).

For the first decade, the SO_2 trading scheme performed exceptionally well from all points of view. Between 1994 and 2004, SO_2 emissions from power plants decreased by 36 percent, even though electricity generation from coal-fired plants increased by 25 percent over the same period. The program reached its emissions goal in 2006, and emissions continued to decrease until the end of the program in 2010. Figure 6 illustrates this trend.

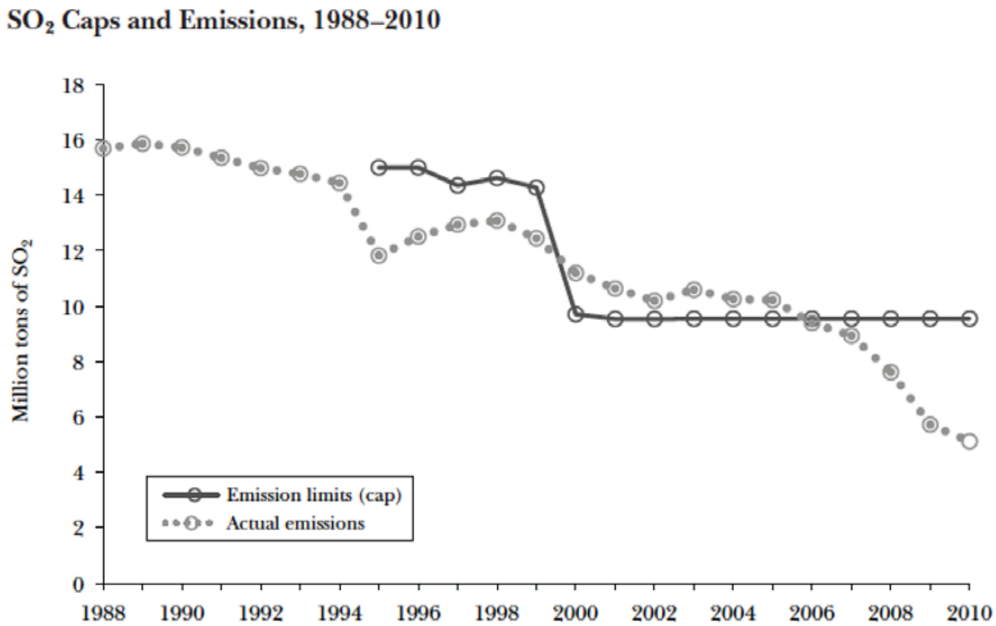

Figure 6: Sulfur Dioxide Caps and Emissions (1988-2010)

Source: Schmalensee and Stavins (2012)

The policy also ended up being between 15 and 90 percent[8] more cost-effective than a traditional command-and-control approach. The EPA's only task was monitoring emissions and issuing allowances. Additionally, abatement costs for the power plants decreased because the policy succeeded in providing incentives for innovation, such as more cost-effective flue gas desulfurization devices, called "scrubbers." Schmalensee and Stavins (2012) argue that abatement costs were further reduced by unrelated railroad deregulations from the 1980s that made low-sulfur coal, produced in the Powder River Basin, more accessible to power plants. Thus, compliance costs for both utilities and consumers were low for the first decade of this program. Nevertheless, the scheme resulted in steady emissions decreases at relatively stable prices of about $150/ton for the first ten years of its implementation. Figure 7 shows the evolution of allowance prices in the SO_2 market.

[8] The wide range of estimates is a result of the logistical fact that there were no comparable command-and-control policies of this scale in place in the United States.

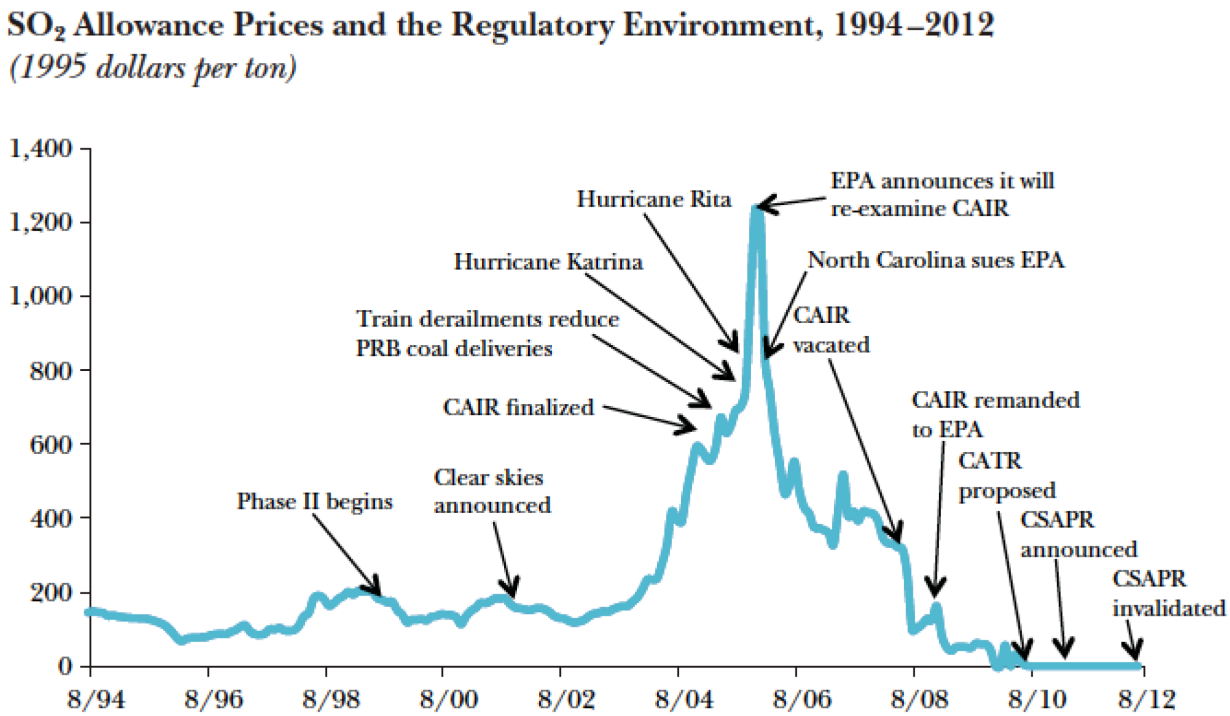

Figure 7: Sulfur Dioxide Allowance Prices (1994-2012)

Source: Schmalensee and Stavins (2012)

The sulfur dioxide trading scheme ultimately collapsed because of further government intervention, court rulings, and regulatory responses. The original purpose of the policy was to prevent environmental harm caused by acid rain; however, by the late 1990s, numerous studies showed that fine particulates associated with SO_2 emissions caused adverse health effects, and scientists consequently argued for a more stringent cap to meet air quality standards. The 10 million ton reduction cap instituted by the Act had been chosen fairly arbitrarily by what economists and policymakers estimated was the “elbow” of the abatement curve, or the point at which abatement costs are high enough to reduce emissions but low enough to not significantly damage economic output. Consequently, in an effort to reduce this cap, multiple administrations attempted to pass policies that were meant to build on the Clean Air Act, but ultimately contradicted them (Schmalensee & Stavins, 2012).

In 2002, President George H. W. Bush proposed the Clear Skies Act, and following its immediate failure in Congress, then introduced the Clean Air Interstate Rule (CAIR), which passed in 2005. CAIR required an emissions cap reduction of two-thirds and extended this cap to statewide emissions (Schmalensee & Stavins, 2012). CAIR provided that firms could band existing allowances under the new market, and in anticipation of this act, prices increased rapidly, peaking at $1,600/ton in 2005[9]. Then, following an announcement that the EPA would reexamine CAIR, prices went back down. In 2006, North Carolina (and several other states and utility companies) sued the EPA over CAIR, arguing that "the EPA had overstepped its authority in expanding the markets and that parts of the new rules conflicted with existing Clean Air Act regulations" (Peters, 2010). North Carolina eventually won its suit in 2008, vacating CAIR in its entirety and driving prices from $315/ton to $115/ton. In July of 2010, the Obama administration proposed state-specific emissions limits to replace CAIR, eliminating the need for allowances and driving the last nail in the coffin of this trading scheme (Schmalensee & Stavins, 2012).

European Union Emissions Trading System

Inspired by the early success of the Clean Air Act, the European Union launched its own Emissions Trading System (EU ETS) in 2005 with the goal of decreasing carbon dioxide emissions by 21% by 2020 and 43% by 2030. The EU ETS is currently the largest and longest-lasting trading scheme for emissions allowances, with 31 participating countries (28 from the EU plus Iceland, Liechtenstein, and Norway). The program limits emissions from more than 11,000 heavy energy-using installations in power generation and manufacturing industry, covering 45% of the EU's greenhouse gas emissions (European Commission, 2016). Though the EU ETS was

[9] Prices hikes were also aided by Hurricanes Katrina and Rita which limited petroleum refinery and natural gas capacity, requiring power plants to burn more coal in response (Schmalensee & Stavins, 2012).

arguably "successful" in its first two phases, a surplus of allowances in the market culminated in price troughs in 2013 that nearly brought the program to an end. Since then, the European Commission has been reforming the system to ensure its survival, though prices still haven't recovered to their pre-Recession levels.

Allowances under the EU ETS are called EUAs, with one EUA being the equivalent to 1 ton of carbon dioxide. There are no limits on carbon offset credits for regulated entities to meet their compliance obligation (Center for Climate and Energy Solutions, n.d.). The program was implemented in four phases, with each successive phase constricting the cap and expanding the program to more industries, much like the Clean Air Act. During the first two phases, the majority of allowances were given to industries, however, unlike the Clean Air Act, the proportion of auctioned allowances was designed to increase with each successive year. Historical prices of EUAs (in euros) are represented in Figure 8.

Figure 8: Historical EUA Prices (2007-2011)

Source: European Environment Agency (2012)

The first two phases of the EU ETS showed relative success. Phase I (2005-2007) was the "learning by doing" phase, represented by the teal line in Figure 8. During these two years, prices were very volatile as industries and the European Commission adjusted to the scheme, dropping to nearly €0 in 2007 due to an over allocation of allowances. In Phase II (2008-2012), stricter caps were introduced, resulting in stable prices that dropped only as a result of the Great Recession at the end of 2008, then flattening out through 2011 (United Kingdom Department of Energy & Climate Change, 2015).

Beginning in 2011, and bleeding into Phase III (2013-2020), a surplus of allowances sent prices reeling by April of 2013. *The Economist* magazine (2013) explains:

> Partly because recession has reduced industrial demand for the permits, and partly because the EU gave away too many allowances in the first place, there is massive overcapacity in the carbon market. The surplus is 1.5 billion-2 billion tonnes, or about a year's emissions. Prices had already fallen from €20 ($30) a tonne in 2011 to €5 a tonne in early 2013.

The article further explains that initial efforts to reduce this surplus by removing allowances from the market for future injection were rejected by the European Parliament. The resulting price plunge can be seen in Figure 9:

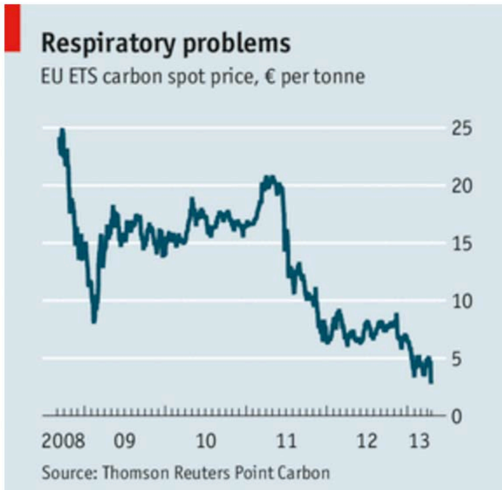

Figure 9: Historical EUA Prices (2008-2013)

Source: The Economist (2013)

EOA prices have not yet recovered from the 2013 drop. According to the Intercontinental Exchange, June 2016 EOA futures contracts have been trading for about €5 in 2016. However, the European Commission has been developing structural reforms to the program with the hopes to get the ETS back on track by Phase IV (2021-2030). The European Parliament eventually approved reductions in allowance auction volumes in February of 2014, and the European Commission successfully removed 400 million allowances in 2014, 300 million in 2015, and 200 million in 2016. The Commission also introduced an EU-wide emissions cap, set to decrease by 1.74% per year. Plans are currently in effect to change this cap decrease by 2.2% each year for Phase IV. Additionally, the Commission will establish a market stability reserve for allowances in 2018 in order to have more flexibility in cap adjustment (European Commission, 2016).

In terms of emissions reduction, the EU ETS has been a successful, though unstable policy. Figure 10 shows historic greenhouse gas emissions for the 28 EU countries involved in the program:

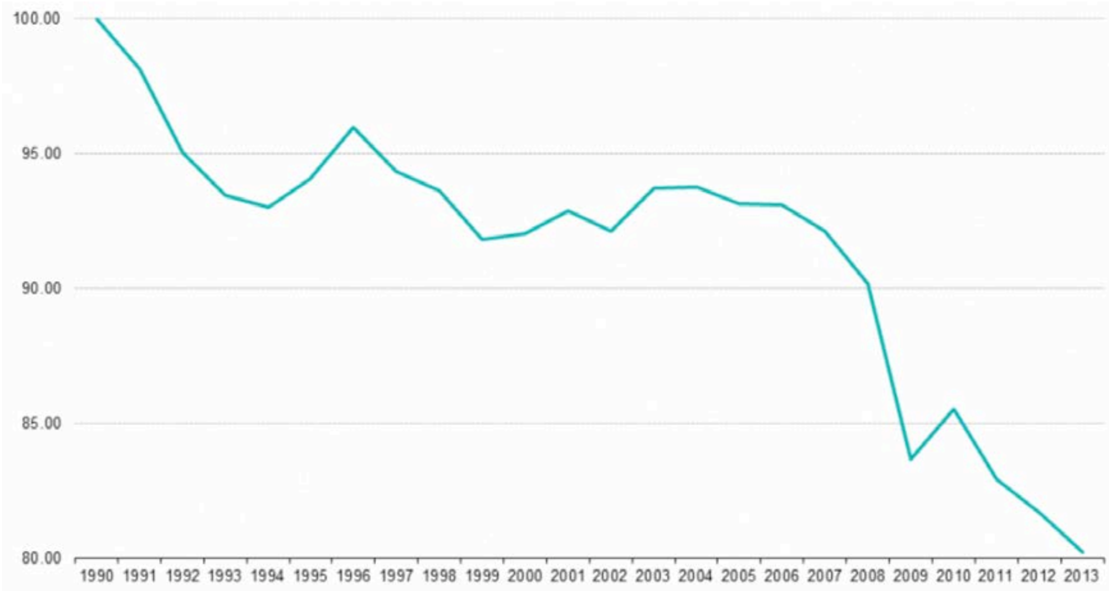

Figure 10: EU-28 Historic GHG Emissions Data (1990-2013)

Source: Eurostat (2015)

Figure 10 clearly illustrates the effect of the EU ETS, with emissions plunging in 2005 with the implementation of the program. The 2008 dip, however, is attributed to the economic recession, which decreased industrial output and thus lowered greenhouse gas emissions. Interestingly enough, despite the relative collapse of the carbon market, GHGs continued to decrease from 2011 to 2013. Unfortunately, this graph represents the most recent data available, so we still don't know how the low prices from 2014 onwards impacted emissions. Still, the European Commission's ongoing efforts indicate that while the EU ETS has been struggling, European policymakers are not quite finished with their cap-and-trade experiment.

Regional Greenhouse Gas Initiative

In 2005, seven northeastern state governors signed an agreement to reduce carbon dioxide emissions in one of the largest emitting regions of the United States. Four years later, the Regional Greenhouse Gas Initiative (RGGI) went into effect as the first mandatory cap-and-trade market for carbon dioxide emissions in the United States (Center for Climate and Energy

Solutions, n.d.). Participating states included Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, New Jersey, Rhode Island, and Vermont. The trading scheme only applied to power plants with capacities to generate 25 megawatts or more, or approximately 168 facilities (Ramseur, 2013).

The RGGI was designed with two phases. Phase I (2009-2014) would limit the cap to 188 million short tons of carbon dioxide emissions per year. Phase II (2015-2018) would reduce the cap by 2.5% each year for a total 10% reduction by 2018 (Legrand, 2013). Unlike the Clean Air Act and Europe's Emissions Trading System, the majority of allowances were auctioned, not given. In the first three years of the program, 70% of the allowances were auctioned, and by 2013, that number climbed to 89%. Carbon offsets could only account for 3.3% of a regulated entity's compliance obligation (Center for Climate and Energy Solutions, n.d.).

From the first day of the program's implementation, the Phase I cap was nonbinding. This was partly due to the economic recession, which coincided with the onset of the program, and decreased both energy use and electricity demand. Additionally, electricity generation had already started moving away from high-emissions sources, notably switching from coal to natural gas, which produces half as many emissions. In 2005, coal accounted for 21% of power generation and natural gas accounted for 25%. By 2011, coal use had decreased to 11% and natural gas had increased to 39%. Petroleum also saw drastic decreases, from 11% of power generation in 2005 to 1% in 2011 (Ramseur, 2013). Consequently, allowance prices during the first phase were between \$3.35/ton of CO_2 and \$1.86/ton (Center for Climate and Energy Solutions, n.d.). Figure 11 illustrates the ineffectiveness of the Phase I cap:

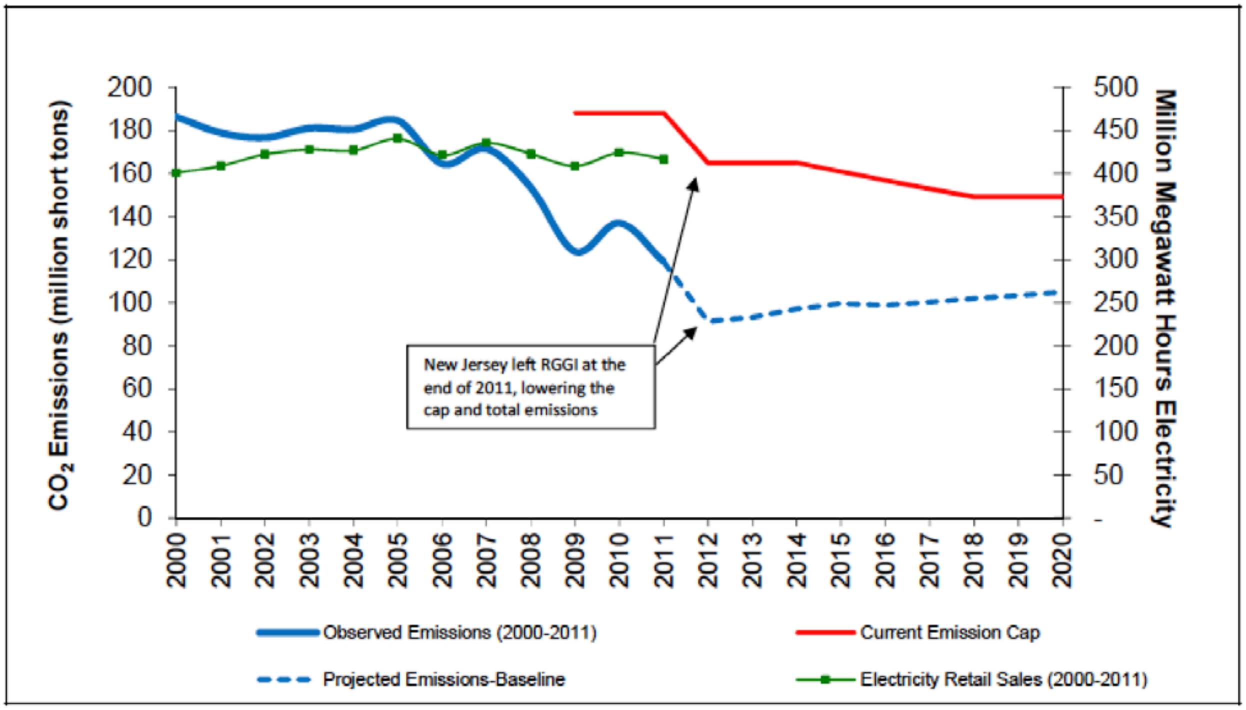

Figure 11: RGGI Observed Emissions and Emissions Cap

Source: Ramseur (2013)

In 2012, New Jersey governor Chris Christie removed his state from the RGGI, further undermining the effectiveness of the cap. Prices during the first half of this year never exceeded the program's price floor of $1.93. The RGGI underwent structural review, and following New Jersey's exit, the program founders lowered the cap to 165 million tons between 2012 and 2013. The structural review also lowered the 2014 cap to 91 million tons. These reforms dramatically increased allowance demand, bringing prices up to $3.21. In 2013, 100% of the allowances auctioned were sold (Center for Climate and Energy Solutions, n.d.). Figure 12 illustrates RGGI allowance demand and prices between 2008 and 2013:

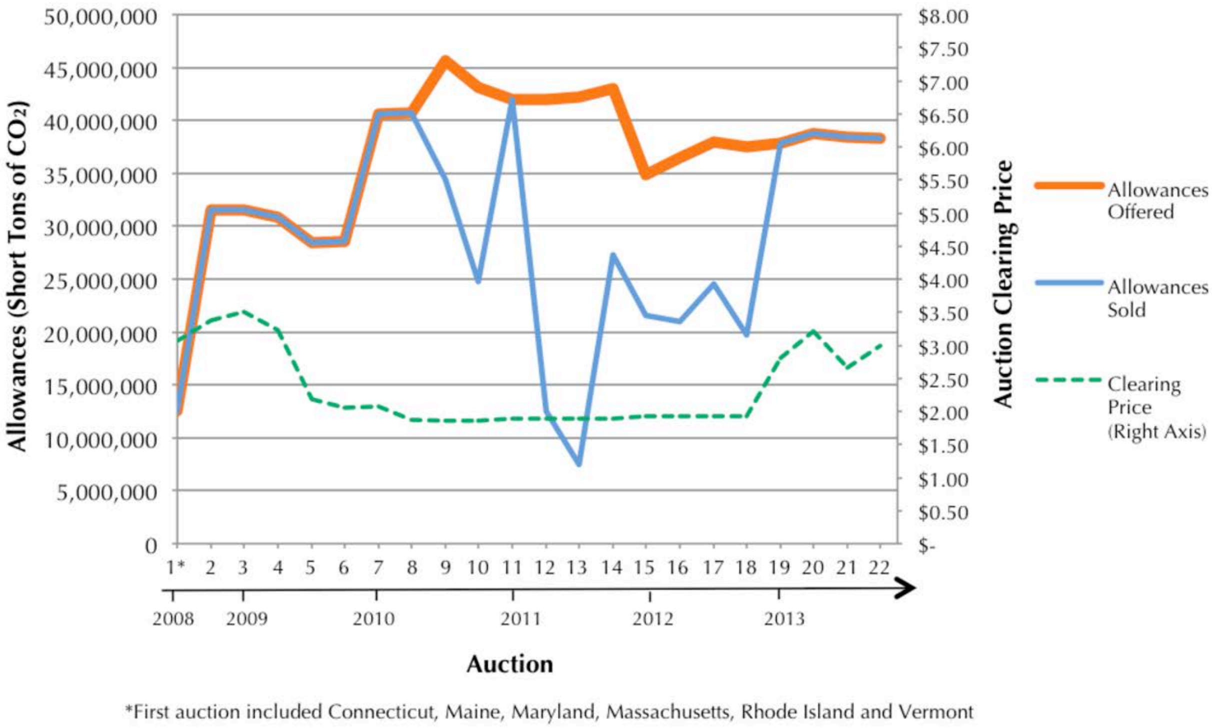

Figure 12: RGGI Allowance Demand and Prices (2008-2011)

Source: Center for Climate and Energy Solutions (n.d.)

The program reforms of 2011 and 2012 have proved effective. Since their implementation, allowance prices have been steadily rising. The most recent auction price available is from March 11, 2016, with 14,838,732 allowances sold at $5.25.

A 2013 review of the RGGI program by the Columbia Law School Journal of Environmental Law found that state governments and consumers benefitted from the program at the expense of producers. The program generated $1.2 billion dollars in cumulative revenue, and RGGI states contributed 65% of that revenue to support energy efficiency, renewable energy, and other climate-related efforts. Some states, like Maryland, gave a portion of that revenue back to consumers in the form of credits on their power bills. At the beginning of the program, power companies were able to shift $900 million of allowance costs back to consumers, raising electricity prices by 0.7%. However, as energy efficiency programs began decreasing electricity demand, consumers actually saw their electricity bills decrease by $2 billion from 2009 to 2011. Cumulative allowance costs of power producers by 2013 amounted to $395 million. Power companies are currently concerned that the RGGI program puts them at a competitive disadvantage with companies outside of the program. As such, they hope to see the program expanded to smaller companies in RGGI states (Ramseur, 2013).

Western Climate Initiative

Similar to the RGGI, the Western Climate Initiative (WCI) began with an agreement, signed in February 2007, by the governors of five western states: Arizona, California, New Mexico, Oregon, and Washington. Between 2007 and 2011, many other states and even some Canadian provinces joined in the efforts to create a North American trading scheme, with hopes of expanding to trade with RGGI states. The program planned to begin emissions trading on July 1st, 2012. Unfortunately, all US states and Canadian provinces, excluding California, Manitoba, Ontario, and Quebec, withdrew from the program by 2011, effectively terminating the WCI before it was ever implemented (Center for Climate and Energy Solutions, n.d.).

California Trading Scheme

As the world's ninth largest economy and a significant emitter of greenhouses gasses, California has spearheaded greenhouse gas reduction efforts in the United States since the passage of its Global Warming Solutions Act of 2006. In 2011, the California Air Resources Board passed legislation that created a trading scheme for the state's power companies and industries emitting more than 25,000 metric tons of CO_2 annually. The scheme expanded to include ground transportation and heating fuels in 2015. Currently, the program covers approximately 35% of California's total greenhouse gas emissions The goal of the program is to bring California's emissions back to 1990 levels by 2020, or 334.2 million metric tons of CO_2 per year. The 2015 yearly cap on emissions was 394.5 million metric tons of CO_2, so the program is well on its way to achieve its emissions goal (Center for Climate and Energy Solutions, n.d.).

California allocates 90% of its allowances and auctions off the rest. The first allowance auction took place on November 14, 2012, and the program linked up with Quebec's new trading scheme in 2014[10]. In its first two years, the trading scheme generated $2.27 billion in revenues from the sale of allowances. Governor Jerry Brown has been investing this money in projects such as a bullet train system, affordable housing and transit, infrastructure, and water conservation (Lazo, 2014). The program also allows regulated entities to purchase carbon offset credits, so long as they do not exceed 8% of their compliance obligation (Center for Climate and Energy Solutions, n.d.).

California's trading scheme also had a price floor for allowance auctions of $10 for 2012 and 2013, with scheduled increases of 5% plus inflation starting in 2014 (Center for Climate and Energy Solutions, n.d.). Figure 13 shows daily carbon allowance futures prices for California's trading scheme.

[10] I will not be analyzing this trading scheme as a case study because it is only three years old and has limited analysis publications and pricing or emissions data.

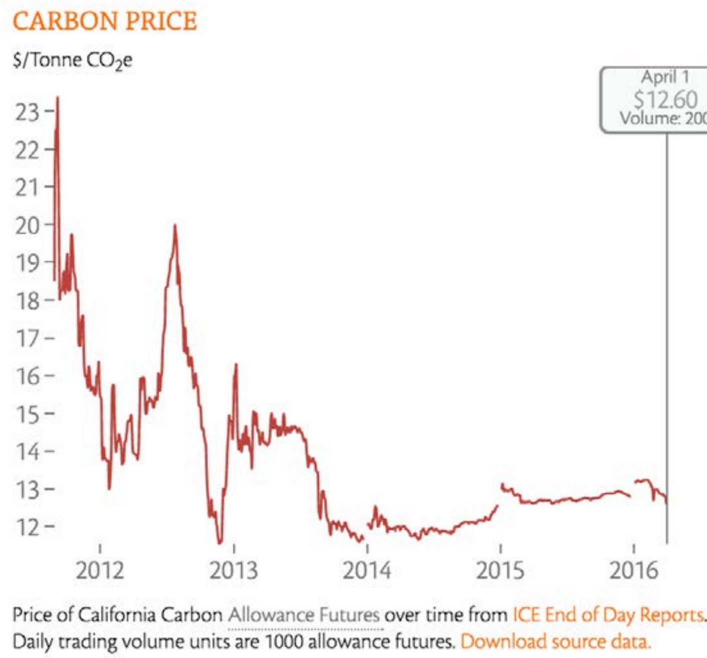

Figure 13: California Carbon Allowance Futures Prices

Source: California Carbon Dashboard (2016)

It appears that prices during the first two years of the trading scheme varied wildly, plateauing around 2014. This is not unusual since businesses and utilities were probably still getting used to the scheme. The steady prices from 2014 to 2016 are a good sign of this program's performance.

It is still too early to tell what the costs and benefits of this program look like. Emissions data is limited, and the program is still too young for sound environmental impact estimates. Costs to businesses have been marginal, but again, there are no sound aggregate estimates. The expansion of the program to ground transportation in 2015 was estimated to increase gas prices by $0.13 to $0.20 a gallon. Beyond that, costs to consumers have also been minimal (Lazo, 2014). More economic research is needed on the successes and failures of this new program.

5.3 Trading Scheme Conclusions

The case studies of this chapter have illustrated a lot of different points about the nuances of trading schemes. Most importantly, they have shown what sort of factors contribute to price volatility, and how policymakers can avoid those mistakes. In Europe, though the EU ETS has struggled for the past four years, ongoing reform of the program promises future stability and demonstrates that policymakers are not quite done with this experiment. Unfortunately, the political climate in Washington has effectively terminated any chances of a the United States Congress passing a national trading scheme. However, if California and the RGGI continue to have positive results, other states may be encouraged to create their own initiatives or join existing regional programs.

Coasian markets, like any other market, need relative price stability. After all, the purpose of a trading scheme is to lower emissions abatement costs by increasing pollution costs. If the latter costs vary wildly, producers will struggle to find optimal strategies to comply with regulators and efficiently reduce their emissions. Furthermore, when allowance prices drop to zero, companies lose their cost incentives to reduce emissions, and the trading scheme becomes useless.

Every case study, excluding the overly-ambitious WCI, demonstrated the need for legislative flexibility in trading schemes. This means that policymakers need to have sufficient public and political support to quickly adjust aspects of a program in order to maintain stable prices. A quick glance at Figure 7, showing allowance prices under the SO_2 trading scheme, illustrates the importance of legislative flexibility. The acid rain market had incredibly stable prices until 2004, when attempts to pass legislation raising the market cap sent prices up. Then, court battles, regulatory review, and further roadblocks brought prices down to zero within a few more years, effectively terminating what had been a successful policy for a decade. Similarly, the delay in the European Commission's reforms of the EU ETS created a surplus of allowances that also sent prices plunging, and the market has still not recovered to pre-2011 levels.

The greatest adjustment tool for policymakers in a trading scheme is changing the cap on emissions. The 2008 Recession shrank world output, decreasing energy demand and therefore decreasing carbon dioxide emissions. For carbon markets, fewer emissions frequently placed regulated entities under their cap, removing their incentives to adopt emissions reduction strategies. The simple remedy to ensure carbon markets continue to function is lowering the cap beneath current emissions levels. Prices rose for both the RGGI and the EU ETS once the market cap was sufficiently reduced.

The sulfur dioxide market also demonstrated another important lesson about cap adjustment. As scientists conducted more studies on the pollutant, policymakers learned that lowering emissions concentrations had large human health benefits, and thus that the true social equilibrium required a more stringent cap. In Chapter 2, I explained how global warming is an ongoing problem, and we are only just starting to see the effects. I expect that as these effects become more pronounced, scientists and policymakers alike will understand the need to further limit carbon dioxide pollution. If and when that moment comes, existing carbon markets need to be ready for a quick and effective cap adjustment.

Trading schemes can also maintain price stability by limiting carbon offset credits and establishing price floors. Though carbon offsets have the same net effect as emissions abatement by the purchasing entity, their prices may differ from carbon prices, creating arbitrage opportunities. The EU ETS does not limit carbon offset credits, and therefore when allowance prices were higher, many companies purchased offset credits instead of investing in abatement technology. Europe’s trading scheme also lacks a price floor, so the surplus of allowances in 2013 sent prices close to zero. Both California and the RGGI have implemented price floors to ensure this does not happen, protecting their markets from exogenous economic shocks.

Despite its many problems, the European Commission seems determined to keep their program running by implementing sweeping reforms. Unfortunately, the United States does not show the same resilience. In their analysis of the sulfur dioxide market, Schmalensee and Stavins (2012) describe how the Republican Party came to demonize their own policy experiment when Congress started debating a national program for carbon dioxide emissions. The (second) Bush administration was actually one of the first policymakers to suggest expanding the Clean Air Act scheme to carbon dioxide pollution. However, disagreements among Republicans on climate change developed into a war of attrition against all climate policies, including carbon taxes and trading schemes. In 2009, the Waxman-Markey bill outlining a national trading scheme under the EPA passed through the Democratic House of Representatives. That was the furthest any carbon pricing bill has gone in Congress, and Senate Republicans terminated the bill by removing it off the discussion docket.

Nevertheless, the regional trading schemes currently in place in the United States seem to be running more smoothly than their larger precedents. Perhaps this policy is more successful if it is built from the ground up, starting out a small regional initiative, then slowly adding more locations to the market. States currently have very strong incentives to establish carbon taxes or cap-and-trade programs, given the recent passage of the Clean Power Plan by the EPA. Regardless, further economic research is needed on the most recently established trading schemes in California and Quebec.

Chapter 6

Voluntary Markets

At the heart of most economic theory is the notion that private markets have the ability to reinstate equilibrium without government involvement. In light of the confusing, contradictory, and at times, unsuccessful carbon policy landscape, economists have been turning their attention to private market solutions to the carbon problem. Currently, the private market champions are carbon offsets, which have been growing in popularity over the past decade.

6.1 Carbon Offsetting

Carbon offsetting is financial investment in renewable energy, forestry, and resource conservation projects that reduce greenhouse gas emissions. The idea behind carbon offsetting is that individuals and businesses can offset their own carbon emissions by investing in projects that reduce emissions elsewhere. These projects, which are usually based in developing countries and designed to reduce future emissions, include wind and solar farms, low-emissions cooking stoves, reforestation, and capturing methane gas at landfill sites (Clark, 2011).

Increasingly, companies and individuals have been taking it upon themselves to purchase offset credits in an effort to minimize their carbon footprints. For example, the new Land Rovers include offsets for the production of the vehicle and the first 45,000 miles of use in their price (Clark, 2011). Data has shown that the leading motivations for companies to purchase carbon offsets are “Corporate Responsibility” and “Public Relations/Branding” (Hamrick & Goldstein, 2015). Figure 14 shows some of the companies that engage in carbon offsets around the world:

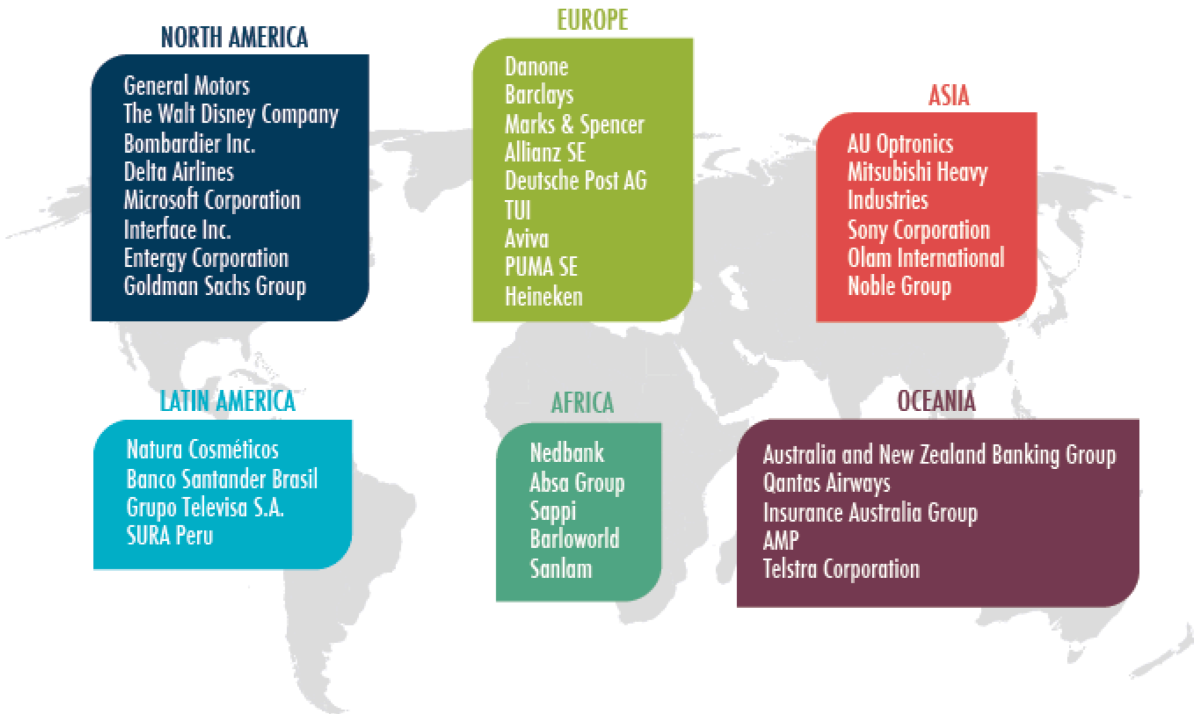

Figure 14: Carbon Offset Buyers by Region

Source: Hamrick and Goldstein (2015)

Similarly, individuals can purchase offsets to neutralize the environmental impact of a specific activity, such as flying. Several carbon offset websites have online tools that can calculate the emissions of a flight. With these tools, users can determine how many offsets to purchase in order to reduce their emissions elsewhere by the same amount (Clark, 2011).

6.2 Defining the Voluntary Market

How do we define the voluntary market? As discussed in Chapter 5, trading schemes typically have carbon credit provisions that allow companies to reduce their emissions through carbon offset investments. Differentiating these investments from pure voluntary abatement is crucial in analyzing the voluntary market. Ecosystem Marketplace, a non-profit initiative that analyzes environmental markets, defines voluntary carbon markets as “All purchases of carbon offsets not driven by an existing regulatory compliance obligation” (Hamrick & Goldstein, 2015). Their most recent report on the state of voluntary markets in 2015 focuses solely on offset transactions outside of mandate policies, and will therefore be referenced throughout this chapter.

In a voluntary market, the "buyers" are businesses and individuals wishing to offset their carbon footprints, and the "sellers" are the project developers working to reduce emissions. Although not required by law, offset projects are typically evaluated by third-parties to ensure their emissions reductions are real and additional, meaning that they would not have been achieved without additional financing. Quality projects receive branding such as the Voluntary Carbon Standard or the Gold Standard as a green light to encourage investment. Then, buyers and sellers meet in the marketplace to generate this investment in one of two ways.

Buyers and sellers in the voluntary market can perform transactions in a number of ways. Experienced buyers and sellers interact directly, though this is usually reserved for large-scale transactions. Alternately, buyers and sellers can connect through brokers (who do not take carbon credit ownership) or retailers[11] (who do take carbon credit ownership). As such, carbon offsets are frequently bought and sold multiple times. When they can no longer be traded, offsets are permanently removed from the marketplace and labeled "retirements" (Hamrick & Goldstein, 2015).

6.3 Offset Prices

The voluntary market has often been criticized for the low prices of carbon offsets. The market average in 2014 ($3.80) was significantly lower than, for example, the carbon tax rates in Ireland ($21.86), British Columbia ($22.20), and, more drastically, Sweden ($168). This is because voluntary market pricing is *not* determined by social cost estimates, but rather by the

[11] For anyone interested in seeing how carbon offset retailers work, visit http://www.terrapass.com/. Please note that this is not an official company endorsement; I am merely including this as an example.

cost of emissions reduction of specific projects. There are currently many inexpensive ways to reduce carbon dioxide emissions, and carbon offsets flock to these "low-hanging fruits," thus contributing to the low prices. In theory, once these projects are used up, offset companies will start more expensive projects, thus increasing offset prices (Clark, 2012).

With so many projects, offset credits vary wildly in terms of price. For example, producing an efficiency stove for Darfurian refugees costs $20 and saves two metric tons of carbon dioxide emissions per year, therefore these carbon credits cost $10/ton (Gadgil, Sosler, & Stein, 2013). Conversely, credits to build wind farms in China only cots $6/ton, and Reduced Emissions from Deforestation and Forest Degradation (REDD) credits cost $5/ton (Hamrick & Goldstein, 2015). Carbon credit buyers can therefore shop around and choose what projects to finance based on their emissions goals and costs, with quality assurance from standards branding.

Figure 15 illustrates the average prices of carbon offsets from 2005 to 2014.

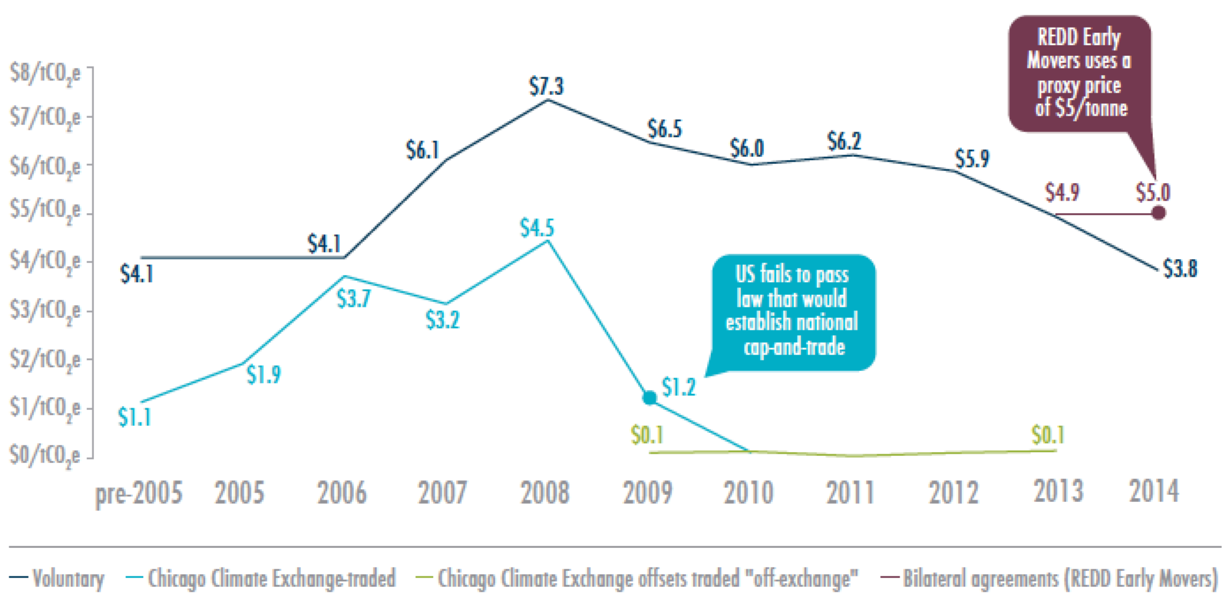

Figure 15: Voluntary Carbon Market Prices 2005-2014

Source: Hamrick and Goldstein (2015)

Hamrick and Goldstein from Ecosystem Marketplace (2015) point out that voluntary markets have been more resilient to economic shocks than mandate markets like the EU ETS. The 2008 recession sent EUA prices from €20 to €5 in just a few years, while voluntary offset prices only decreased by about $2.50 during the same period. However, Hamrick and Goldstein also argue that, “carbon price regulations (actual or anticipated) have a greater influence on voluntary demand than does economic performance, offset prices – or anything else.” This is because buyers from regions with a price on carbon are more likely to engage in voluntary offsetting, largely because this gives them more experience and familiarity with market-based mechanisms for emissions reductions.

6.4 Voluntary Market Trends

In 2014, the demand for carbon offsets increased by 14%, reaching 87 million tons of carbon dioxide equivalent. This amounted to $395 million in offset investments, a 4% increase from the year before. The recent influx of demand can be attributed to heightened corporate climate initiatives in anticipation of the 2015 Paris Conference, as well as a growing interest in supporting carbon projects with co-benefits. Leading offset projects in 2014 include forestry and land use ($31.4 million), renewables ($16.7 million), gases and methane ($4.9 million), household devices ($3.6 million), and efficiency and fuel switching ($4.5 million).

Since 2005, voluntary market transactions have totaled 0.93 billion tons of CO_2 equivalent, or $4.4 billion. Figure 16 illustrates historical voluntary offset transaction volumes:

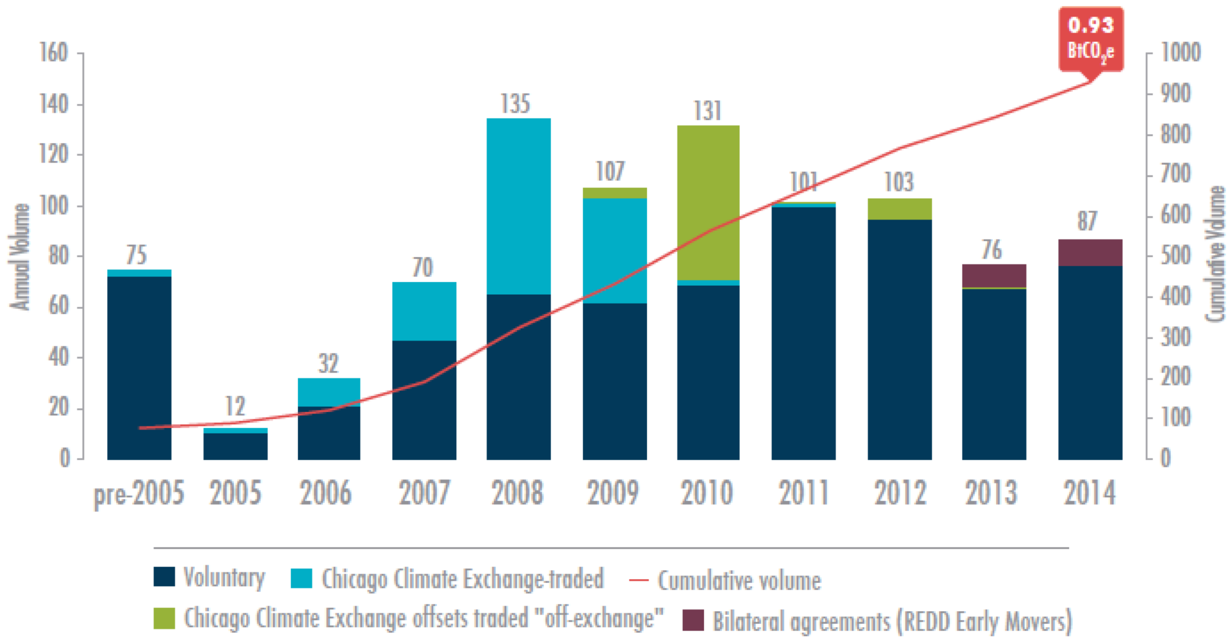

Figure 16: Historical Market-Wide Voluntary Transaction Volumes

Source: Hamrick and Goldstein (2015)

Figure 16 shows a variety of different programs that were important to the growth of voluntary markets. The Chicago Climate Exchange (CCX) was developed as a voluntary carbon offset market in North America in anticipation of a federal trading scheme in the United States. However, when no such program passed through Congress (the American Clean Energy and Securities Act died in the Senate in 2009), the CCX was terminated in 2010. Offset credits from the dead program continued to trade on the regular market until February of 2013, but their prices were so low that transactions contributed little to market value. Figure 16 also includes the REDD Early Movers program, a bilateral agreement between Germany and Brazil where the former country paid the latter to avoid deforestation. This program has since expanded to include Norway (as a buyer) and Ecuador and Colombia (as sellers), and has accounted for one tenth of market value over the past two years (Hamrick & Goldstein, 2015).

With offset projects and buyers around the world, voluntary carbon markets create a dynamic, international marketplace. In 2013, offset buyers were based in 32 countries from every continent except Antarctica. The current top voluntary offset buyer countries are, in decreasing order, the United States, Japan, the United Kingdom, and Australia. Offsetting typically takes on a North-South dynamic, with companies headquartered in high-emitting northern countries financing emissions reductions in Latin America, Africa, and southern Asia. Ironically, the three countries home to the most voluntary offset supply locations, the United States, Brazil, and Turkey, all lack national carbon pricing regimes (Hamrick & Goldstein, 2015).

6.5 Environmental Impact of Carbon Offsets

Voluntary markets have three metrics to measure market size: offset transactions, issuances, and retirements. Unfortunately, none of these metrics is an exact measure of environmental impact. If we consider the first metric, offset transactions, as an accurate representation of removed emissions, the voluntary market represented only a fraction of 1% of global emissions in 2014. Hamrick and Goldstein (2015) estimate that emissions reductions exceed the volume of offsets that have been transacted historically since many carbon offset projects provide long-term emissions reductions (i.e., wind farms). Further economic research is needed on this topic to improve assessments of voluntary market performance, especially given the increased interest in this carbon pricing mechanism.

Chapter 7

Analysis and Conclusions

Carbon pricing has only been around for two decades, and both policymakers and economists have been "learning by doing" in this approach to emissions reduction. Both Pigouvian and Coasian policy experiments are incredibly young and therefore riddled with mistakes. Similarly, carbon offsetting and the voluntary market is a very recent development. In this chapter, I will bring together the lessons from the previous three to compare and contrast the successes and failures of carbon pricing mechanisms.

7.1 Mandate Markets vs. Voluntary Markets

Voluntary offset markets are arguably more efficient forms of carbon pricing. They match up emissions reduction projects with abatement-seeking buyers at prices determined by project costs. Buyers have numerous projects and sellers to choose from, and branding standards ensure quality products. Conversely, mandate markets are dependent on policymakers to produce desired effects, and prices are dependent on policy setup. For carbon taxes, the price is the tax rate, established by the government as an estimate of social cost. For trading schemes, the price is dependent on the cap and therefore the demand for allowances. When carbon tax rates remain untouched, abatement behavior is decentivized, and emissions climb right back up. The same effect occurs when trading schemes do not have the legislation to increase their caps.

Unfortunately, the environmental impact of voluntary markets is too small to stand on its own. No matter how many projects are proposed to offset emissions in China, there exists a limited demand for offset purchases. However, imposing a carbon tax or trading scheme on the world's largest emitter of greenhouse gasses would undoubtedly have a significant impact on global emissions. To illustrate this point, despite all its bumps and bruises, the EU ETS covers

45% of the EU's greenhouse gas emissions, which is substantial considering that the EU is responsible for 10% of global emissions.

Furthermore, voluntary markets are dependent on mandate markets, regardless of compliance with regulations. This is because mandate markets familiarize buyers with market-based approaches to emissions reduction. In recent years, voluntary markets, such as the Chicago Climate Exchange, have sprouted up in anticipation of trading schemes or carbon taxes. Companies expecting the implementation of such programs have used offsets to slowly integrate abatement costs into their business models. When countries did not follow through with a mandate policy (for example, the US failing to pass a national trading scheme in 2009), offset investment dried up.

7.2 Tax or Trade?

Carbon taxes have proven to be more stable forms of carbon pricing at a large scale than trading schemes. The first two large trading schemes, the sulfur dioxide market in the United States and the European Union's EU ETS, both collapsed, though the latter is struggling to push through with sweeping structural reforms. Conversely, only two carbon tax experiments have been repealed. Australia's tax was a political disaster, imposed on a public that was not ready to pay more for electricity to save the environment. Meanwhile, Montgomery County's tax only applied to one power company that, understandably, sued and won under grounds of a punitive fee.

This stability has been pushing more and more countries to adopt carbon taxes. To date, nine countries (Finland, the Netherlands, Norway, Sweden, Denmark, Costa Rica, the United Kingdom, Switzerland, and Ireland), two Canadian provinces (British Columbia and Quebec), and one US city (Boulder, Colorado) have carbon taxes. Conversely, there are only four operational trading schemes (the EU ETS, the RGGI, California, and Quebec).

7.3 Carbon Pricing in the United States

Carbon pricing in the United States has been substantially more successful at the regional level than at the national level. Two large trading schemes and one successful carbon tax are limiting emissions among states and cities, yet Congress has failed time and time again to create a national program. After botching their own successful policy experiment, Republicans demonized trading schemes and were responsible for halting the passage of a similar system for carbon dioxide in the Senate. With carbon taxes receiving equally minimal support in Washington, the Supreme Court and the Obama administration have since tasked the EPA with creating a command-and-control approach.

In 2015, the EPA released its Clean Power Plan, a policy designed to limit greenhouse gasses from power production. Currently, power production is the sector with the largest greenhouse gas emissions, about 32% of total US emissions. The plan will essentially levy quotas tailored to specific states, giving the states flexibility for implementation so long as their utilities meet the emissions quotas. Implementation of the Clean Power Plan was delayed by the Supreme Court in February of 2016 due to judicial review (EPA, 2016). With this quota setup, and the relative successes of both California's scheme and the RGGI, it is very possible that more US states will establish trading schemes. So far, no additional states have proposed such a scheme, however this may change once the Clean Power Plan is implemented.

7.4 An International Solution

As mentioned in Chapter 5, trading schemes, in theory, have the most potential for an international carbon mandate market. Trading schemes are flexible enough to set different national caps, while creating a global market where companies in one country can trade allowances with companies in another. Unfortunately, the collapse of the two largest trading schemes in the world, the sulfur dioxide market in the US and the EU ETS, indicate that the policy falls apart when implemented at a large scale. The need for constant legislative reform for such a controversial topic where policymakers are frequently in disagreement undermines the system and limits its efficacy.

With each successive conference, the UNFCCC has struggled to bring countries in agreement for an international treaty. These conferences have almost always dissolved into bickering between developing nations who refuse to sacrifice economic development and developed nations who plead for cooperation (excluding the United States who always seems to wriggle out of significant or binding promises). Even if the international community would reach an agreement, enforcing such a treaty would be practically impossible, as demonstrated by the Kyoto Protocol failure. The UNFCCC has no means of forcing countries to ratify a treaty or even to punish non-compliance. It will ultimately be left up to individual nations to take it upon themselves and reduce their emissions.

7.5 Areas for Further Research

There is still a lot of uncertainty and debate over the big environmental questions behind carbon pricing. What is the optimal level of global emissions? What degree of warming will be the tipping point for disaster climate scenarios? How will the climate respond to the emissions we have already produced? As described in Chapter 2, these questions are incredibly difficult to answer, and we may not know the real answers for decades to come.

Economists still have a lot to learn about carbon pricing. They too have some difficult questions to answer, like what is the "elbow" of the abatement cost curve for an economy? What is the true social cost of carbon? What is the optimal tax rate for a particular nation? What is the optimal cap? However, rather than focusing on these big, contested issues, narrowing research to other areas could produce more meaningful results and provide the basis of improved carbon pricing policies.

Developed countries have led the way with policy experiments. Policymakers considering carbon taxes or trading schemes can research case studies like I did and see what worked and what didn't. However, one of the first things I learned as an economist is that correlation does not imply causation, and for carbon pricing, I found little research isolating the effect of a policy on emissions reduction. For example, for the acid rain trading scheme, Schmalensee and Stavins (2012) argue that a huge chunk of the policy's success was due to the greater availability of low-sulfur coal as a result of railroad deregulation. The RGGI likewise struggled with its emissions cap because power companies were already switching from coal and petroleum to natural gas. More in-depth analyses for all existing carbon pricing programs are needed if policymakers want to make their policies more effective in the areas that count.

Similarly there is a large gap of literature on the environmental impact of carbon offset markets. Market analysts have no ways of measuring the emissions reduction of the past decade of voluntary market transactions. As more businesses and individuals explore this option to carbon pricing, research on its effectiveness is crucial.

Additionally, with the developing world poised to take the lead in emissions generation, further research is needed in modeling these economies with carbon pricing programs. Countries like Sweden and regions like British Columbia have decoupled their emissions from GDP; can developing countries, with their dependence on cheap energy sources, do the same? Can carbon pricing policies implemented in developed countries also succeed in the developing world?

One final area in need of research is the effect of economic shocks on carbon markets. The 2008 recession has been the only event to create such economic shocks on most carbon markets. More recently, however, Canada's economy dipped into a recession, and several European countries have been struggling as well. Though more data will be available with time, research into this area can provide important lessons for improving the price stability or emissions reductions of carbon markets.

7.6 Final Remarks

Almost two decades have passed since 2,500 economists came together to sign the Economists' Statement on Climate Change. Those two decades alone have seen a plethora of policy experiments and carbon pricing mechanisms. Unfortunately, with each passing year, global output of greenhouse gasses has increased, as have global temperatures. The struggle to reduce emissions and mitigate climate change is far from over. Economists and policymakers alike need to build on current progress to ensure that our planet is protected for generations to come.

REFERENCES

Andersson, M., & Lövin, I. (2015, May 22). Sweden: Decoupling GDP Growth from CO2 Emissions is Possible. Retrieved January 30, 2016, from http://blogs.worldbank.org/climatechange/sweden-decoupling-gdp-growth-co2-emissions-possible

Baye, R. (2011, June 21). Appeals Court Rules MontCo's Carbon Tax is a 'Punitive Fee' Retrieved March 01, 2016, from http://www.washingtonexaminer.com/appeals-court-rules-montcos-carbon-tax-is-a-punitive-fee/article/115382

Beaty, R., Lipsey, R., & Elgie, S. (2014, July 9). The Shocking Truth About B.C.'s Carbon Tax: It Works. Retrieved February 26, 2016, from http://www.theglobeandmail.com/opinion/the-insidious-truth-about-bcs-carbon-tax-it-works/article19512237/

Boden, T.A., Marland, G., and Andres, R.J. (2015). National CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2011, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, doi 10.3334/CDIAC/00001_V2015.

British Columbia Ministry of Finance. (2012). How the Carbon Tax Works. Retrieved February 26, 2016, from http://www.fin.gov.bc.ca/tbs/tp/climate/A4.htm

Burns, W. C. G. (2011). Carbon Tax. In D. Mulvaney & P. Robbins (Eds.), *The SAGE Reference Series on Green Society: Toward a Sustainable Future*. *Green Energy* (pp. 57-61). Thousand Oaks, CA: SAGE Reference. Retrieved from http://go.galegroup.com.ezaccess.libraries.psu.edu/ps/i.do?id=GALE%7CCX3021700029&sid=summon&v=2.1&u=psucic&it=r&p=GVRL&sw=w&asid=051c9754f0d26da5d75e9392785cf273

Cai, Y., Judd, K. L., & Lontzek, T. S. (2015). The Social Cost of Carbon with Economic and Climate Risks. Retrieved October 15, 2015, from http://arxiv.org/pdf/1504.06909v2.pdf

California Carbon Dashboard. (2016). Retrieved April 02, 2016, from http://calcarbondash.org/

Center for Climate and Energy Solutions. (2013, February). Options and Considerations for a Federal Carbon Tax. Retrieved March 01, 2016, from http://www.c2es.org/publications/options-considerations-federal-carbon-tax

Center for Climate and Energy Solutions. (n.d.). Regional Greenhouse Gas Initiative (RGGI). Retrieved April 04, 2016, from http://www.c2es.org/us-states-regions/regional-climate-initiatives/rggi

Center for Climate and Energy Solutions. (n.d.). Western Climate Initiative. Retrieved April 02, 2016, from http://www.c2es.org/us-states-regions/regional-climate-initiatives/western-climate-initiative

City of Boulder. (2015). Climate Action Tax. Retrieved March 01, 2016, from https://bouldercolorado.gov/climate/climate-action-plan-cap-tax#

Clark, D. (2011, September 16). A complete guide to carbon offsetting. Retrieved April 02, 2016, from http://www.theguardian.com/environment/2011/sep/16/carbon-offset-projects-carbon-emissions

Convery, F. (2012, September 21). Budget 2013 – Three Cheers For The Carbon Tax. Retrieved February 27, 2016, from http://www.publicpolicy.ie/budget-2013-three-cheers-for-the-carbon-tax/

Convery, F. J., L. Dunne and D. Joyce (2013), “Ireland's Carbon Tax and the Fiscal Crisis: Issues in Fiscal Adjustment, Environmental Effectiveness, Competitiveness, Leakage and Equity Implications”, OECD Environment Working Papers, No. 59, OECD Publishing. http://dx.doi.org/10.1787/5k3z11j3w0bw-en

Deegan, G. (2015, December 28). Michael McGrath: Review €385m Carbon Tax. Retrieved February 27, 2016, from http://www.irishexaminer.com/business/michael-mcgrath-review-385m-carbon-tax-373366.html

Economics Online. (n.d.). Negative Externalities. Retrieved March 31, 2016, from http://www.economicsonline.co.uk/Market_failures/Externalities.html

EPA (n.d.) Global Greenhouse Gas Emissions Data. Retrieved November 15, 2015, from http://www3.epa.gov/climatechange/ghgemissions/global.html

Environmental Protection Agency, Ireland. (2016). Environmental Indicators. Retrieved February 28, 2016, from http://www.epa.ie/irelandsenvironment/environmentalindicators/#.VtMI6ZMrK1s

European Commission. (2016, March 29). The EU Emissions Trading System (EU ETS). Retrieved April 02, 2016, from http://ec.europa.eu/clima/policies/ets/index_en.htm

European Environment Agency. (2012, November 29). EUA future prices 2005–2011. Retrieved April 02, 2016, from http://www.eea.europa.eu/data-and-maps/figures/eua-future-prices-200520132011

Eurostat. (2015, December). Greenhouse Gas Emission Statistics. Retrieved April 2, 2016, from http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics

Fouché, G. (2008, April 18). Sweden's Carbon-Tax Solution to Climate Change Puts it Top of the Green List. Retrieved February 10, 2016, from http://www.theguardian.com/environment/2008/apr/29/climatechange.carbonemissions

Foulis, P. (2014). Britist Columbia's Carbon Tax: The Evidence Mounts. Retrieved February 20, 2016, from http://www.economist.com/blogs/americasview/2014/07/british-columbias-carbon-tax

Fowlie, J., & Anderson, F. (2008, February 22). B.C. Introduces Carbon Tax. Retrieved February 27, 2016, from http://www.canada.com/vancouversun/story.html?id=ecea1487-507c-43ef-ab88-5a972898e0b7

FUND: Climate Framework for Uncertainty, Negotiation and Distribution. (n.d.). Retrieved November 9, 2015, from http://www.fund-model.org/home

Gadgil, A., Sosler, A., & Stein, D. (2013, March). Stove Solutions: Improving Health, Safety, and the Environment in Darfur with Fuel-Efficient Cookstoves. Retrieved April 03, 2016, from http://www.thesolutionsjournal.com/node/2371

Gollier, C. (2010). Ecological Discounting. *Journal of Economic Theory*, 145 (2), 812–829.

Gollier, C., & Weitzman, M. L. (2010). How should the distant future be discounted when discount rates are uncertain? *Economics Letters*,*107*(3), 350-353. doi:10.1016/j.econlet.2010.03.001

Hamrick, K. & Goldstein, A. (2015). *Ahead of the Curve: State of the Voluntary Carbon Markets 2015*. Washington, DC: Forest Trends.

Helbling, T. (2012, March 28). Externalities: Prices Do Not Capture All Costs. Retrieved March 31, 2016, from http://www.imf.org/external/pubs/ft/fandd/basics/external.htm

IPCC (2014): Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Retrieved December 28, 2015, from IPCC website: http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf

Johansson, B. (2000). Economic Instruments in Practice 1: Carbon Tax in Sweden. Retrieved February 15, 2016, from http://www.oecd.org/sti/inno/2108273.pdf

Kelley, K. (2006, November 18). City Approves ‘Carbon Tax’ in Effort to Reduce Gas Emissions. Retrieved March 01, 2016, from http://www.nytimes.com/2006/11/18/us/18carbon.html?ex=1321506000

Komanoff, C., & Gordon, M. (2015, December). British Columbia's Carbon Tax: By the Numbers. Retrieved February 25, 2016, from http://www.carbontax.org/wp-content/uploads/CTC_British_Columbia's_Carbon_Tax_By_The_Numbers.pdf

Lazo, A. (2014, September 28). How Cap-and-Trade Is Working in California. Retrieved April 02, 2016, from http://www.wsj.com/articles/how-cap-and-trade-is-working-in-california-1411937795

Legrand, M. (2013, April 24). The Regional Greenhouse Gas Initiative: Winners and Losers. *Columbia Journal of Environmental Law*. Retrieved April 2, 2016, from http://columbiaenvironmentallaw.org/articles/the-regional-greenhouse-gas-initiative-winners-and-losers

Markandya, A., Antimiani, A., Costantini, V., Martini, C., Palma, A., & Tommasino, M. C. (2015). Analyzing Trade-Offs in International Climate Policy Options: The Case of the Green Climate Fund. *World Development*, *74*93-107. doi:http://dx.doi.org.ezaccess.libraries.psu.edu/10.1016/j.worlddev.2015.04.013

McGowan, E. (2010, May 25). Maryland County Carbon Tax Law Could Set Example for Rest of Country. Retrieved March 01, 2016, from http://insideclimatenews.org/news/20100525/maryland-county-carbon-tax-law-could-set-example-rest-country

NASA. (2016, March 23). Global Climate Change: Vital Signs of the Planet. Retrieved March 27, 2016, from http://climate.nasa.gov/

Nordhaus, W. D. (2008). *A Question of Balance: Weighing the Options on Global Warming Policies*. Yale University Press. Retrieved from http://www.jstor.org.ezaccess.libraries.psu.edu/stable/j.ctt1npzkh

Nordhaus, W. D. (2011). *Estimates of the Social Cost of Carbon: Background and Results from the RICE-2011 model.* National Bureau of Economic Research.

Office of the Revenue Commissioners. (n.d.). Solid Fuel Carbon Tax. Retrieved February 28, 2016, from http://www.revenue.ie/en/tax/excise/solid-fuel-carbon-tax/index.html

Oskar, G. (2016). Lecture on Negative Externalities. Personal Collection of G. Oskar, The Pennsylvania State University, State College, PA.

Peters, M. (2010, July 12). Changes Choke Cap-and-Trade Market. Retrieved April 02, 2016, from http://www.wsj.com/articles/SB10001424052748704258604575360821005676554

Peterson, H. (2010, June 06). Billion-Dollar Power Company Sues Montgomery Over Carbon Tax. Retrieved March 02, 2016, from http://www.washingtonexaminer.com/billion-dollar-power-company-sues-montgomery-over-carbon-tax/article/13350

Pielke, R. A. (1998). Rethinking the Role of Adaptation in Climate Policy. *Global Environmental Change, 8*(2), 159-170. doi:10.1016/S0959-3780(98)00011-9

Ramseur, J. A. (2013). The Regional Greenhouse Gas Initiative: Lessons Learned and Issues for Policymakers (CRS Report No. R41836). Retrieved from Congressional Research Service. https://www.fas.org/sgp/crs/misc/R41836.pdf

Rausch, S., & Reilly, J. (2015). Carbon Taxes, Deficits, and Energy Policy Interactions. *National Tax Journal*, *68*(1), 157-177.

Ravindranath, N. H., & Sathaye, J. A. (2002). *Climate Change and Developing Countries*. Dordrecht: Springer Netherlands.

Redefining Progress. (n.d.). Economists' Statement on Climate Change. Retrieved March 20, 2016, from http://rprogress.org/publications/1997/econstatement.htm

Robson, A. (2014). Australia's Carbon Tax: An Economic Evaluation. *Economic Affairs*, *34*(1), 35-45. doi:10.1111/ecaf.12061

Rosenthal, E. (2009, June 12). Climate Change Treaty, to Go Beyond the Kyoto Protocol, Is Expected by the Year's End. Retrieved March 20, 2016, from http://www.nytimes.com/2009/06/13/science/earth/13climate.html

Rosenthal, E. (2012, December 27). Carbon Taxes Make Ireland Even Greener. Retrieved February 27, 2016, from http://www.nytimes.com/2012/12/28/science/earth/in-ireland-carbon-taxes-pay-off.html?_r=0

Schiermeier, Q. (2014). Anger as Australia Dumps Carbon Tax. *Nature*, *511*(7510), 392. Retrieved from http://search.proquest.com.ezaccess.libraries.psu.edu/docview/1549958239?accountid=13158

Schmalensee, R., & Stavins, R. (2012). The SO2 Allowance Trading System: The Ironic History of a Grand Policy Experiment. *Journal of Economic Perspectives*, *27*(1), 103-122. Retrieved March 15, 2016, from https://www.aeaweb.org/articles.php?doi=10.1257/jep.27.1.103.

Stern, N. H. (2006). *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press. Retrieved November 12, 2015, from http://webarchive.nationalarchives.gov.uk/20080910140413/http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

Swedish Institute. (2016). Sweden tackles climate change. Retrieved February 15, 2016, from https://sweden.se/nature/sweden-tackles-climate-change/

Taylor, L. (2014, December 19). Politics in 2014: The Coalition dished out slogans, and its sentence is clear | Lenore Taylor. Retrieved February 02, 2016, from http://www.theguardian.com/australia-news/2014/dec/19/politics-in-2014-the-coalition-dished-out-slogans-and-its-sentence-is-clear?CMP=share_btn_tw

The Economist. (2013, April 20). ETS, RIP? Retrieved April 02, 2016, from http://www.economist.com/news/finance-and-economics/21576388-failure-reform-europes-carbon-market-will-reverberate-round-world-ets

Tol, R. S. J. (2002a). Estimates of the Damage Costs of Climate Change. Part 1: Benchmark Estimates. *Environmental and Resource Economics, 21*(1), 47-73. doi:10.1023/A:1014500930521

Tol, R. S. J. (2002b). Estimates of the Damage Costs of Climate Change, Part II. Dynamic Estimates. *Environmental and Resource Economics*, *21*(2), 135-160. doi:10.1023/A:1014539414591

Tol, R. S. J. (2009). The Economic Effects of Climate Change. *Journal of Economic Perspectives*, 23(2): 29-51.

Tol, R. S. J. (2013). Targets for Global Climate Policy: An Overview. *Journal of Economic Dynamics and Control*, 37(5), 911-928. doi:10.1016/j.jedc.2013.01.001

United Kingdom Department of Energy & Climate Change. (2015, October 23). Participating in the EU ETS. Retrieved April 02, 2016, from https://www.gov.uk/guidance/participating-in-the-eu-ets

Van den Bergh, J. M., & Botzen, W. W. (2015). Monetary Valuation of the Social Cost of CO2 Emissions: A Critical Survey. *Ecological Economics*, 114, 33-46. doi:http://dx.doi.org.ezaccess.libraries.psu.edu/10.1016/j.ecolecon.2015.03.015

World Bank, World Development Indicators (2012). *CO2 emissions (metric tons per capita)* [Data file]. Retrieved from http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#

ACADEMIC VITA

Maria Cosma

EDUCATION

The Pennsylvania State University – University Park, PA
Bachelor of Science: Economics Fall 2012 – Spring 2016
Minors: French and Energy, Business & Finance

THESIS

Capping Carbon: A Survey of Carbon Pricing Mechanisms and their Efficacy
Thesis Supervisor: Ronald Gallant, Professor of Economics

HONORS AND ACTIVITIES

Schreyer Honors College
Honors Student Fall 2012 – Spring 2016

- Researched and wrote original thesis
- Maintained GPA requirement each semester
- Completed 32 credits of honors-level courses

Penn State Mock Trial Association
Judging Coordinator, Captain, Competitor Fall 2012 – Spring 2016

- Managed the student club on the Executive Board
- Networked with over 300 law students, law professors, attorneys, and judges to organize competitions
- Led teams and competed as both attorney and witness

WORK EXPERIENCE

Scipione & Kovalcin, P.C. - State College, PA
Supervisor: Joe Scipione
Paralegal 05/2013 – 08/2013

- Helped attorneys conduct oil and gas title searches
- Accompanied and assisted the attorneys in various hearings
- Drafted emails to clients and prepared a response to preliminary objections for a case

Penn State Bookstore – University Park, PA
Supervisor: Jen Guyer
Bookseller 05/2013 – Current

- Provided superior customer service and cashier services
- Organized displays and managed product inventory
- Opened and closed the store, counted revenues and ran revenue reports

Nittany Notes – University Park, PA
Supervisor: Eric Yoder
Note Taker 09/2014 – 05/2015

- Created lecture notes for multiple courses
- Designed practice problems and practice exams
- Provided notes to students with disabilities

Friends of the USA Pavilion– Milan, Italy
Supervisors: Gerald Giaquinta, Chiara Sanaivo, and Francesca Ripa
Student Ambassador 04/2015 – 07/2015

- Represented the United States at the World's Fair
- Interacted with over 20,000 international visitors per day
- Collaborated with the US Department of State
- Performed translation services in French

INTERNATIONAL EDUCATION

Centre de linguistique appliquée – Besançon, Franche-Comté, France
Study Abroad: French Summer 2014

- Received Certificate for B2 level of French proficiency
- Completed 7 credits for French minor

GRANTS RECEIVED

Schreyer Abassador Travel Grant

- Summer 2014 for study abroad
- Summer 2015 for internship abroad

Schneider Electric National Merit Scholarship

- Every fall and spring semester
- Full-time credit requirement

AWARDS

Dean's List: Fall 2012, Spring 2013, Spring 2014, Fall 2014, Spring 2015, Fall 2015
Outstanding Attorney at the Elon University Mock Trial Invitational: October 2013
All-Regional Attorney at the State College Regional Tournament: February 2016

LANGUAGE PROFICIENCY

Bilingual proficiency in English and Romanian
Professional working proficiency in French
Elementary proficiency in Spanish and Italian