Regulating Greenhouse Gases in the United States: Carbon Tax or Cap-and-Trade

Thesis

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Abstract

Climate change, brought on by an accumulation of greenhouse gases in the atmosphere, will present a variety of social, economic, environmental, and political issues; surely, climate mitigation will be crucial to avoid serious climate change effects. In the United States, two market-based policies at the center of the discussion on how to regulate greenhouse gases- carbon tax and cap-and-trade. Although the policies are identical in theory, there are substantive differences that arise when they are actually implemented. This study analyses four factors- government efficiency, price volatility, uncertainty, and carbon leakage. The results indicate that a carbon tax may be more favorable than cap-and-trade, especially in terms of cost-efficiency and a lack of price volatility. Although there are no quantitative comparisons of the two programs about their ability to reduce carbon leakage, economic analysis suggests that the stronger incentive from a carbon tax may increase carbon leakage compared to cap-and-trade.

Dedication

In loving memory of Valerie Ann Gaylord, a passionate, hardworking, self-made woman, first generation college student, and a wonderful mom. I love you and I miss you!

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I would like to express my deep and sincere gratitude to my thesis committee, including my committee chair, Christopher Papouchis, along with James Goldstene, and Dr. Lee Simpson. Thank you for the opportunity to do interesting research and for your invaluable guidance and support.

I am extremely grateful to my family and friends, especially my dad and brother. Your love and support mean the world to me and inspires me to work hard and dream bigger every day. To my friends, thank you for believing in me and for encouraging me to live life to the fullest. I would not be half the person I am without all of you. I love each of you dearly!

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Chapter 1: Introduction

Climate change is one of the most complex social, political, economic, and environmental issues the world has yet to face. Scientists have well established that the combustion of fossil fuels releases carbon dioxide and other gases into the atmosphere which have a warming effect on the planet. According to the Intergovernmental Panel on Climate Change (2018), Earth's lower atmosphere has warmed by 1.0 degrees Celsius from pre-industrial levels, with a likely range of 0.8 degrees Celsius to 1.2 degrees Celsius. They predict with high confidence that global warming will reach 1.5 to 2 degrees Celsius if it continues to increase at the current rate. This physiological change in Earth's atmospheric composition, called 'climate change', not only results in a long-term shift in temperature patterns; it also contributes to sea level rise, and changes in precipitation patterns and severe storms that will displace and harm millions of people, leading to a whole host of economic and social problems that policymakers will be forced to confront (United States Global Research Program, 2018). Hsiang *et al.* (2017) estimated that climate change costs about 1.2 percent of the gross domestic product of the United States economy per additional Celsius degree change. In particular, they found that national agricultural yields decline by about 9.1 percent per degree Celsius; annual mortality rates rise by about 5.4 deaths per 100,000 per degrees Celsius; electricity demand rises by about 5.3 percent per degrees Celsius change; total hours of labor supplied declines by about .11 percent per degrees Celsius for low-risk workers who are not exposed to outdoor temperatures, and by .53 percent per degree Celsius for high-risk workers who are exposed to the elements; and violent crime rates also increased by .88 percent per degrees Celsius. A decline in human health associated with climate change and fossil fuel use is another significant cost of climate change. The Natural Resources Defense Council (2021) estimated that additional health care costs as a result of climate change amounted to $820 billion per year- costing each American roughly $2,500 in extra medical bills and contributing 107,000 premature deaths per year.

Undoubtedly, the effects of climate change will be experienced throughout the world; however, the same effects will not be experienced everywhere and to the same degree. According to the *Fourth National Climate Assessment*,

> risks posed by climate variability and change vary by region and sector and by the vulnerability of people experiencing impacts… including low-income communities, some communities of color, children, and the elderly... Climate change threatens to exacerbate existing social and economic inequalities that result in higher exposure and sensitivity to extreme weather and climate-related events and other changes (2018).

Further, there is a growing body of research which suggests that climate change impacts could have a greater cost than was previously estimated. There is evidence that when a region experiences multiple climate change effects concurrently, that the overall cost of addressing these issues has the potential to be much greater than the sum of the costs associated with each event individually

(Smith & Katz, 2013). When it was discovered that the release of carbon dioxide into the atmosphere was being accelerated in the Artic (Steffen *et al.*, 2018), it was estimated that this physiological feedback would increase the cost of climate change by $24.8 trillion with 1.5 degrees Celsius of warming, $33.8 trillion with two degrees Celsius of warming, and $66.9 trillion under a business-as-usual scenario (Yumashev *et al.*, 2019). Clearly, the cost of climate change is largely unknown, but recent studies indicate that climate costs may be far greater than they were previously believed to be.

To address climate change, the Intergovernmental Panel on Climate Change, an amalgamation of climate and social scientists from around the world, warn that "far-reaching, multilevel and cross-sectoral" policies will be necessary in order to avoid the most severe climate change impacts (2018). In the United States, which is the single greatest contributor to climate change (Ritchie, 2019; United States Environmental Protection Agency, 2021), there is a legal precedent for regulating harmful atmospheric gases; the Clean Air Act authorizes the Environmental Protection Agency to regulate the emission of greenhouse gases because they are found to endanger public health and welfare (42 U.S.C. § 7411; 42 U.S.C. § 7415). The United States is also bound by international agreements to reduce their carbon dioxide emissions. At the most recent United Nations Framework Convention on Climate Change, the United States pledged to reduce carbon dioxide emissions by 45 percent by 2030 along with 100 other countries (Council on Foreign Relations, 2021).

The two most prominent market-based policies at the forefront of the discussion on how to regulate greenhouse gases emissions in the United States are carbon tax and cap-and-trade. Both programs work by creating a financial incentive for firms to reduce greenhouse gas emissions and for consumers to shift towards less carbon-intensive goods and services by putting a price on carbon emissions (Goulder & Shein, 2013). A carbon tax creates a financial incentive by putting a price on carbon emission directly. Slightly more complex, a cap-and-trade program sets an emission limit (‘cap’) that constrain overall emissions, partitions the cap into emission allowances, and allow firms to buy or sell these allowances to meet the emission requirements of the program. With cap-and-trade, firms are incentivized to reduce emissions because they must buy allowances for the right to emit a certain amount of carbon dioxide emissions, which will increase their production costs (Congressional Research Service, 2021).

Carbon tax and cap-and-trade programs are theoretically the same because either policy can be modified to achieve similar results (Weitzman, 1974), but substantive differences arise when the policies are actually implemented (Goulder & Shein, 2013; Stavins, 2019). The goal of this study is to evaluate some of the most contentious social, economic, and political criticisms of carbon pricing policies to see which policy would be best fit to reduce greenhouse gases in the United States. Policy amendments and real-life examples of actual carbon tax and cap-and-trade programs are explored to illustrate key differences and are considered in the overall comparison of the efficacy of the two programs.

Chapter 2: Methods Explained

To examine how the carbon tax and cap-and-trade differ, and which program is ultimately more favorable for regulating carbon dioxide emissions in the United States, the structure and similarities between the two policies were established first, along with a descriptions of real-life programs- both nationally within the United States and internationally. The social, economic, and political differences between the two policies were explored next; this analysis focuses on how the policies differ in their ability to achieve government efficiency, control emission price volatility, address uncertainty, and avoid carbon emission leakage. This study also highlights adjustments that can be made to either policy to achieve desirable results. Real-life carbon pricing policies are also used to evaluate the efficacy of the carbon tax and cap-and-trade to regulate greenhouse gas emissions in the country.

A thorough literature review was conducted to compile relevant peer-reviewed journal articles on the structure, similarities, and differences between the carbon tax and cap-and-trade programs. Additional information was supplemented by a variety of national government sources, including the United States Environmental Protection Agency, Congressional Research Service, and Global Change Program, and international government sources from British Columbia, the European Union, and Switzerland to analyze real-life examples of the two carbon pricing policies. News reports were also used sparingly to describe instances when certain outcomes, particularly emission price volatility and carbon leakage, occurred as a result of actual carbon pricing policies.

Chapter 3: How Carbon Pricing Policies Work

A carbon tax and cap-and-trade program work by creating a financial incentive for firms to reduce their greenhouse gas emissions per unit of output (Goulder & Shein, 2013). From a consumer perspective, these policies encourage shifts to less carbon-intensive goods and services because they cause the price of carbon-intensive goods to increase relative to other products. Carbon pricing policies increase the production cost of carbon-intensive goods and services, so producers will also reduce emissions if it allows them to reduce their costs. This shift in consumer and producer activity implies lower output by carbon-intensive entities and further emission reductions. The main difference between these policies is that a carbon tax controls the price of carbon dioxide emissions, while a carbon trading scheme controls the quantity of emissions that are released (Pizer, 1999). The structure of the cap-and-trade and carbon tax are discussed in the following sections, along with national and international examples.

3.1 Cap-and-Trade Program

A cap-and-trade program works by setting an upper limit, ‘cap’, on the amount of overall allowable emissions, while leaving it up to individual firms to decide to either reduce on-site emissions or purchase and trade emission credits (Congressional Research Service, 2021). The ‘cap’ is partitioned into emission allowances, or permits, that typically equal the right to emit one metric ton of carbon dioxide equivalent emissions. Policymakers choose to either distribute allowances to emitting sources for free, usually based on some metric such as the previous year’s emissions; or to sell allowances at periodic auctions, thus generating a new government revenue stream, or some combination of these two strategies (Center for Climate and Energy Solutions, 2009). At the end of a compliance period under a cap-and-trade program, covered entities will submit emission allowances to the implementing agency for the tons of carbon dioxide equivalent emitted during that period. There are typically penalties for firms who fail to submit enough allowances at the end of each compliance period. One distinguishing feature of the program is that firms who reduce their emissions below their respective 'cap' can sell their unused permits in an emissions trading market (Goulder & Shein, 2013).

The price of carbon is set indirectly under a cap-and-trade program, because the regulatory authority sets a 'cap' of allowable emissions, splits the 'cap' into allowances, and the price of carbon is set through the market of those allowances. Thus, a cap-and-trade program creates a financial incentive for covered entities to reduce emissions because entities could sell their unused emissions allowances to firms who face higher costs to reduce emissions, reduce the amount of emission allowances they need to purchase, or bank emission allowances to be used at a later date (Pizer, 1999).

3.1.1 Examples of Cap-and-Trade Programs

With the 1990 Clean Air Act Amendments, the first national cap-and-trade program in the United States was enacted to reduce sulfur dioxide emissions to reduce acid rain. This program is commended for being "nearly perfect" in that it ultimately achieved total compliance with little to no litigation at a relatively low cost (Burtaw & Szambelan, 2009). One factor that is indicative of a successful trading scheme is a low allowance price, because it means that the price to reduce emissions, which is relative to the price of allowances, is much lower than previously expected. In 2021, the allowance prices under the sulfur dioxide program range from $.01 to $.5- which is about four times lower than regulatory agencies predicted when the policy was first adapted (United States Environmental Protection Agency, 1991).

The success of cap-and-trade in reducing emissions from other pollutants at a relatively low cost inspired policymakers to employ the same strategy for greenhouse gases within the first few years of the twenty-first century, most notably with the Regional Greenhouse Gas Initiative in the United States and the European Union’s Emission Trading Scheme.

The first mandatory cap-and-trade program in the United States to reduce carbon dioxide emissions in the power sector, the Regional Greenhouse Gas Initiative began in 2005. Power plants that produce over 25 megawatts in Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont are all covered under the program. By 2020, this cap-and-trade program is expected to reduce carbon dioxide emissions by 45 percent in the region’s power sector compared to 2005 levels (Center for Climate and Energy Solutions, 2009). During the first implementation stage from 2005 to 2008, the program distributed emission allowances for free to covered entities. This led to an oversupply of allowances in the market, which caused the relative price to emit to become extremely low; diminishing the incentive to reduce emissions. Since the Initiative’s ultimate purpose was to reduce carbon dioxide emissions, all subsequent phases of the program have distributed emission allowances at a competitive auction to avoid the oversupply problem (Regional Greenhouse Gas Initiative, 2021).

The European Union also implemented a regional cap-and-trade program to reduce carbon dioxide emissions, called the Emissions Trading System. The first trial period of the program began in 2003 before the official first phase started in 2008. During the trial period, almost all allowances were distributed for free; similar to the Regional Greenhouse Gas Initiative, this led to an oversupply of allowances, triggering allowances prices to drop significantly until they eventually equaled zero dollars in 2007 (European Commission, 2021). In order to avoid the oversupply problem, the European Union's Emission Trading System now distributes a significant portion of allowances through competitive auction. In 2013, 40 percent of allowances were sold at auction, while other carbon-intensive industrial firms and firms that may exacerbate carbon leakage- whereby firms move their production, and by default their emissions, to a region with less stringent climate policies- still receive allowances through free allocation. Despite the fact that more allowances are distributed at auction, the carbon emission allowance price is still relatively low under this program because excess allowances from previous years are still saturating the market. The European Union's Emission Trading System most recent goal to reduce carbon dioxide emissions by 20 percent below 1990 levels by 2020 was achieved almost seven years early, exempting 2017 (European Commission, 2021). By 2020, the 27 European Union member states had reduced their net emissions by 34 percent below 1990 levels- far exceeding their original target of 20 percent. Due to its recent success, the member states agreed to reduce their emissions by 43 percent below 1990 levels by 2030. As such, the number of available allowances will decrease by 2.2

percent annually beginning in 2021, opposed to the 1.74 annual decrease implemented in the previous period (European Commission, 2021).

3.2 Carbon Tax

Unlike a cap-and-trade system, a carbon tax incentivizes emissions reductions by setting a rate for carbon dioxide equivalent emissions (Goulder & Shein, 2013). Policymakers have a great deal of choice in how they choose to set a carbon tax; they can choose a rate to achieve a specific emissions target and decide if the tax increases over time, and by how much (Center for Climate and Energy Solutions, 2009). The tax rate can also be set to eliminate the social costs of greenhouse gas emissions; as the social costs are minimized the relative tax rate would decline (Environmental Protection Agency, 1991). Similar to the cap-and-trade program, a carbon tax also creates a new government revenue stream. The amount of government revenue generated by a carbon tax depends on the tax rate and the amount of revenue that is redistributed to the public through subsidies or tax credits (Environmental Protection Agency, 1991), which can take up a considerable portion of tax revenues compared to cap-and-trade (Carl & Fedor, 2016).

3.2.1 Examples of Carbon Taxes

North America's first carbon tax was enacted in 2008 in British Columbia, Canada. It covers 70 percent of greenhouse gas emission in the province, including the purchase and use of fossil fuels. In 2021, the rate of the carbon tax rose from 40 to 45 Canadian dollars (equivalent to about 32 to 36 United States dollars) per ton of carbon dioxide equivalent emissions, and it will rise again to 50 Canadian dollars per ton of carbon dioxide the next year. The revenues of the British Columbia carbon tax are used to provide carbon tax relief, maintain industry competitiveness, and incentivize less carbon-intensive technologies. For low- and middle-income families, the province provides rebates of $174 per adult and $51 per child up to four times a year (British Columbia, 2021). The first of its kind in North America, the British Columbia carbon tax has failed to meaningfully reduce carbon dioxide emissions, according to recent studies. The Canadian Research Institute found that the British Columbia carbon tax failed because the tax rate was too low (Millington *et al.*, 2020). They concluded that the rate must be increased from 40 Canadian dollars to about 50 Canadian dollars per ton of carbon dioxide equivalent emissions in 2020, eventually reaching anywhere from about 62 Canadian dollars to 126 Canadian dollars per ton of emissions in 2030, for any meaningful emissions reductions to occur (Carbon Pricing Leadership Coalition, 2017).

Unlike British Columbia's carbon tax, whose low rate and high rebates contributed to substandard emission reductions, the Switzerland Confederation's carbon tax is one the highest in the world and has achieved significant carbon dioxide reductions in the region (Millington *et al.*, 2020). Anyone who purchases fossil fuels must pay the tax, although carbon-intensive firms may be exempt from the program if they make a commitment with the Switzerland Confederation to reduce greenhouse gas emissions. Like the carbon tax in Canada, Switzerland's Carbon Dioxide Levy began in 2008 with a carbon tax rate equivalent to about 13 United States dollars (Federal Office for the Environment, 2018). Over the next decade, the tax rate increased four times and is currently 103.91 United States- one of the highest carbon tax rate in the world (Asen, 2021). The relatively high carbon tax rate effectively incentivized low-carbon or carbon neutral investment, reducing Switzerland's overall emissions by 4.3 to 9.6 from 2005 to 2015. Switzerland also redistributes the funds from the carbon tax to citizens and firms; the Federal Office for the Environment (2018) reports that two thirds of the funds from the tax program are returned to the public and the other one third of the money funds an energy-efficiency program in the region.

Sweden currently has the highest carbon tax rate in the world, equivalent to $132.10 per metric ton of carbon dioxide emissions, which it applies to fossil fuels used for heating and motor vehicles (Asen, 2021). Established in 1991, the tax rate began at about $28 per ton of emissions and has incrementally increased over time. The policy has done much to advance Sweden's goal to reduce greenhouse gas emissions; since 1990, the carbon tax has decreased emissions by over 30 percent. In 2020 alone, Sweden reduced its overall emissions by four percent compared to the year prior (Jonsson *et al.*, 2020). In addition, Sweden's per capita emission rate, 3.54 metric tons of carbon dioxide emissions per capita per annum, is about half that of the European Union average (World Bank, 2018).

3.3 How Carbon Pricing Policies Incentivize Emission Reductions

Although a cap-and-trade and carbon tax have different mechanisms for regulating greenhouse gas emissions, the programs are similar in that they create a financial incentive to reduce carbon dioxide emissions by effectively putting a price on carbon (Figure 1). Cap-and-trade does so indirectly, through the sale of permits which give firms the right to emit a certain amount of carbon dioxide. Unlike the cap-and-trade program, the carbon tax directly establishes the cost of emissions by setting the tax rate.

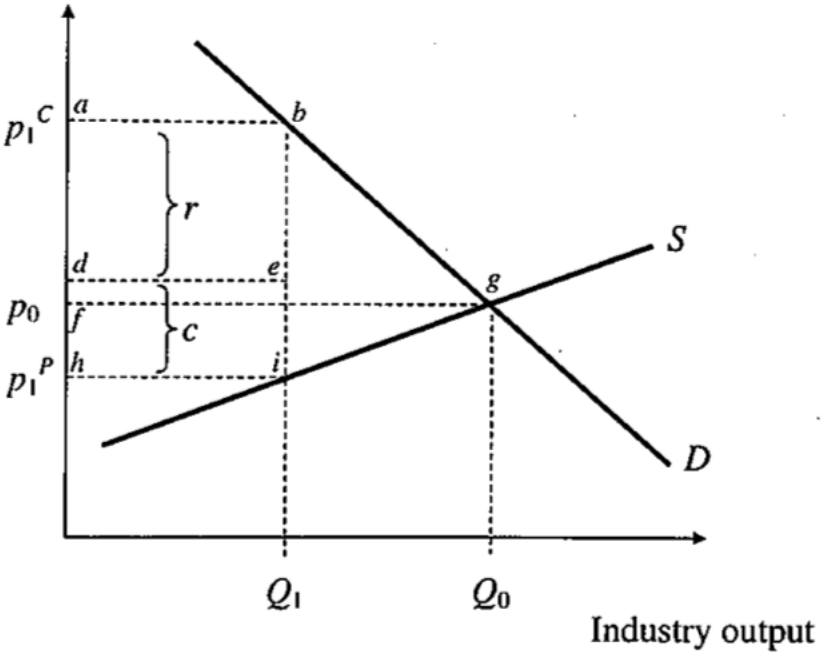

Figure 1 Cap-and-Trade Program and Carbon Tax Impact on Social Surplus (Goulder & Shein, 2013)

Under both policy mechanisms, there is an opportunity cost for each additional unit of emissions that a firm decides to emit- derived from the fact that the money firms pay to emit could be spent elsewhere, such as marketing or business acquisition. If firms are cost-minimizing, a basic economic assumption, then they will reduce emissions up until the point at which the marginal cost of mitigating greenhouse gas emissions equals the price of carbon, set by either a carbon tax or cap-and-trade program. The impacts of these policies are depicted graphically in Figure 1 (above), where the vertical axis represents price and the horizontal axis is industry output or quantity. In the absence of either carbon pricing policy, the output price and quantity are P_o and Q_o, respectively. Under a cap-and-trade program with a competitive auction of emission permits (or a carbon tax), producers incur a cost, c, from induced as a direct result of either carbon pricing policy. The cost of the remaining emissions, which is equivalent to the allowance price times emissions per unit of output, is represented as r. The resulting consumer and producer prices are $p^C{}_1$ and $p^P{}_1$, and the industry output decreases to Q_1 (Goulder & Shein, 2013).

The impact of a cap-and-trade program on firms and consumers depends on how the emission allowances are distributed, either by competitive auction or free allocation (Environmental Protection Agency, 1991). With an auction, no rents are distributed to either party, meaning there are no excess payments being made through the program. The loss of producer surplus is represented by the trapezoid *fgih* as a result of reduced output caused by the cost, c, of induced compliance. Trapezoid *abgf* represents the loss of consumer surplus from the cap-and-trade policy with a competitive auction of allowances, resulting from higher production costs that will inevitably affect the price that consumers pay for electricity. A competitive auction would also generate government revenue which is illustrated in the graph as *abed*. If policymakers choose to distribute allowances for free, they effectively forgo their government revenue and square *abed* is transformed into rents for producers. Although government revenue is minimized, freely allocating emission allowances allows policymakers to compensate or subsidize firms who have a high marginal cost to reduce emissions (Goulder & Shein, 2013).

A carbon tax works in similar ways. Assuming a tax rate equal to the market price of allowances, the loss of producer surplus, *fgih*, and consumer surplus, *abgf*, are the same as with a cap-and-trade program. A carbon tax can also function in a similar manner to cap-and-trade with freely allocated allowances by granting tradable tax exemptions for firms that emit below a certain threshold. In other words, the tax would only apply to firms that emit a certain amount of emissions. Similar to the cap-and-trade system with free allowances, a carbon tax with a tax exemption market would eliminate government revenue and convert it into producer surplus, represented graphically as square *abed* (Goulder & Shein, 2013).

Thus, the carbon tax and cap-and-trade policies have no inherent differences in their impact on firms, consumers, and government revenue. The policies have vastly different structures, but each policy can theoretically be tailored or adjusted to create desirable outcomes. However, differences arise when these carbon pricing policies are actually implemented; including their ability to achieve government efficiency, control allowance price volatility, address uncertainty, and avoid carbon leakage.

Chapter 4: Differences Between Carbon Tax and Cap-and-Trade System

4.1 Government Efficiency

One important factor in deciding between a carbon tax and cap-and-trade program is their ability to achieve government efficiency, by reducing administrative costs or increasing cost-efficiency.

4.1.1 Reduce Administrative Costs

The cost of administering a carbon pricing policy, either a tax or a trading scheme, depends on the number of entities that must be evaluated and monitored and the overall design of the implemented system. When administering a carbon tax or cap-and-trade program, policymakers must choose whether to apply the rule to "upstream" firms who provide the inputs for the production of goods and services, or "downstream" firms responsible for the production, distribution, and marketing of products. Generally speaking, there are far fewer "upstream" entities than "downstream" ones, so policymakers will typically choose to administer the policy to "upstream" firms or a subsect of firms farther down the supply chain. Since a carbon tax or cap-and-trade program can be administered "upstream" or "downstream", Goulder and Shein (2013) contend that there is no inherent difference in the overall cost to administer either policy under this logic.

The point of implementation is not the only indicator of overall administrative costs for carbon tax and cap-and-trade programs; the relative complexity of the programs also affects how much they cost to implement. One economic assumption of carbon pricing policies, especially of cap-and-trade, is that cost to emit should be equalized over all covered entities to allow for the cheapest abatement measures to be selected. In reality most of the carbon pricing policies to date include some form of tax differentiation among industrial, commercial, and residential emitters. Böhringer and Rutherford (2002) suggest that differentiated standards may be employed to correct preexisting distortions in the tax rate, prevent firms from leaving the regulated region, and other market factors. According to their analysis, this policy alteration is a “very costly way to meet distributional objectives” compared to other methods, such as redistributing program funds in the form of tax credits and subsidies. Although there is little evidence about the actual cost of administering a differentiated carbon pricing policy, differentiation is estimated to increase the implementation cost of cap-and-trade programs by eight percent compared to an equalized rate (Stavins, 1995). Some studies even conclude that all cap-and-trade program, with or without differentiated standards, are inadvisable as a national policy because of their high administrative costs (Kuik & Mulder, 2004).

Still, the overall cost to administer a cap-and-trade program compared to a carbon tax may be higher because of their vastly different implementation strategies. Government administrators of either policy is responsible for monitoring and recording emissions for all covered entities, but only a cap-and-trade program requires the administrator to manage an emission allowance market by tracking allowance prices and transactions. This additional responsibility implies a higher overall administrative cost for a cap-and-trade program compared to a carbon tax (Goulder & Shein, 2013).

4.1.2 Cost-Efficiency

When choosing between a carbon tax and cap-and-trade program, some policymakers may forgo a policy that implies lower administrative costs for one that offers higher overall cost-efficiency, choosing the one that increases emissions at a lower cost. Zhou *et al.* (2021) quantitatively compare the cost-effectiveness of a cap-and-trade program versus a carbon tax. Their analysis concludes that both policies have a similar influence on gross domestic product since their prices would theoretically be tied to the same emission reduction goals. The carbon tax program had a higher gross social production value-based influence than the trading program because it affected all industries in the economy, whereas cap-and-trade only affects certain sectors. These results imply that a carbon tax is more cost-efficient than cap-and-trade. Other studies also find significant cost-efficiency issues with cap-and-trade programs. In their analysis of United States carbon pricing policies, Aldy and Armitage find that cap-and-trade's inherent uncertainty surrounding the future price of emission allowances can increase the cost of "irreversible" pollution abatement measures by over 20 percent compared to a carbon tax (2020). Wittneben (2009) also found that cap-and-trade under the European Union's Emission Trading System was less cost-efficient than a carbon tax.

4.2 Volatility of Emission Prices

Volatility refers to price fluctuations of a good or even a market; the bigger and more frequent the price swings, the more volatile the good or market is (Forbes, 2021). Volatility is measured by the standard deviation of price changes- that is, how much the daily price reflects the average price. When volatility intensifies in the context of a carbon tax or cap-and-trade program, firms may choose to delay investment in low-carbon or carbon neutral technologies and other decisions or increase their risk management activities. Another common issue with price volatility is that it may lead to premature investment in emission-minimizing technologies or change in production that is less cost-efficient (Aldy & Armitage, 2020). This undermines the purpose of implementing a carbon pricing policy- to deliver a low-cost option for regulating greenhouse gases. Because of the behavior change it can inspire, policymakers generally try to avoid enacting legislation that exacerbates price volatility.

Therefore, emissions price volatility is not a problem with a carbon tax because the emission price is the tax rate. Since the rate is imposed by policymakers, it can be reasonably assumed that the tax rate will increase at a relatively steady rate rather than through abrupt changes (Goulder & Shein, 2013). Conversely, price volatility is an issue under a cap-and-trade system where the emission price is set through the allowance price. This is because the supply of emission allowances is perfectly inelastic, which means that shifts in demand can cause significant price changes- and extreme or irregular demand shifts can lead to price volatility. Nordhaus (2007) notes that demand for allowances is also highly inelastic in the short run, leading to an even greater potential for high price volatility in the first few years the program is implemented.

There are plenty examples of price volatility under cap-and-trade programs. According to a study by Ellerman and Joskow (2008), regulated reductions of nitrous oxide emissions under the Regional Clean Air Incentives Market program resulted in price volatility during the 2000 energy supply crisis. Low supply incentivized firms to bring older generators back online in the Los Angeles region. This led to a significant increase in the demand for nitrous oxide emission allowances. As a consequence, allowance prices rose from about $400 per ton to an average of over $400,000 per ton in 2000 (Ellerman and Joskow, 2008).

Within the first few months of the first phase of the European Union Emission Trading Scheme there was also significant price volatility because allowances were distributed too generously to firms, meaning there was a weak incentive to reduce emissions. This caused the price of allowances to drop significantly. There was more price volatility later in the first phase. For example, the price of an allowance was 31.65 euros per ton of emissions on April 19, 2006 compared to 11.95 euros on May 3, 2006 (Goulder & Shein, 2013). By the end of the first phase in 2007, the emission allowance price was equivalent to zero dollars (European Commission, 2021).

One way to reduce price volatility within the cap-and-trade program is to allow for intertemporal banking and borrowing of allowances. This caveat allows firms to save emission credits they do not use for a later period and allows them to use allowances that they banked for future periods. Intertemporal banking makes the price of allowances more elastic and can thereby damp price volatility. For example, nearly unlimited banking under the sulfur dioxide trading scheme is believed to have reduced emissions faster than without banking (Ellerman and Buchner, 2008). Conversely, a lack of intertemporal banking is pegged for the price volatility of nitrous oxide emission allowances under the Regional Clean Air Incentives Market program (Stavins, 2007; Ellerman *et al.*, 2003) as well as for the volatility during the first phase of the European

Union Emission Trading Scheme (Market Advisory Committee to the California Air Resources Board, 2007).

Another strategy to reduce price volatility under a carbon trading program is to incorporate an emission allowance price floor or ceiling, or both (Congressional Budget Office, 2009). Price ceiling and floors guarantee that emission credit prices stay within a certain range based on the marginal abatement cost of covered entities. Robert and Spence found that a hybrid option, whereby both a price floor and ceiling are instituted, is the best way to minimize price volatility (1976). With such a caveat, covered firms would know with certainty that the price to emit would not exceed a certain minimum and maximum limit. If either a price floor or price ceiling are implemented independently, firms could only be sure of one limit, a minimum or maximum; this uncertainty could affect a firm's incentive to reduce emissions. Still, Wood and Jotzo (2011) conclude that just a price floor can be a sufficient indicator for firms to make cost-efficient carbon abatement choices.

4.3 Address Cost Uncertainty or Emission Uncertainty

The design of the cap-and-trade and carbon tax programs guarantee certain outcomes, while leaving other factors unclear. A cap-and-trade program stipulates emission levels, but it does not guarantee a certain price per ton to emit carbon dioxide emissions. The latter of the two policies, the carbon tax, guarantees a certain price of carbon, but the level of emission reduction under this policy can vary.

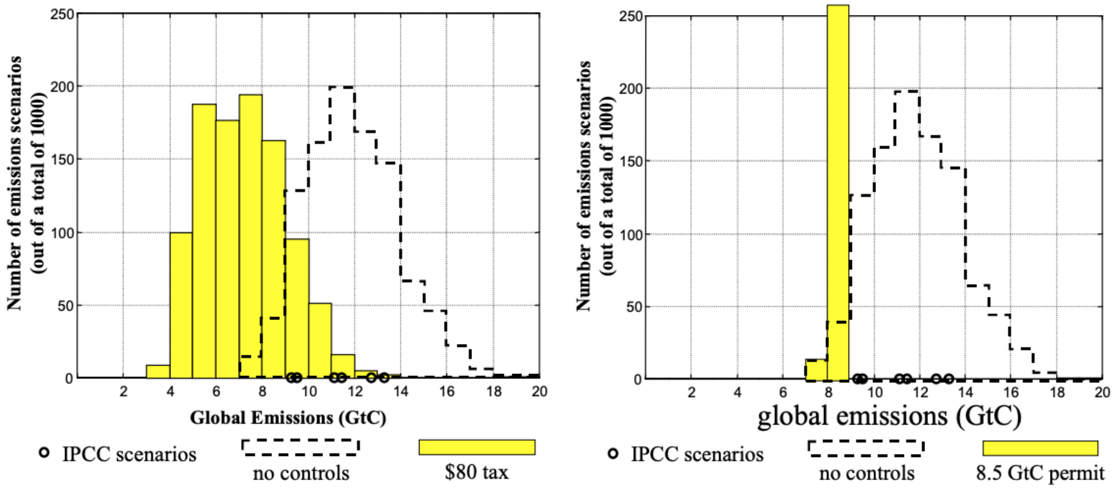

Figure 2 Effect of Carbon Pricing Policies on Price and Emissions (Pizer, 1999)

Pizer (1999) models the difference arising from the two different policies: a carbon tax or $80/ton or a quantity target of 8.5 gigatons of carbon dioxide equivalent gases. Figure 2 shows the distribution of outcomes arising from the two policies in 1,000 potential scenarios. The left panel indicates that the carbon tax reduced carbon dioxide levels below 8.5 gigatons 75 percent of the time, and the carbon tax even has the potential to achieve emissions as low as 3 gigatons of carbon- significantly more than the cap-and-trade program achieved in the stimulation. Still, the carbon tax does not guarantee that a certain level of emission reductions will be reached. Cap-and-trade, indicated in the right panel of Figure 2, guarantees that the emission target is met 100 percent of the time. Some emission scenarios with no controls are high and others are low; the higher the emissions level, the greater the cost associated with the cap, and vice versa. This means that the cost associated with a quantity control, like a cap-and-trade program, could be high or low, depending on future reduction costs and the future level of unregulated emissions. This implies that the emission price associated with the cap could fluctuate more than the carbon tax. On the other hand, the carbon fee's financial incentive to reduce carbon emissions is consistent regardless of the level of uncontrolled emissions. While it is possible that a carbon tax policy could result in emissions much greater than the target, there is no guarantee of any emission outcome. It follows that neither policy outweighs the other in terms of uncertainty.

4.4 Avoid Carbon Leakage

An important point of consideration when deciding between a tax or trading program to regulate carbon dioxide emissions, carbon leakage refers to the phenomenon whereby businesses in regions with strict climate policies will move to other states, countries, or regions where the rules on carbon emissions are more relaxed or even nonexistent. Carbon leakage can create many environmental and economic issues. In particular, the phenomenon increases overall emissions because these firms simply moved their operations to a region where the emissions of carbon dioxide are unregulated. The main economic issue with carbon leakage is that it can weaken a country's international competitiveness. When firms in affected markets outsource their production to places with no carbon policies in place, the price to produce goods and services decreases. Theoretically this enables firms in unregulated regions to sell goods and services at lower prices than products in regulated areas. Since consumers will largely choose goods and services that are cheaper, carbon leakage, the exodus of carbon-intensive firms to other regions, threatens the competitiveness of products from regulated countries in the world market.

There are numerous examples of leakage occurring in countries or regions with stringent carbon pricing policies, especially when they are trade intensive with other countries. In Canada, which administers a carbon tax at a rate of $32 per metric ton of carbon dioxide emitted, carbon leakage seriously offsets domestic emission reductions. Leakage containment measures have been instituted to minimize the mass exodus of regulated firms; still, leakage ranged from 13 percent, under a scenario with high gas prices and border adjustments, to 76 percent, with low gas prices and no leakage measures (Bistline *et al.*, 2020). The main takeaway of this study is that regardless of whether measures are taken to avoid carbon leakage under a carbon tax, the phenomenon still persists, even under best-case scenarios. Further, leakage containment measures are effective in reducing net emissions and leakage rates, but this policy caveat can also increase the cost to administer the policy and gross national emissions.

Leakage is not specific to carbon taxes; it can occur as a result of a cap-and-trade program as well. Beginning in 2013, the European Union Emission Trading Scheme began addressing carbon leakage by providing higher number of free allowances to firms at high risk for carbon leakage. The trading scheme creates carbon leakage lists based on certain criteria that they believe puts a firm at a significant risk of carbon leakage: if the production costs of a sector increase by at least five percent in proportion to their gross value or if the sector's trade intensity with non-European Union countries is above 10 percent (European Commission, 2019). Studies find similar issues with the Regional Greenhouse Gas Initiative in the United States. Yan (2021) found that the cap-and-trade program had reduced coal and natural gas consumption by 73 percent and 30 percent, respectively in regulated states. However, the consumption in nearby states without emission regulations increased; natural gas consumption increased by 237 percent and coal consumption decreased by only seven percent (Yan, 2021).

Although there are quantitative studies of the degree of carbon leakage in either a carbon tax or cap-and-trade program (Bistline *et al.*, 2020; Yan, 2021), there is little to no research which compares the two policies in their ability to minimize carbon leakage. Carbon tax may have a greater effect on carbon leakage because of it sends a stronger economic incentive than a cap-and-trade program. Typically cap-and-trade programs are applied to certain sectors, such as electricity production, therefore the policy only affects that industry and other electricity-intensive markets and products. On the other hand, carbon tax applies to the economy as a whole, and therefore sends a stronger incentive to reduce emissions. This in turn can cause more carbon leakage since firms can predict with higher confidence that future carbon prices will be high (Parker & Blodgett, 2008).

Chapter 5: Conclusion

In theory, a tax and cap-and-trade program create the same financial incentive to reduce greenhouse gas emissions, so either policy can be tailored to achieve desirable outcomes that are the same. It is clear that theory does not describe reality- various carbon tax and cap-and-trade programs exist around the world and substantive differences exist among the policies when they are actually implemented.

One distinction between the two policies is their ability to achieve government efficiency, through lower administrative costs or higher cost-efficiency. Cap-and-trade program was found to have higher overall administrative costs as a result of the additional governmental responsibility brought on by managing an allowance trading market (Goulder & Shein, 2013) and by the higher incidence of rate differentiation among different sections of covered entities, which are estimated to increase average cap-and-trade administration costs by eight percent. Carbon taxes are also more cost-efficient than cap-and-trade (Zhou, 2021), so carbon tax outweighs the trading program in terms of government efficiency. The price to emit is very volatile under cap-and-trade program, especially under the European Union's Emission Trading Scheme and California's nitrous oxide trading program. There are proven ways to reduce price volatility under emission trading policies, such as intertemporal banking and borrowing and an emission price ceiling, floor, or both, but neither of these choices completely eliminate the sudden price fluctuations that constitute price volatility. Since the emission price is set directly by the tax rate, price volatility is a nonissue, making it more favorable in that regard as well. Neither policy outweighs the other in terms of their ability to address uncertainty because they both leave different factors up to chance; it is uncertain under a carbon tax whether a certain level of emission reduction will be achieved, whereas the relative price to emit in the future under cap-and-trade is largely unknown. There are numerous examples of carbon leakage under both cap-and-trade and carbon tax policies, but there have not been any studies that quantitatively compare the two policies to determine which one is better in this area. Still, the overall economic incentive that a carbon tax sends to the market about the future price to emit carbon is significantly stronger than with cap-and-trade. This stronger incentive implies that carbon leakage would be much worse with carbon tax.

These results imply that a carbon tax has many advantages over a cap-and-trade program. In theory, cap-and-trade should reduce emissions at a cheaper cost by leaving it up to firms to decide if they should reduce emissions or purchase allowances. However, this study concludes that carbon tax actually has higher cost-efficiency since it sends a stronger incentive to reduce emissions for about the same price as cap-and-trade. This seriously undermines the argument that cap-and-trade is preferable over a carbon tax from a market perspective.

Areas of future study should aim to quantify the effects of carbon tax and cap-and-trade on carbon leakage and compare them to one another. Identifying the best policy in this regard will be crucial to meet global emission targets and maintain economic stability and international competitiveness. Additionally, comparing the carbon tax's ability to address emission uncertainty and the cap-and-trade's ability to address price uncertainty should be compared quantitively to determine which policy outweighs the other. It has been well established that cap-and-trade programs struggle with price volatility, but studies have not yet explored how well a carbon tax can achieve certain emission reduction targets. These areas of research will provide meaningful insight into which policy is better suited to regulate carbon dioxide emissions in the United States.

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