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A Review of Emission Trading Systems

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By

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ABSTRACT

This paper serves as a review of emission trading systems as a means to achieve reductions in the level of greenhouse gas emissions and other pollutants around the world. The review begins with the history of emission trading, beginning with early theoretical frameworks developed by economists in the 1960s and 1970s, followed by early implementations of permit markets similar to modern day emission trading systems. International negotiations related to emission reductions such as the Kyoto Protocol and Paris Agreement are discussed. Next, the economic mechanisms of emission trading systems are discussed, including a brief comparison to carbon taxes as an alternative market based implement to enact emission reductions. Finally, primary failures of emission trading systems are presented, showcasing some of the downfalls of such systems. The conclusion of this paper is that while emission trading systems provide a means to achieve a specified level of emission reductions at minimal cost, their dependence on the target level of reductions defines their effectiveness at reducing emissions. While not guaranteed to effectively reduce emissions, emission trading systems remain a powerful administrative tool to reduce the burden of cost when faced with meeting emission targets.

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INTRODUCTION

Anthropogenic climate change, often referred to as global warming, is one of the greatest risks humans have faced in recent history. It refers to human-caused changes in weather patterns and global average temperature, which affect the entire biosphere of the planet. Svante Arrhenius, a Swedish scientist, was the first to estimate the effect that atmospheric carbon dioxide (CO_2) has on the temperature of the planet. In his 1896 publication "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground," Arrhenius quantified the effect CO_2 has on the warming of Earth's climate caused by the greenhouse effect. He developed what is known as Arrhenius's rule, which states the following: the change in the rate of heating of Earth's surface during a specified time period is proportional to the natural logarithm of the ratio of the atmospheric concentration of CO_2 at the end of the period and the atmospheric concentration of CO_2 at the beginning of the period. Mathematically, $\Delta_T = \alpha \ln\left(\frac{CO2^{END}}{CO2^{START}}\right)$. Arrhenius's colleague, Arvid Högbom, found that CO_2 emissions from industrial sources such as the burning of coal and other fossil fuels was comparable to emissions from natural sources. This led Arrhenius to conclude that human-caused emissions would eventually lead to global warming; however, based on the emissions levels of the late 19th century, Arrhenius thought that the warming would take place over the course of thousands of years.

Scientists continued studying the effects of CO_2 on Earth's climate, with much debate surrounding the truth of the findings. As more effort was put towards researching these effects throughout the 20th century, scientists were finding more evidence showcasing CO_2's effect on the temperature of the Earth's atmosphere. Since the end of the 19th century, the major expansion of industrialization has caused an enormous increase in the amount of anthropogenic CO_2 emissions, as seen in Figure 1. This

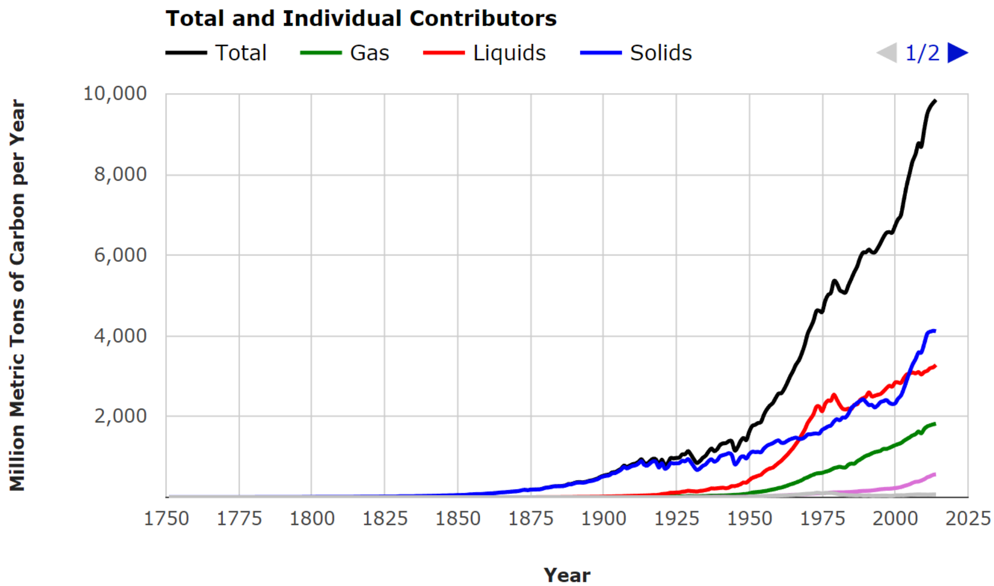

Figure 1. CO_2 emissions per year listed by emission source. Source: Boden, T.A., G. Marland, and R. J. Andres, 2015. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Caron Dioxide Information Analysis Center. Oak Ridge National Laboratory. U.S. Department of Energy. Oak Ridge, Tenn., U.S.A. doi:10.3334/CDIAC/00001_V2015

increase in the amount of CO_2 and other greenhouse gasses (GHGs) such as methane (CH_4) and nitrous oxides (NO_X) has contributed significantly to rising average global temperatures. Multiple recent studies have shown that 97.1% of publishing climate scientists have reached a consensus that humans are causing the observed trend of rising average global temperatures (Cook et. al., 2013). Additional independent studies have found the consensus to be between 90 percent and 100 percent, showcasing the robustness of this consensus (Cook et. al., 2016). With climate scientists expressing the need to reduce GHG emissions, international, national, and subnational regulatory bodies have been trying to develop policies to reduce GHG emissions while avoiding major economic consequences of such reductions.

The need for the creation of such policies has been driven in large part by anticipated damages to be caused by an increase in the world's average temperature. The International Panel on Climate Change, which researches and releases reports regarding global climate change, has predicted large social and economic damages caused by anthropogenic climate change. Potential damage includes increases in extreme weather events such as hurricanes and earthquakes, reductions in food production and food security, and rising sea levels which threaten to make coastlines around the world uninhabitable (Hoegh-Guldberg et. al., 2018). Extreme weather events are likely to cause damage to human infrastructure, leading to massive repair costs and potential loss of human life. Increases in droughts are likely to lead to famines in less developed nations, as well as decreased agricultural production potentially leading to global food shortages. Rising sea levels may cause flooding around many of the world's coasts, threatening people's ability to live in coastal areas. There are likely to be future effects of global warming that cannot be predicted, due to the complexity of the systems affected by changes in the Earth's climate.

While there have been many proposed environmental regulations for reducing GHG emissions around the world, they typically fall into one of two categories: command-and-control regulations and market based regulations. The first of these categories, command and control regulations, refers to the traditional approach of direct regulation of an activity where legislation is passed stating what is and is not allowed. The administrative costs of this type of regulation become exceedingly large as more sources and activities need to be accounted for under the legislation, and enforcement often becomes extremely difficult. An example of market based regulations is cap and trade programs. This type of regulation sets a cap on the total amount of emissions allowed to be discharged within a region, and allows agents to trade amongst each other for the right to pollute in the form of emission allowances. While each system has different names for different types of emission allowances, some common names are emission credits or emission reduction units. Almost all emission trading systems have standardized emission units to refer to one tonne of CO_2 equivalent, meaning the amount of a pollutant that causes the same impact as one tonne of atmospheric CO_2. Market based regulations have been proven to greatly reduce the cost of achieving a desired level of emissions, however their effectiveness compared to traditional command-and-control regulations is still debated.

Efforts to reduce global GHG emissions have been increasing since 1992, when a large group of United Nations member states created the United Nations Framework Convention on Climate Change (UNFCCC). The goal of the UNFCCC was to create a framework for international cooperation to combat climate change, and currently consists of 197 member states. The UNFCCC eventually drafted the Kyoto Protocol in 1997, an international treaty that set legally binding emission reduction targets for signatories. The Kyoto Protocol, which includes 192 member states of the United Nations, focuses mainly on developed countries as they were seen as primarily responsible for the high levels of GHGs that have been emitted in the past century and a half. Countries with an emission reduction commitment under the Kyoto protocol are referred to as Annex B countries. In addition to nationally implemented measures to reduce GHG emissions, the Kyoto

Protocol provides several market based mechanisms as additional means for member states to reduce their emissions. These mechanisms will be discussed in Chapter 1.

The purpose of this paper is to review market based regulations as a policy instrument to affect reductions in the levels of GHG emissions, in particular cap and trade systems. Other forms of emission reduction regulations are carbon taxes and subsidies for reductions. While this paper focuses primarily on emissions trading, a brief comparison with carbon taxes will be discussed. While different implementations of cap and trade systems around the world vary in their specific metrics, such as the total cap on the quantity of emissions allowed, the underlying concept of allowing participants to trade allowances on a free market is present in all systems.

Chapter one of this paper details the history of cap and trade systems and how the systems have evolved over time. Chapter two explains the economic theory behind cap and trade systems, while chapter three presents some failures of cap and trade systems. Concluding remarks are presented in chapter four.

CHAPTER 1: HISTORY OF EMISSIONS TRADING SYSTEMS

Early Theoretical Frameworks

The concept of using cap and trade systems to lower the cost of reducing pollution was first explored during the 1960s and 1970s by economists such as Coase, Dales, and Montgomery in their work regarding permit markets. In addition to this early theoretical work, researchers at the U.S. National Air Pollution Control Administration (NAPCA), now known as the United States Environmental Protection Agency (EPA), were independently working towards showcasing the efficiency of individual emissions control combinations compared to traditional abatement regulations. These traditional abatement regulations, often referred to as command and control regulations, involve the direct regulation of an industry or activity through government legislation. The work done during this period would go on to become the basis for modern cap and trade systems seen throughout the world today.

Coase (1960) discusses the economic implications of well-defined ownership rights on efficient trading outcomes, while Dales (1968) and Montgomery (1972) provide outlines of theoretical cap and trade models. Burton and Sanjour (1970), working for the NAPCA, used computer simulations to showcase how least-cost emissions control combinations are more efficient at reducing emissions than direct abatement strategies. What follows is a summary and discussion of these early contributions to the literature surrounding emission trading systems.

In his 1960 paper "The Problem of Social Cost," Coase explores the problem presented by the presence of externalities on allocative efficiencies. Externalities, which are costs or benefits affecting someone who did not choose to incur such costs or benefits, tend to skew allocative outcomes to be less socially optimal than if those costs or benefits were internalized in the optimization process. An example in the context of environmental regulations would be a firm emitting pollutants which cause adverse health effects on a surrounding neighbourhood. Unless the cost of such health problems caused by the firm's emissions are included in the cost of emitting, the firm will tend to emit more than is socially optimal. Coase's first theorem shows that if transaction costs are non-existent, consumers and firms will bargain with each other to obtain a distribution of resources that is optimally allocated based on a cost-benefit framework (Coase, 1960). He argues that such an allocation would be more efficient than one produced through regulatory litigation. An important point Coase brings up in his paper is that when dealing with the problem of one agent harming another, the problem is in fact reciprocal in nature; the issue is not how to stop A from harming B, but whether A should be harmed or B should be harmed, as it is not possible to stop harm caused to one agent without harming the other in some way.

Coase (1960) provides multiple examples to illustrate the reciprocity of these problems, including the above example of a firm's emissions causing harm to the surrounding region. He argues that from a legal standpoint, the firm has the right to pollute on its own property; however, neighbouring residents have the right to not be harmed by the firm's actions. When deciding whether or not the firm should be harmed to reduce the harm being caused to the neighbouring residents, Coase says that a cost-benefit analysis taking into account all externalities is sufficient. When performing a cost-benefit analysis, the total cost to society caused by the firm's emissions should be weighed against the total benefit of the firm emitting as a necessary means of production. Since we do not live in a world of zero transaction costs, these transaction costs significantly hamper agents' ability to bargain towards an efficient outcome. While Coase argued that litigation and government regulations often create a cost to the market that could possibly outweigh the benefit, emissions trading systems help to reduce these costs as well as transaction costs between firms for reducing emissions; this allows participants to get closer to the ideal allocation achieved with zero transaction costs proposed by Coase.

In addition to the theorem presented above, Coase presented a second theorem in which bargaining is costly and information is imperfect. In this case, Coase argued that property rights are even more significant than in the previous case. Coase argued that strong liability rules in this case help achieve an optimal distribution of resources, by requiring the party with the least cost of dealing with the externality to be responsible for paying its associated costs. Since bargaining in our world is costly, and perfect information does not exist, this second theorem seems more applicable to many of the social problems we as a society face, including pollution. Emission trading systems embody this second theorem by setting legal limits to the amount of pollution permitted and allowing those with the least cost of reducing emissions to do so in order to achieve the required level of reductions. This is analogous to the liability rules referred to in the second theorem, and by creating well defined "rights to pollute" through the implementation of emission permits, the ability to trade them in a market setting will theoretically lead to an efficient outcome.

In Dales' 1968 paper "Land, Water, and Ownership" he presents a framework for a cap and trade system to reduce water pollution in a given region that is virtually identical to those seen today. Dales begins his paper by detailing how the lack of an ownership-rental system for water gives way to over-use and the degradation of water resources, an example of the Tragedy of the Commons as presented by Hardin (1968). While these problems have been sufficiently controlled for land use by the implementation of ownership-rent systems, creating a similar system for water proves to be much more difficult. Historically, property rights over water have never been established, thus no rents for the use of water have been established either. If it is assumed that there is a direct relationship between the level of rent and the development of new technologies, then it is expected that zero rents for water have led to zero improvements in technology used to reduce the degradation of water supplies. As such, levels of water pollution have increased over time and the quality of water sources has continued to degrade. Pollution has continued to cause externalities relating to both water and air resources, both without pricing processes, which Dales believes has caused social friction and economic waste as a result of the lack of an ownership-rental system (Dales, 1968).

In attempting to describe an ownership-rental system for natural water sources, Dales (1968) begins by identifying how certain characteristics of water sources provide special problems for ownership rights. A key component to ownership rights is the divisibility of the asset one is attempting to create an ownership system for. For something like land, the smallest asset size that can still have exclusive use enforced is rather small; however, when it comes to water sources, the smallest asset size is very large in comparison. Dales purports that the only sensible form of ownership in a democratic society for this type of resource is monopoly ownership by the government, which is the system that has been implemented in Canada. This implies that it is the government's responsibility to decide how the water sources must be used, as well as to enforce the regulations it puts forth. This problem is, for all intents and purposes, identical to that faced by regulatory bodies around the world when dealing with air pollution and GHG emissions. Dales classifies uses of water sources under two categories: waste disposal and everything else. While there exist different quality demands among all users excluding those interested in waste disposal, Dales argues that some of these users would be benefitted, and none harmed, by an improvement in water quality. On the other hand, waste disposers would be harmed by an improvement in water quality as that implies a reduction in the amount of waste disposed of in the water. This cost-benefit dichotomy of an improvement in water quality leads to a reduction of the many uses of water to only the two described above. The government must then decide how best to divide the water supply between these two conflicting uses.

Dales goes on to explain that there is no economic basis to how the government should decide to divide the water sources between the two uses. He believes that it is purely a matter of collective decision-making, since the social value of water cannot be measured. In effect, the division of water sources between uses translates into how much waste polluters may emit into the water source, which as stated above, must be economically arbitrary. Once an amount of allowed waste is decided upon, Dales suggests there are six main avenues of enforcement available to the government-owner. Suppose the government caps the amount of waste disposal allowed to be emitted per year at X equivalent tonnes of waste, which represents a 10 percent reduction from the amount of waste currently being discharged. The government-owner can regulate in one of two ways: (1) a quota can be assigned to each polluter and set so that the sum of the quotas does not exceed X; or (2) it can implement an across-the-board regulation stipulating that each emitter must reduce their waste discharge by 10 percent. It can subsidize in one of two ways: (3) polluters can be subsidized to reduce their wastes, either individually or (4) on an across the board basis of a certain amount per tonne of emissions reduced. Finally, it can charge using one of two schemes: (5) an effluent charge can be levied on polluters, either individually or (6) on an across the board basis of a certain amount per tonne of emissions (Dales, 1968).

In his paper, Dales immediately rules out the individual procedures, due to the prohibitive administrative costs, further rejecting these measures due to their inability to distribute the cost of reducing pollution in an economically optimal way. Additionally, he rules out an across the board regulation that each emitter must reduce their waste discharge by 10 percent, since this would result in a non-optimal distribution of the cost burden. This leaves the across-the-board schemes of subsidization and charging left to be compared. Both schemes would result in an optimal cost distribution, since each polluter would reduce its waste up to the point where the marginal cost of reduction equals the subsidy provided or the charge levied. Both schemes would need a certain amount of experimentation to determine the level of subsidy or charge necessary to produce the emission target X, and the levels would need to vary annually to account for industrial and demographic growth or decline to maintain the emission target. The subsidy scheme has two disadvantages that the charging scheme does not. The first is that with a subsidy, firms that can reduce their pollution at a cost that is less than the subsidy will gain profits from reducing their emissions, thereby making a change to the relative prices of goods unnecessary. This leads to consumers maintaining their current consumption decisions, whereas higher prices will reduce consumption and with it the amount of pollution emitted. With the charging scheme, there will be no extra profits generated and there will be a change in the relative prices of goods, leading to a socially desirable adjustment to consumption. The second is that the subsidy scheme provides no incentive to reduce the amount of waste discharge, whereas the charging scheme provides incentives to reduce the amount of waste discharged as well as to improve the technology of treating waste before it is discharged (Dales, 1968). Dales concludes that the across-the-board charging scheme is the optimal way of implementing the government's emission target.

He continues by describing a market based implementation of a charging scheme similar to cap and trade programs currently implemented, whereby the government issues *X* pollution rights and puts them up for sale, while passing a law that requires emitters to hold pollution rights equal to their actual amount of emissions. The price of each pollution allowance would be set by competition between buyers and sellers of these allowances, allowing it to adjust to industrial and demographic growth or decline. This price would represent the rental value of water for waste disposal purposes, thereby creating an ownership-rental system which will theoretically reduce the amount of pollution emitted and improve the technology used to clean waste before it is discharged. Dales suggests that not just polluters should be able to buy and sell emission allowances, but anybody should be able to trade for them. An example given is a clean-water advocacy group purchasing emission allowances and not using them to emit any pollution, reducing the total amount of emissions in the economy.

Dales concludes his paper by making note of deficiencies of an across-the-board charging scheme such as the market based approach previously described. There are four arbitrary elements to such a system: the mapping of water regions, the setting of waste equivalents, the choice of the allowable amount of waste discharge, and the interval of time during which the number of pollution rights is fixed (Dales, 1968). While a market based approach to reducing emissions should theoretically lead to an optimal allocation of reductions, these four elements are likely to reduce the efficiency of the charging scheme being used. Dales suggests that the savings in administrative costs achieved by using a market based system outweighs any loss of efficiency created by these arbitrary elements. Finally, Dales notes that the market for emission allowances is not a "true" or "natural" market, where price information affects amounts supplied as well as demanded. In the emissions market, a rise in the price of an emission allowance signals that the waste disposal use of water is becoming more valuable; however, it does not mean that the supply of emission allowances should be increased. The proposed market for emissions allowances is an administrative tool to reduce the levels of emissions, rather than a "true" market.

Montgomery builds upon Dales' work on emissions license markets in his 1972 paper "Markets in Licenses and Efficient Pollution Control Programs." Montgomery's goal for this paper is to provide a solid theoretical foundation to be used in the implementation of these markets. Montgomery believes that while emissions markets are unlikely to lead to Pareto optimality, they valuably function as a policy tool to achieve a specified level of environment quality, similar to Dales' claim that such markets are merely an administrative tool (Dales, 1968). In his paper, Montgomery discusses two types of licenses, emission licenses and pollution licenses. Emission licenses directly provide the right to emit pollutants up to a certain rate, while pollution licenses provide the right to emit pollutants at a rate that will not increase levels of pollution above a specified amount. While these two types of licenses are similar, the primary difference is that emissions licenses cover only the direct emissions from a pollution source, whereas pollution licenses are required for each area an emitter may pollute, potentially requiring a polluter to hold more pollution licenses than the amount of emissions they produce.

Consider the following example: there are three regions along a river, and each region has one firm that emits pollutants which then travel downstream. The total amount of pollution in a given region is thus the amount of emissions emitted by that region's firm plus the emissions from each firm that is upriver. Each firm would need emissions licenses that cover their individual quantities of emissions, however each firm would need pollution licenses that cover each region whose pollution level is affected by their emissions. In our example, the firm that is furthest downriver would need pollution licenses to cover only the pollution created in its own region, since no other region is affected by their emissions. The firm in the middle region would need pollution licenses to cover the pollution caused in its own region as well as the pollution it creates in the downriver region as well. The firm that is furthest upriver would need pollution licenses to cover the pollution it creates in all three regions. Montgomery's primary thesis is that the market in pollution licenses will be much more widely applicable than the market in emission licenses. This is due to pollution typically affecting many more areas than the area it is first emitted in. Emission licenses fail to capture the full extent of damages caused by pollution.

Montgomery notes that the model he has created is only applicable in situations where the concentration of pollutants is a linear function of emissions. While this result is not easy to be generalized, Montgomery puts forth that concentrations of nonreactive atmospheric pollutants are approximately linearly related to their emissions, as long as average emission rates and average concentrations are used. Examples of nonreactive atmospheric pollutants include emissions such as sulphur dioxide (SO_2) and CO_2, thus Montgomery's model is relevant to developing an emission license market for these common pollutants that are of large concern today. Montgomery creates a theoretical relationship between average emission rates and average concentrations through the use of a diffusion matrix, which defines the contribution one unit of emission by a single firm has on the average concentration of pollution at multiple points. This diffusion matrix represents the results of a meteorological diffusion model formulated by Martin and Tikvart in their 1968 paper "General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources." Martin and Tikvart base their model on an equation describing the shape of a smoke plume emitting at a constant rate with a wind of constant direction and speed.

Montgomery's model solves for an efficient allocation of emissions for a given diffusion matrix and specified target concentration levels of pollutants throughout an area. The model finds that if it is assumed that firms minimize their total production costs and the market for licenses is competitive, then the total cost of achieving a desired environmental standard will be minimized. This result is one of the reasons why emission trading systems have received as much attention as they have. Montgomery believes that since emissions from different locations affect other surrounding areas differently, the market for pollution licenses will be more applicable as a policy instrument than the market for emission licenses. Additional work on finding policies with the lowest cost of reducing pollution was performed by Burton and Sanjour.

Early work by Ellison Burton and William Sanjour used computer simulations to model the emission sources of several U.S. cities in order to compare the cost and effectiveness of various abatement strategies to reduce pollution in these areas. Their 1970 paper, "A Simulation Approach to Air Pollution Abatement Program Planning," compares abatement strategies for the reduction of particulates and sulfur oxides (SO_X) in the Kansas City area. There are four proposed alternatives for particulate and SO_X emission controls: mechanical controls, low-sulfur coal, low-sulfur oil, and natural gas. In this context mechanical controls are machines that may be installed by a firm that reduces either particulate or SO_X emissions in some way. The authors stipulate that each individual firm included in their simulation is unique, and differences in physical capital, size, and income implies significantly different problems of technical and economic feasibility for each abatement alternative. For example, no mechanical controls were allowed for small emitters due to prohibitive costs; the only alternative allowed in the simulation for these firms is to switch to using a lower sulfur-percentage coal. Larger firms have much more flexibility in emission controls, however limitations still exist. The simulation allows for multiple emission controls to be used in conjunction with each other, allowing as many as 50 different possibilities for each emitter to control their particulate and SO_X emissions. The simulation includes 129 different emission sources in the Kansas city area, leading to an astronomical number of combinations of abatement strategies to exist, but only relatively few are of interest to area-wide abatement.

There are four abatement strategies selected to be compared to the theoretical least-cost solution in Burton and Sanjour's (1970) paper, which are: maximum control of particulates and SO_X, maximum control of particulates alone, equi-proportional reductions of all major sources of particulate to various percentages of uncontrolled emissions, and the prohibition of fossil fuels with more than two percent sulfur content by weight. The least-cost solution is the combination of emission controls which achieves the same levels of particulate and SO_X emissions as the strategy it is being compared to for the lowest cost. This allows for a comparison of the cost of the direct abatement strategy to that of the least-cost emission control combination, as the effectiveness of the two strategies is by definition the same. In all cases, a least-cost emission control combination with an equal measure of effectiveness to the respective abatement strategy was found to exist, with a cost far lower than that of the abatement strategy compared. This paper showcases the potential efficiency of individual emission control combinations compared to traditional economy wide abatement regulations. The results of these simulations have helped lead to the concept of cap and trade systems as a means to efficiently find the least-cost combination of emission reductions through a market based system.

All of the papers discussed above conclude the effectiveness of markets for emission allowances as an administrative tool for achieving a desired emission reduction target while minimizing the cost of such reductions. While there are some barriers towards achieving the most optimal reduction strategy, these early papers have shown through theoretical and empirical approaches how artificial emission markets tend to be more efficient than traditional command and control abatement strategies. Even though this work showcases the merits of such market mechanisms, these systems were not implemented in full for years to come. It was not until growing concern over anthropogenic climate change in the early 1990's that complete emission trading systems were seriously looked at as a means to combat global warming, and it took still more years for these markets to become a strategy used to reduce emissions around the world.

Early Permit Market Implementations

One of the earliest emission trading programs was implemented as part of the United States Clean Air Act (CAA). The CAA included an offset trading program established throughout the 1970's, which although not a complete emission trading system included many features of emission trading systems. This program was the first attempt at using market mechanisms in environmental regulation in the United States (Hahn & Hester, 1989); however, it was not very successful in reducing the amount of emissions from participating firms. Hahn and Hester examine this system among others in their 1989 paper "Marketable Permits: Lessons for Theory and Practice." When examining the system, Hahn and Hester distinguish between internal and external emission trades, which are defined as between sources in the same facility, and between sources in different facilities, respectively. While external trades are typically carried out between two different firms, they do not need to be. Hahn and Hester believe this distinction to be important for gaining insights into the limitations and potential for trading activities allowed within the program.

For the purpose of the offset program, the CAA divided firms into three types - new, modified, and existing - and also divided regions throughout the United States into two categories, attainment and nonattainment areas. Attainment areas are those that already met air quality standards, while non-attainment areas are those that did not. New firms are those which were built after emissions were first inventoried in the mid-1970's, and existing firms are those that existed before this inventory. Modified firms refer to existing firms that have been modified to lead to significant increases in emissions since the program was implemented. Both new and modified firms were expected to comply with more stringent emissions standards than existing firms were. The goal of the system was to bring non-attainment areas up to the air quality standard, while attainment areas were to maintain their quality standards. Firms were either mandated or allowed access to different trading activities depending on their categorization, and whether or not they were in an attainment or nonattainment region. These divisions are summarized in Table 1.

The program included four distinct activities that firms could engage in, namely "offsets," "netting," "bubbles," and "banking." Of these four activities, the first three involve the trading of emission rights. Here, emission rights refers to the right a firm has to emit a certain type of pollutant, which is equivalent to an emissions permit authorized by a regulatory body. If a firm emits fewer emissions than what it has permits (or emission rights) for, that difference is referred to as an emissions credit. This emissions credit represents the tradable right to emit. Offsets were instituted as part of the CAA in 1976 to allow for new emission sources in a region. New and modified sources in a given region would need to purchase emission credits from existing sources in the same region in order to offset their new emissions, otherwise they were not allowed to be built. These sources were not allowed to emit past their given limit, even if they purchased a greater amount of offsets than their limit. An important note on the trading of offset credits is that the terms of trade set by the regulations was such that the trading ratio was always greater than one. That is, for a source to purchase the right to emit a single unit of emissions from another source, the source that is selling the offset would need to reduce their emissions by *more than* one unit. In the end, this increased the transaction cost of offsets, providing a disincentive for their use relative to the other trading activities available.

SOURCE TYPE	AREA CLASS	EMISSIONS TRADING OPTIONS	OPTIONAL OR MANDATORY	APPLICABLE EMISSION LIMIT[1]	CAN LIMIT BE AVOIDED BY TRADING?
NEW					
	ATTAINMENT	OFFSETS	OPTIONAL	BACT	NO
	NON-ATTAINMENT	OFFSETS	MANDATORY	LAER	NO
MODIFIED					
	ATTAINMENT	NETTING	OPTIONAL	BACT	YES
	NON-ATTAINMENT	NETTING	OPTIONAL	LAER	YES
		OFFSETS[2]	MANDATORY	LAER	NO
EXISTING					
	ATTAINMENT	BUBBLES	OPTIONAL	STATE LIMITS[3]	YES
		BANKING[4]	OPTIONAL	STATE LIMITS[3]	NOT APPLICABLE
	NON-ATTAINMENT	BUBBLES	OPTIONAL	RACT	YES
		BANKING[4]	OPTIONAL	RACT	NOT APPLICABLE

Notes:
[1] Of these limits, LAER (Lowest Achievable Emission Rate) is the most stringent, Clean Air Act § 171(3), 42 U.S.C.A. § 7501(3); BACT (Best Available Control Technology) is the next most stringent, *id.* § 169(3), 42 U.S.C.A. § 7479(3); and RACT (Reasonably Available Control Technology) is the least stringent, *id.* § 172(3), 42 U.S.C.A. § 7502(3). Modified sources that use netting are exempted from BACT or LAER, but *may* be subject to other limits called NSPS (New Source Performance Standards) that are typically approximately equivalent to BACT. For stringency of state limits, see note 3 below.
[2] Offsets are mandatory in nonattainment areas for modified sources that do not use netting. EPA, Emissions Trading Policy Statement, 51 Fed. Reg. 43,814, 43,830 (1986).
[3] There are no specific federally defined emission limits that states must apply to existing sources in attainment areas. However, states are required to institute measures that assure the maintenance of air quality in attainment areas. Clean Air Act § 107(a), 42 U.S.C.A. § 7407(a). To do so, states usually employ a permit system as they do in nonattainment areas and impose emission limits on existing sources through that system. While the resulting state limits can vary widely, they are typically no more stringent than RACT, and may be less stringent.
[4] Applicable emission limits are used to calculate emission credits for banking, but the use of banking does not, in itself, enable firms to avoid emission limits. *See* EPA, Emissions Trading Policy Statement, 51 Fed. Reg. 43,814, 43,835 (1986). The use of their banked credits in other emissions trading activities may enable firms to avoid applicable emission limits, however.

Table 1. Relation of Emission Limits by Source Type and Area Class to Emissions Trading. Source: Hahn and Hester, 1989

Netting allows for modified sources to avoid some emission limits on the modification in question by reducing the emissions from another source within the same plant, thereby reducing the net emissions from the plant to below an acceptable level. The definition of netting necessarily implies that it allows for only internal trading. While the purchase of offsets did not allow the modified source to emit above its maximum emission level, netting did, making it a much more enticing option for firms with multiple emission sources. Another benefit to netting was that the terms of trade did not stipulate a trading ratio greater than one.

Bubbles refer to the concept of placing an imaginary bubble over existing multi-source plants, stipulating that the total emissions from the plant be within an acceptable level. This allows for the levels of emissions controls for different emissions sources within the plant to be adjusted to reduce overall costs of reducing the total emissions of the plant. Essentially, emissions credits would be created by some sources within the bubble and be used by other sources within the same bubble. The program only allowed existing plants to make use of bubbles. Banking allows sources to keep their emission credits for future use, and as such is not a form of trading per se, although an argument could be made that the source is trading its emission credits to its future self.

Ultimately, Hahn and Hester (1989) found that the effects of the four activities allowed by the program had insignificant effects on environmental quality. While this result is disappointing, the program did lead to significant aggregate cost savings for firms to attain the required emission limits. However, these savings were mostly achieved through internal trading due to the nature of program, and are much smaller than would have potentially been realized in the presence of increased external trading. The largest determinant of program performance was high transaction costs, a large part of which came from regulatory restrictions on trading and administrative requirements that extended the time required for trades to be approved. A major regulatory restriction that impeded the performance of this program in particular was new and modified sources being barred from meeting or avoiding their stringent emissions control regulations through external trading. This provided a disincentive for credit trading for these sources, reducing the overall demand for emission credits. Another source of high transaction costs which impeded program performance was simply the level of technology available at the time, in the context of measuring emissions. Since emission sources needed to provide information about their emission rates and reductions themselves, they had to bear the cost of measuring these quantities. This was a relatively costly process that further disincentivized trading. While this CAA program was seen to have disappointing results in terms of emission reductions, it provided an excellent proof of concept for the ability of emissions trading to reduce the cost of emission reductions.

In comparison, the Acid Rain Program implemented by the United States EPA can be thought of as the evolution of the previous offset program and is one of the earliest examples of a “true” cap and trade program. The EPA states that it is the first national cap and trade program seen in the United States and it is still in effect at present. Information on the Acid Rain Program is sourced from the Acid Rain Program section of the EPA’s website on Clean Air Markets (Environmental Protection Agency, 2018). The goal of the program was to reduce the amount of SO_2 and nitrous oxide (NO_X) emissions from the power sector, two major precursors to acid rain. SO_2 emissions were targeted to be reduced by 10 million tonnes below 1980 levels, and NO_X emissions were targeted to be reduced by 2 million tonnes below 1980 levels. The companies regulated under this program are fossil fuel-fired power plants for SO_2 regulations and coal-fired utility boilers for the NO_X regulations. While both SO_2 reductions and NO_X reductions had flexibility in the method of emissions reductions, SO_2 reductions were the only part of the Acid Rain Program to utilize a cap and trade system. Unlike the offset program implemented throughout the 1970's, the EPA took a much more hands off approach to reducing emissions with the Acid Rain Program. Companies that fall under the program's regulations are required to install emission monitors on sources of pollution, which the EPA compares to the amount of allowances held by the company. By acting primarily as a record keeper, administrative costs were lowered substantially from the previous offset program, which played a large part in the Acid Rain Program's success.

The Acid Rain Program operates like most other emission trading systems. The EPA sets a cap on the total level of SO_2 allowed within the region the program operates in for the given time period. The EPA then allocates emission allowances to firms based on the rate of SO_2 emissions and a baseline fuel consumption for each firm. Total emission allowances cannot exceed the total cap on SO_2. In addition to these allowances allocated by the EPA, firms have the option to buy additional allowances either directly from other firms or individuals, or from a variety of brokers. Any firm or individual may purchase or sell emission allowances through the Acid Rain Program, even those not regulated by the program. This allows for individuals or groups to "retire" emissions allowances by purchasing them and not utilizing them to emit pollutants, thereby reducing the overall level of pollution. At the end of each monitoring period, typically one year, firms regulated by the Acid Rain Program must hold in their accounts an amount of emissions allowances equal to the tonnes of SO_2 they emitted over the monitoring period. If a regulated firm does not hold emissions allowances to cover their level of emissions, the EPA issues an automatic monetary penalty per tonne of emissions not accounted for with allowances. If firms reduce their emissions levels below their initial allocations from the EPA, they can then sell their extra emissions allowances on the market, or bank their extra allowances for future compliance periods.

The Acid Rain Program has been wildly successful at reducing the level of SO_2 and NO_X emissions throughout the United States. As of 2016, SO_2 emissions have been reduced to 91 percent below their 1980 levels, and NO_X emissions have been reduced to 87 percent below their 1990 levels. The success of the Acid Rain Program throughout the United States provided a concrete showcasing of the power of emissions trading schemes to reduce emissions levels to a desired target without compromising economic activity. This success is a likely contributor to the numerous other cap and trade programs that have been implemented globally since the program's beginnings. Since the program's inception, similar programs have been implemented around the world. These include international emission trading systems such as the ones implemented by the Kyoto Protocol and the European Union Emission Trading Scheme, national emission trading systems such as those in Australia, New Zealand, and South Korea, and subnational emission trading systems such as the Quebec-California emission trading system and the Tokyo emission trading system.

International Climate Negotiations

International negotiations regarding climate change and global GHG emissions were spurred by the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC was created by the United Nations Environment Program and the World Meteorological Organization. The goal of the IPCC was to prepare comprehensive reviews on the global state of knowledge regarding the science of climate change, and to provide recommendations based on these reviews to leaders around the world. Since its inception in 1988, the IPCC has released five assessment reports outlining the social and economic impacts of climate change, and potential strategies to help combat the negative effects. In addition to the assessment reports, the IPCC has provided numerous methodology reports and technical papers to various requests for information from the United Nations Framework Convention on Climate Change (UNFCCC), world governments, and international organizations.

The UNFCCC is an international treaty put forward by the United Nations in response to the first assessment report released in 1990 by the IPCC, which acts as a framework for international cooperation to combat climate change. The treaty was opened for signatures in 1992 at the United Nations Conference on Environment and Development held in Rio de Janeiro, and currently has 197 member states included as signatories. These member states are classified as Annex I or Non-Annex I countries, where Annex I countries are defined as industrialized nations and economies in transition. Countries listed by the UNFCCC as Annex I are shown in Table 2 on the following page.

The UNFCCC entered into force in 1994, and by 1995 negotiations had begun amongst countries to determine how best to combat climate change (UNFCCC, 2019a). These international negotiations gave rise to the creation of the Kyoto Protocol, which was adopted in 1997. The Kyoto Protocol set legally binding emission limits focusing primarily on developed nations due to their historic high levels of industrial activity (UNFCCC, 2019b). Countries with emission limits under the Kyoto Protocol are defined within Annex B of the Kyoto Protocol (UNFCCC, 1998). These countries include all Annex I countries at the time the Kyoto Protocol came into effect, which at the time did not include Belerus, Cyprus, Malta, or Turkey. The United States did not ratify the Kyoto Protocol, making its target emissions non-legally binding. Currently, the United States is the only signatory of the Kyoto Protocol that has not ratified the treaty (United Nations, 2005). The Kyoto Protocol has so far defined two commitment periods for emission reductions. The first commitment period for Annex B countries started in 2008 and ended in 2012.

Australia	Austria	Belarus
Belgium	Bulgaria	Canada
Croatia	Cyprus	Czech Republic
Denmark	Estonia	European Union
Finland	France	Germany
Greece	Hungary	Iceland
Ireland	Italy	Japan
Latvia	Liechtenstein	Lithuania
Luxembourg	Malta	Monaco
Netherlands	New Zealand	Norway
Poland	Portugal	Romania
Russian Federation	Slovakia	Slovenia
Spain	Sweden	Switzerland
Turkey	Ukraine	United Kingdom
United States of America		

Table 2. List of Annex I countries as defined by the UNFCCC (UNFCCC, 2019c).

The target level of emissions among Annex B countries ranged from 8 percent below base year levels, to 10 percent above base year levels. The base year level is the level of a country's emissions from a previous time period that is used as a reference quantity. For most countries, the base year is 1990, however some countries, considered economies in transition, use base years in the late 1980's (UNFCCC, 2019d). These countries include many of the former Soviet states. While the Kyoto Protocol expects countries to enact national measures to reduce their level of emissions, it also provides several international mechanisms to Annex B countries to achieve their reduction targets. There are three such mechanisms: international emissions trading, the clean development mechanism, and joint implementation.

International emissions trading is a cap and trade system among Annex B countries where each country's emission cap is their reduction target under the Kyoto Protocol. An Annex B country that reduces its level of emissions below its target commitment is able to sell its excess allowances to another Annex B country. This incentivizes countries that are able to more cheaply reduce their emissions to reduce further in order to earn money selling the extra emission units. It also provides flexibility to Annex B countries with higher reduction costs by allowing them to purchase allowances at a lower cost than their autarkic cost to reduce.

The clean development mechanism is a way for Annex B countries to earn additional emission allowances through the implementation of emission reduction programs in developing countries. The Annex B country which implements the project earns certified emission reduction credits from the UNFCCC which are the equivalent to one tonne of CO_2 and are able to be traded like other emission allowances on the international carbon market. The clean development mechanism provides an incentive for richer countries to invest in green technologies in countries that may not be able to afford them. The joint implementation program is similar to the clean development mechanism. Instead of an Annex B country implementing an emission reduction project in a developing country, they receive an emission reduction unit for implementing an emission reduction project in another Annex B country. This allows for additional flexibility for the implementing party to meet its reduction targets, while the country hosting the project benefits from foreign investment and technology transfer.

When looked at in isolation, the Kyoto Protocol seems to be a success, with two thirds of Annex B countries meeting or exceeding their reduction targets under the treaty while half of the remaining third have only missed their target by a moderate margin. However, there are several countries which have greatly missed their reduction targets, with New Zealand, Canada, and Austria being the worst offenders (Clark, 2012). Canada’s failure to achieve emission reductions in accordance with the Kyoto Protocol led to its withdrawal from the Kyoto Protocol in 2011. The reason given by Environment Minister Peter Kent was that the fines for failing to achieve the reduction targets would be too great of an economic impact on Canada (CBC News, 2011). While Annex B countries have reduced their emissions significantly, these reductions have been vastly overshadowed by rising emissions from other countries in the world not bound by the Kyoto Protocol. As such, the level of GHG emissions throughout the world has increased by a large amount, and continues to rise. Ultimately, the Kyoto Protocol has so far failed to reduce GHG emissions to a level able to combat climate change.

While looking deeper into the emission levels of developing countries such as China - which do not have reduction commitments through treaties such as the Kyoto Protocol - a large flaw of the Kyoto Protocol is revealed. Many of these emissions throughout the developing world are caused by the production of goods that are then exported to many of the developed countries that have been reducing their emission levels. Since the Kyoto Protocol assigns emissions to the country from which they originate, a huge portion of the carbon footprint of Annex B countries is not accounted for under the Kyoto Protocol. While it may be that emissions have been reduced by these countries, their carbon footprints have continued to grow as they "outsource" their emissions to countries not bound by international regulations (Clark, 2011). Global CO_2 emissions caused by the production of exported products have almost doubled from 1990 to 2008, and it has been found that international trade has relocated 16 gigatonnes of CO_2 from Annex B countries to non-Annex B countries from between 1990 and 2008, and the rate of net emission transfers between Annex B and Non-Annex B countries has been increasing (Peters et. al., 2011). This failure of the Kyoto Protocol to account for the "outsourcing" of emissions from Annex B countries to non-Annex B countries must be remedied in future treaties if they are to be effective at reducing global emission levels of GHGs.

The most recent United Nations treaty focusing on combating climate change, the Paris Agreement, seems to attempt to fix some of the fundamental issues of the Kyoto Protocol. The Paris Agreement entered into force in November 2016 and as of April 2019 has been ratified by 185 countries (UNFCCC, 2019e). The central aim of the Paris Agreement is to limit global average temperature increases to be well below two degrees

Celsius above pre-industrial levels, and to pursue efforts to limit the temperature increase to be below 1.5 degrees Celsius above pre-industrial levels. The key difference between the Kyoto Protocol and the Paris Agreement is the level of emission reduction targets. In the Kyoto Protocol, Annex B countries who ratified the treaty were legally required to reduce emissions to a target set forth by the Kyoto Protocol. In contrast, the Paris Agreement allows for countries to volunteer their own reduction targets, and offers no enforcement mechanisms to hold countries accountable should they fail to meet their targets (Reguly, 2019).

While the Paris Agreement is a step forward in some respects such as by including a way for developing countries such as China and India to set emission reduction targets, there is still much doubt as to whether nationally proposed reduction targets will be enough to keep rising temperatures below the treaty's goal. The UNFCCC has expressed serious concern about the carbon-reduction pledges' ability to reduce temperature increases to a safe level (Reguly, 2019). Concern over the lack of enforcement mechanisms is especially valid, as a "name and shame" system is likely to have little effect on rational decision making from the standpoint of profit maximization. This lack of enforcement may well be the downfall of the Paris Agreement, and may subvert its effectiveness before even given a chance at success. This, coupled with voluntary reduction targets, leaves much doubt as to whether this agreement will come close to its stated goals. The adoption of new technologies that reduce the amount of emissions needed in the production of goods, or a decrease in economic growth leading to less production, are required to combat rising temperatures around the globe. In light of these drastic changes, the supposed goodwill of participating governments does not instill confidence that these decisions necessary to avert environmental disaster will be made.

The Paris Agreement includes carbon mitigation frameworks similar to those in the Kyoto Protocol, such as international emission trading and the so-called Sustainable Development Mechanism, which is intended to be a successor to the Clean Development Mechanism. While details of the Sustainable Development Mechanism are yet to be determined, one major difference between it and the Clean Development Mechanism is that countries other than Annex B countries are allowed to participate, making the program much wider in scope. There are no specific commitment periods under the Paris Agreement, however the implementation of the agreement by member countries will be evaluated and a new reduction commitment made every five years. The first such evaluation will be in 2023. Time will tell how effective the Paris Agreement will be at reducing global GHG emissions, or if inherent issues with the treaty will cause it to be a failure similar to the Kyoto Protocol.

CHAPTER 2: ECONOMICS OF EMISSION TRADING SYSTEMS

A problem faced by regulators designing an emission reduction policy is the difference in abatement costs between emission sources. Regulations that require across the board reductions in emission levels for differing sources cost more for sources with higher abatement costs. This is especially true for international emission reduction commitments such as those required by the Kyoto Protocol or Paris Agreement, where countries may have very different marginal abatement costs (MACs) depending on various factors. Emission trading systems are a means of utilizing differing MACs to achieve a reduction target at the least total cost to sources involved. The primary idea behind emission trading systems is that sources with a lower MAC can reduce more than is required by a specified emissions cap, while selling the excess pollution rights to sources with a higher MAC.

Marginal abatement cost refers to the dollar amount required for a given source to reduce emissions by one additional unit of CO_2 equivalent. Marginal abatement cost is typically represented through the use of a marginal abatement cost curve (MACC.) There are two primary forms of MACCs, continuous MACCs and measure-explicit MACCs. Continuous MACCs are depicted as a continuous line representing a single dollar value for a single quantity of emission units reduced. Measure-explicit MACCs represent the costs and quantities of emissions abated by multiple specific abatement policies and procedures (Vogt-Schilb and Hallegatte, 2013). While continuous MACCs are useful for mathematical modeling and calculating marginal, average, and total cost they do not accurately describe situations faced by policy makers when developing an abatement strategy. Regulators are faced with having to choose between specific policies and procedures, each with their own total costs and levels of emission reductions. For this decision making process, measure-explicit MACCs more accurately depict the cost structure being decided upon. It is possible to use computable models to find least-cost combinations of such policies in order to generate a continuous MAC from the possible abatement policies. By generating a continuous MAC from policies depicted by a measure-explicit MAC and estimating a corresponding mathematical function, the resulting curve can be utilized in analytic models.

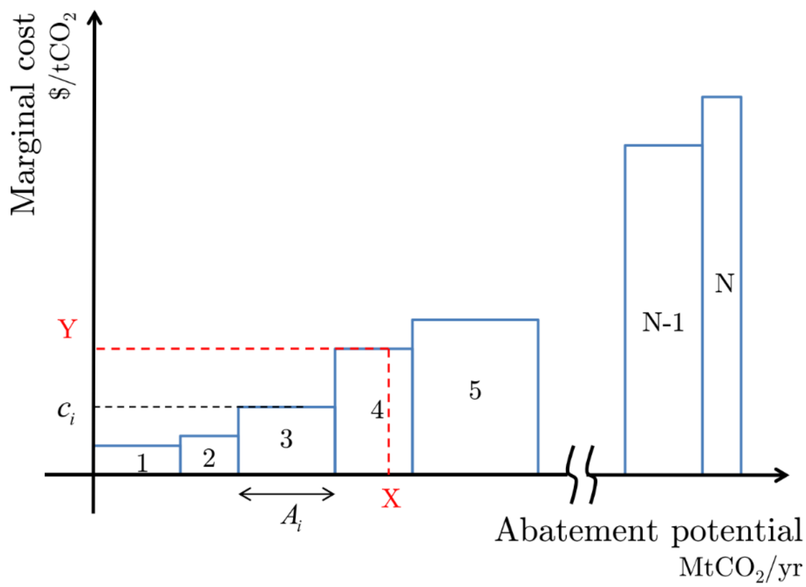

Figure 3. A measure-explicit MACC exhibiting N abatement options ranked from the least to the most expensive. Each option i is characterized by their abatement potential A_i and their marginal abatement cost c_i. These curves are for a given date T. Source: Vogt-Schilb and Hallegatte, 2013.

To illustrate the gains from trade between two emission sources made possible by an emissions trading system, consider the following simplified example illustrated by Figure 4. There are two countries, Sweden and Germany, such that the slope of Sweden's MAC curve is steeper than the slope of Germany's MAC curve. This is implies that for reduction levels sufficiently large, the Sweden's MAC is greater than Germany's MAC, or $MAC_S > MAC_G$. For the sake of this example, we will assume the MAC curves are linear, implying that marginal abatement cost increases at a fixed rate. Each country faces an emissions cap, and thus must reduce emissions by an amount R_{REQ}, which need not be the same for both countries. Either may choose to reduce their emissions by the required amount, or choose to buy or sell emission permits through the emission trading system. The prevailing price of permits in the emission trading system is P. The point where the price P intersects the MAC curve is denoted by R^* and represents the point where the marginal cost of abating a single unit of emissions is equal to the price of one emissions unit permit.

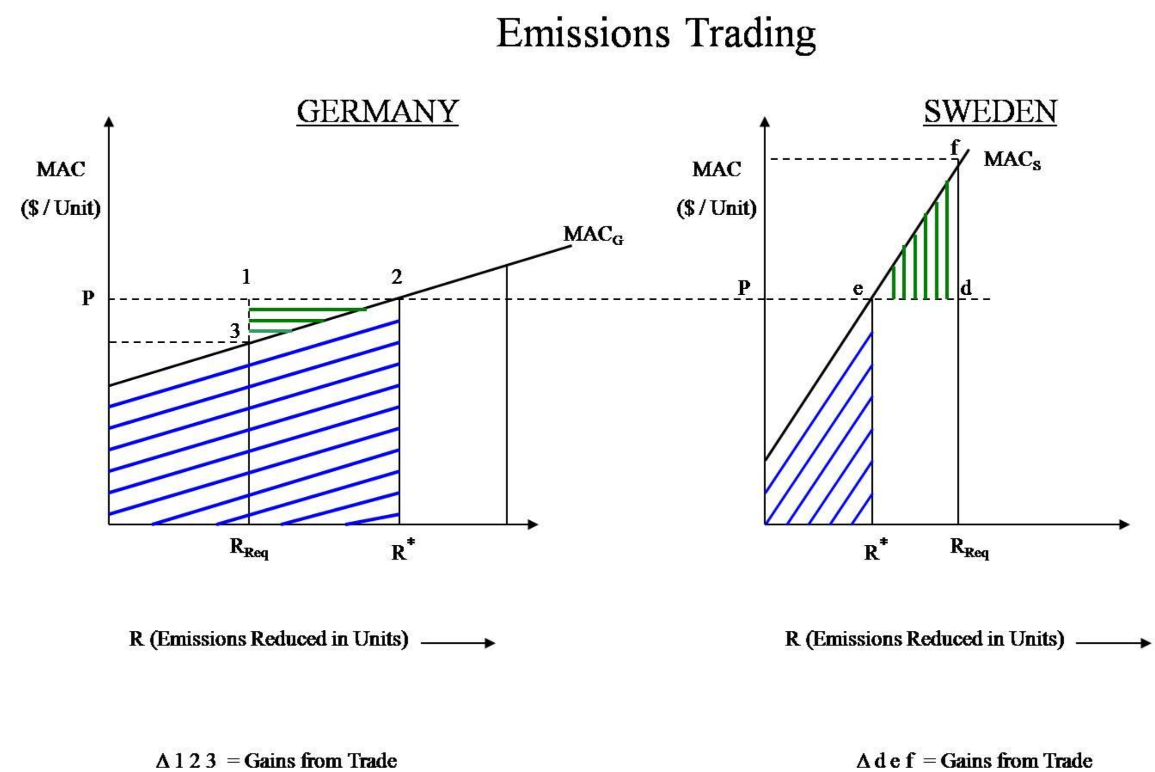

Figure 4. "The Emissions Trading Economics of Two Participating Countries" by "Foxscully xf" at English Wikipedia is licensed by CC BY 3.0.

In this example, R_{REQ} for Germany is lower than R^*, and for Sweden R_{REQ} is higher than R^*. Germany stands to make a profit by reducing additional units of emissions $R^* - R_{REQ}$ and selling these additional units at price P, represented by the green shaded region $\Delta 123$. Meanwhile, Sweden stands to benefit from a reduction in the cost of emission abatement by buying a quantity of permits equal to $R_{REQ} - R^*$ at price P. The total reduction in cost is represented by the green shaded region Δdef. The total benefit to the economy is the sum of these two regions, consisting of increased profits for Germany and reduced costs to Sweden. This example can be generalized to individual sources within an economy as opposed to entire countries, or to a number of participants in an emission market greater than two. Those with abatement costs greater than the prevailing market price of permits will benefit from trading through a reduction in cost, while sources with abatement costs lower than the market price stand to profit from the sale of additional abatement permits. It is worth noting here that the gains from trade for Sweden are larger than those for Germany in this example. The size of each participant's gains from trade depends on the slopes of the MAC curves of the participants. A steeper slope for a MAC curve will lead to a large potential gain from trading.

An Economic Analysis of the Kyoto Protocol

Ellerman and Decaux perform an analysis of emissions trading under the Kyoto Protocol in their 1998 paper "Analysis of Post-Kyoto CO2 Emissions Trading Using Marginal Abatement Curves." Their analysis is based upon MAC curves for different regions around the globe generated by MIT's Emissions Prediction and Policy Analysis (EPPA) model. These MAC curves may be used to determine marginal, average, and total costs of specified levels of emission reductions, as well as to quantify the gains from trade realized by permit trading. The EPPA is a multi-regional, multi-sectoral Computable General Equilibrium model developed by Yang et. al. (1996) for the MIT

Joint Program on the Science and Policy of Global Change. Ellerman and Decaux use version 2.6 of this model published in 1996 for generating the MAC curves used in their analysis. The most recent publication of this model is version 6 published in 2015 by Chen et. al. (2015), which continues to be broadly applied on energy and climate policy analyses.

The EPPA model produces a shadow price for a specified constraint on emissions for a given region and time, such as a 10 percent reduction below a reference year for the United States in 2010. This shadow price is the implicit cost of the defined constraint within the model when solved for general equilibrium, and represents the social opportunity cost of meeting the constraint, in contrast to a price found within a real-world market. By running the EPPA model under different constraints for the same region and time period, the corresponding shadow prices produced by the model can be plotted to estimate a marginal abatement cost curve for the given region and time period. It is worth noting that this paper uses calculations from 1998, using predictions for emissions in 2010 based on data from this period. As such, while the qualitative results are likely to still be applicable, the quantitative results are likely to not match current data, and should be viewed with this in mind.

In order to test the robustness of the MAC curves generated by the EPPA, Ellerman and Decaux (1998) generated MAC curves under various policies and compared the curves to determine if any significant differences exist. The first such policy used to generate MAC curves is a proportional reduction (1%, 5%, 10%, 15%, 20%, 30%, and 40% of reference levels) of emissions by all OECD countries. Next, they compare the MAC curves corresponding to various levels of abatement under no emissions trading and fully efficient emissions trading. The result is less than a 10 percent variation in price for a given level of abatement, showcasing the robustness of the MAC in regard to these different policies. Similar comparisons are made for Annex B trading and global trading. Additionally, the authors examine one region's MAC curve when all other region's reductions vary by as much as a 60 percent reduction from reference levels. In all cases, the difference between MAC curves is negligible, indicating that abatement costs in one country are largely independent of the level of abatement in other countries.

The significance of the robustness of MAC curves is that each region at a specific time has a unique MAC curve associated with it. Estimating a well-fitting mathematical expression for such a curve greatly simplifies the analysis of emissions trading among regions. Unfortunately, such a simplification causes a potential loss of detail in the underlying model. These approximated MAC curves do not capture all of the effects of emissions trading. For the sake of Ellerman and Decaux's analysis however, they are sufficient. The importance of estimating these MAC curves is that they are essential to describing the supply and demand of emission permits. The supply of emission permits is produced by an emission source abating more than it is required to do so, and the demand for permits depends on the market price of permits compared to a source's marginal abatement cost. Thus, both the supply and demand of permits is determined by the price of permits and each participants MAC curve. This measure of supply and demand is summarized by Figure 5.

The vertical axis represents the market price of permits P while the horizontal axis represents the quantity of emissions abated q. The curve depicted is the marginal

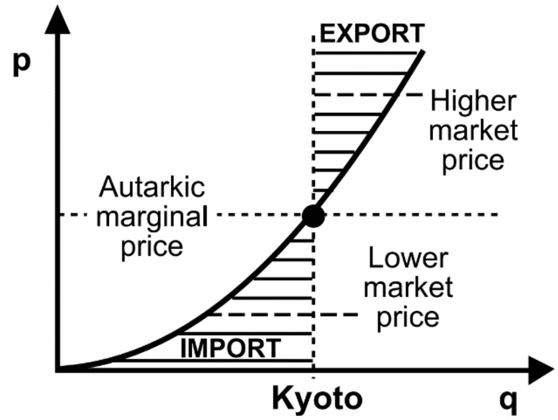

Figure 5. Willingness to buy or sell permits with regard to a market price of permits. Source: Ellerman and Decaux, 1998.

abatement cost curve of an emission source, and the vertical dotted line denoted “Kyoto” is the level of abatement required to meet the source’s Kyoto commitment. In the absence of emissions trading, the intersection of the Kyoto line and the MAC curve will be the marginal cost of abating emissions to meet the commitment. This marginal cost without trading is referred to as the autarkic marginal price. If emissions trading is a possibility, the emission source will choose to either import (buy) or export (sell) emission permits depending on the price of permits P as shown by Figure 5. In the case of sources that are not constrained by an abatement commitment, the autarkic marginal price is zero, and such sources would supply permits to the market at any price greater than zero. The corresponding market aggregate supply and demand curves can be generated by adding up the private supply and demand curves belonging to each participant. The intersection of these two market curves represents the market clearing price and quantity of emission permits traded (Ellerman and Decaux, 1998).

Ellerman and Decaux structure their analysis of the cost of Kyoto commitments by beginning with the simple case of OECD countries only, then expanding the market to include all Annex B countries, and finally opening the market to include full global trading. Ellerman and Decaux divide the OECD into four distinct regions: the United

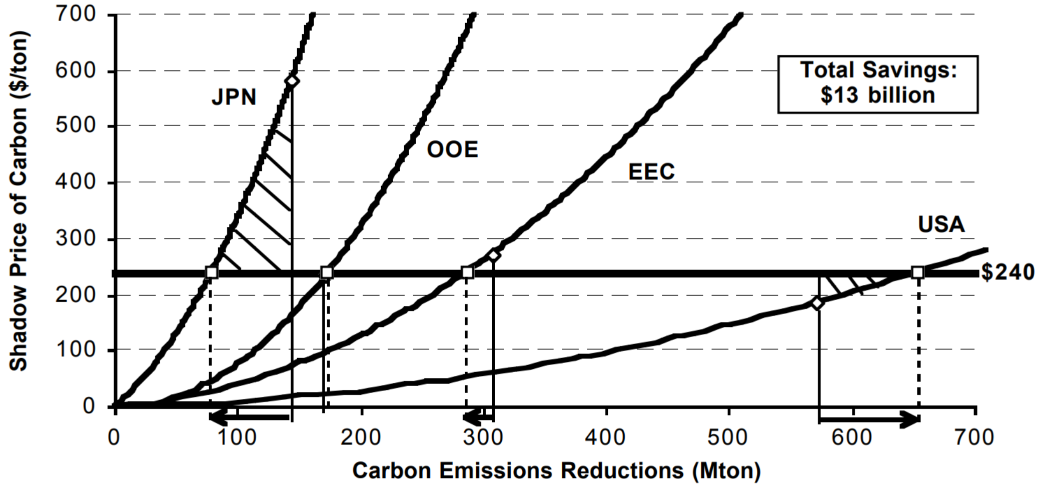

Figure 6. Carbon Emission Reductions with an Emission Trading System between OECD Countries. Source: Ellerman and Decaux, 1998.

States (USA), Japan (JPN), the European Union (EEC), and all other OECD countries (OOE). The MAC curves of these four regions, their Kyoto commitment quantities, and the price of permits that generates a reduction of emissions equal to the total commitment quantities are shown in Figure 6. The price is this model is found to be equal to $240/tonne, which seems to be much higher than is expected in a permit market, although an OECD only permit market does not exist to check the prices.

The diamond on each MAC curve represents the quantity of emission reductions required by the Kyoto commitments of each region, the horizontal line represents the market clearing price of emission permits, and the square on each curve represents the actual amount of emission reductions undertaken by each country. The crosshatched areas under the curves represent the gains from emissions trading; areas above the price line represent cost savings and areas below the price line represent profits from permit sales. The quantity of permits purchased or sold is represented by the arrows beneath the x-axis. In this example, Japan and the European Union are importers of permits to the amount of 86 million tonnes of carbon, while the Unites States and the rest of the OECD countries take on additional abatement efforts to export the same number of permits. The total savings for OECD countries from utilizing emissions trading is equal to $13 billion. Japan sees the largest benefit from trade equal to $10 billion, the Unites States sees the second largest benefit equal to $2 billion, and the rest of the OECD countries benefit a portion of the remaining $1 billion.

Ellerman and Decaux (1998) then repeat this process after adding the two regions Eastern Europe (EET) and the Former Soviet Union (FSU). A major difference regarding the FSU is that the commitments made under the Kyoto Protocol do not constrain the region’s carbon emissions, since the Kyoto commitment it made corresponds to an emission level higher than the one predicted for 2010. This implies that compliance with the Kyoto commitment would cost nothing for the FSU, and any reductions made by the region would go towards supplying emission permits to the market. The FSU is also able to sell a quantity of permits equal to the difference between their commitment level and their actual emission levels. The authors refer to this difference as “Hot Air.” While many observers argue that the export of such permits should not be allowed since they do not correspond to any actual reduction in emissions, the authors point out that the commitment level made under the Kyoto Protocol represents a *permissible* level of emissions. As such, Ellerman and Decaux argue that the FSU should be allowed to bank or export these permits should they remain unused.

The result of adding the two remaining regions of Annex B countries, Eastern Europe and the FSU, is a reduction in the market clearing price of emission permits. With only OECD countries included in the analysis the price per tonne of CO_2 was $240. The price per tonne drops to only $127 once the EET and FSU regions are added to the analysis. While this is a significant drop in price, it is still much higher than is expected from a permit market implemented in the real world. Since this price is lower than the autarkic marginal abatement cost of all OECD countries, they all become importers of permits; the EET and FSU are permit exporters. The total gains from trade among all constrained Annex B countries is $32 billion, and the FSU receives gains from trade equal to $34 billion: $14 billion from selling the unused Kyoto entitlement (hot air) and $20 billion from selling permits obtained from voluntary abatement.

The total gains from trade for all Annex B countries is therefore $66 billion, bringing the cost of meeting the Kyoto commitments down to $54 billion. The total cost of achieving these commitments without trade is $120 billion, more than double the cost when emissions trading is allowed. It is possible to model trading among Annex B countries without allowing the export of hot air permits, which has the effect of a higher market clearing price ($150/tonne) and a reduction in the gains from trade of approximately $16 billion. Nevertheless, the reduction in total cost of meeting the Kyoto commitments is still significant without the export of "Hot Air."

To illustrate full global trading, Ellerman and Decaux utilize supply and demand curves for permits generated from the potential quantities that are bought and sold among various regions at different prices. There are two supply curves generated for comparison, one for trading among Annex B countries, and one for global trading. There is only one demand curve, since the constrained countries who wish to purchase permits are the same in both trading situations. A graph of these supply and demand curves is provided in Figure 7.

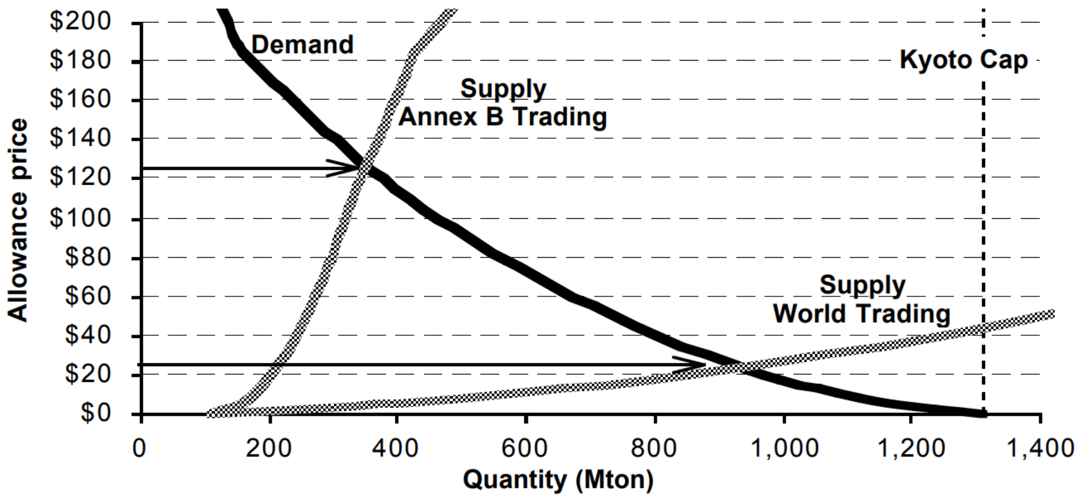

Figure 7. Supply and Demand Curves for Emission Permits with Annex B and Global Trading. Source: Ellerman and Decaux, 1998.

The market clearing permit price of $127 per tonne is shown by the intersection of the Annex B Trading supply curve and the demand curve. When global trading is allowed, the market clearing price is far lower, only $24 per tonne. This price seems to be a much more reasonable estimate for a market price of permits. At this price, all Annex B countries aside from the FSU are importers of permits. In the aggregate, 71 percent of constrained countries' commitments are met by importing permits. Three countries account for 81 percent of the supply of permits in the world: China (47%), FSU (23%), and India (11%). With this lower price of emissions, the total cost of meeting the Kyoto commitments is extremely low, only $11 billion compared to $54 billion with Annex B trading and $120 billion with no trading (Ellerman and Decaux, 1998).

If other countries around the world had been subject to emission reduction commitments under the Kyoto Protocol, there would be shifts in the supply and demand curves depending on the level of commitments. These commitments would come with an associated cost of abatement and thus an increase in the demand for permits at prices lower than each country's marginal abatement cost. Thus for low price levels, the demand curve would be expected to shift to the right. It is unclear as to whether this would result in a different market clearing price of emission permits. If the marginal abatement cost of non-Annex B countries is lower than the market clearing price indicated above with global trading, there would be no change in price. However, if the marginal abatement cost of one or more countries is above this price, the demand curve would shift to the right and the market clearing price would increase. The price increase would be larger as more countries exist with marginal abatement costs above the unconstrained price level above ($24 per tonne).

While these results qualitatively make sense from the viewpoint of economic theory, quantitatively they vastly overstate the price of Certified Emission Reduction (CER) permits, which are the main tradable permit under the Kyoto Protocol. According to market data from the Intercontinental Exchange, an electronic market for trading energy commodities, the price of one CER permit costs €0.24/tonne, one hundred times less than the full global trading case. This seems to be more than just error from predicted data, and seems to point to larger problems between the theoretical model and what has happened in the world since. It is possible that the model itself is incorrect, vastly overstating the implicit costs of reducing emissions. Another possibility however is that Kyoto Protocol reduction targets were not met or enforced properly, or that emissions have grown faster than expected, increasing the supply of permits and driving the price down. Indeed, this price seems excessively low, especially compared to the price of an emissions permit from the European Union Emission Trading System, which is listed on the Intercontinental Exchange at €26.60/tonne. This is almost the same as the price predicted for full global trading of emission permits, but far below the price determined in the Annex B trading scenario. The price of an emissions permit in the Quebec-California emission trading system lie between these two prices, fluctuating around $16/tonne depending on the auction they are purchased from.

The implications of an emissions trading scheme that allows for gains from trade among sources is a greater ability for a region to meet reduction requirements imposed upon it by regulators. Compared to a region without trade, the cost savings afforded to high-MAC emission sources may allow them to meet their abatement requirements when they are not able to afford to do so in the absence of trade. This has the potential to provide a region with a measure of economic stability, under the assumption that not complying with abatement regulations can lead to the closure of a firm or heavy monetary penalties. The other gains afforded by emissions trading are the increased profits achieved by low-MAC sources. While the level of reductions is the same under both autarkic and trading scenarios, these profits can be reinvested by firms to achieve further reductions or increased productivity within a region. While current emission trading systems are a step in the right direction to place a price on carbon and help curb usage, it seems that the price is not indicative of the true cost of emissions, when considering potential damages caused by increases in global average temperature. Due to the way emission trading systems work, it is likely that these prices show that the allowable quantity of emissions are far lower than what is required to avert disaster.

Permit Allocation

There are three primary distribution channels that regulators can use to initially allocate permits to individuals and firms within an economy. Once the initial round of permits has been allocated, market participants are able to trade the permits among one another through market channels similar to other commodities. The first method to allocate permits is for regulators to sell them, either with a fixed price or through an auction mechanism. The benefit to an auction over a fixed price sale is that prices are flexible, and thus an efficient market clearing price is more easily found. Regulators setting a fixed price incurs administrative costs to determine the market clearing price, reducing the efficiency of the emission trading system. By utilizing an auction mechanism, firms bid for permits based on their demand and the available supply of permits. Firms with a higher level of emissions would have a higher demand for permits and would thus be willing to pay more, whereas firms with low levels of emissions would bid less due to a smaller number of permits demanded. Regulators are able to have some control over auction prices by setting a reserve bid price, essentially placing a price floor on permits and guaranteeing a minimum cost. In conjunction with permit supply controls, regulators are able to entice firms and individuals to reduce their emission levels by making permits more expensive or more scarce.

The second option for regulators is to simply give the initial allocation of permits away to firms and individuals for free. This would reduce the total cost of emitting, and would potentially increase profits from the sale of unneeded permits on the secondary market after the initial allocation. By not having to incur extra costs to cover emissions, firms that compete in highly competitive international industries are able to keep their current competitive position. A concern of charging such firms for emissions is that by increasing their cost of production, they will no longer be able to compete with rival firms in regions that do not have emission regulations. This could have widespread negative effects on some economies where the primary employers are firms such as these. The increase in costs could cause these firms to move to a less regulated region, or to have to shut down entirely if they are unable to raise prices sufficiently to cover the increase in cost. There is a downside to giving permits to firms for free. By doing so, there is no incentive for firms to change their emission decisions from past behaviour, since they will expect to receive permits covering their emissions for free. While this does limit emission growth when combined with a cap, there is no incentive for firms who receive free permits to innovate to reduce emission levels beyond what the cap requires.

The third allocation option available to regulators is offset generating programs. Offsets are emission allowances generated by individuals or firms through programs typically organized by regulators of emission trading systems. Offset permits are generated by either reducing the amount of GHG emissions from a source, such as a methane capture program on a dairy farm, or by sequestering atmospheric carbon such as through the creation of forests. Each offset is the equivalent of one tonne of CO_2 and is able to be bought and sold through emission trading markets. Often times emission trading systems only include a small subset of firms and emission sources under their regulations, and offset programs allow for individuals and firms that are not included in the trading program to participate.

There is no difference between offset permits generated within an emission trading system and emission permits allocated to sources with commitments. The greatest advantage of offset programs is that they incentivize individuals with small carbon impacts to enact reductions by allowing for the sale of such offset permits to earn additional income. The potential downside is that if large enough firms undertake efforts to generate offset permits in a large enough quantity, the increased market supply of permits may provide downward pressure on prices, making all emissions in the economy cheaper. This has the potential to reduce the incentive to innovate in low-emission technologies, and allows firms to emit more for the same price they were paying previously. While regulators can impose restrictions on how many offset permits may be used towards a specific firm's emission cap, it becomes increasingly costly to monitor the distribution of offsets and where they are being used.

All allocation methods have benefits and costs that must be weighed when deciding how to initially allocate permits in an emission trading system. Regulators will likely have to balance a combination of these methods to achieve their goal of reduction in overall emission levels while maintaining a level of economic stability in the region they operate. An analysis of the firms within a region for a potential emission trading scheme will be necessary to determine the levels of permits allocated by each method. While the majority of permits should be sold either with a fixed price or by auction, as well as through the use of offset programs, it may be necessary to give some firms free permits to maintain certain jobs for consumers, or to maintain competitive standing in international markets.

Comparisons to Carbon Taxes

There exist other market-based reduction schemes that have been implemented in various regions around the world to incentivize emission reductions aside from emission trading systems. The most common system of this type is a tax on carbon emissions set by regulatory bodies. Both a carbon tax and an emissions trading system place a price on carbon with some overlap of policy design. A cap and trade system that is comprehensive in scope and has an upstream point of regulation is very similar to a comprehensive, upstream carbon tax. Comprehensive in scope means that the policy covers all emissions in a given region, and an upstream point of regulation refers to regulations applied where the emissions enter the market, typically as part of the production process (Durning et. Al., 2009). Cap and trade systems and carbon taxes however, work in two fundamentally different ways. An emissions trading system acts as a quantity instrument, while a carbon tax acts as a price instrument. What this means is that an emissions trading system sets an allowable quantity of emissions and lets the market determine the price of emissions, while a carbon tax sets a price for emissions and lets the market determine the quantity of emissions produced (Durning et. al., 2009).

There are several other smaller differences between the two systems aside from the type of instrument they are. Carbon taxes may be simpler to set up and be able to be administered faster than an emission trading system. If a regulator faces severe time constraints or administrative restrictions, a carbon tax system may be a better solution than a cap and trade system. A large advantage of emission trading systems, however, is that they are able to be linked together among various regions, either sub-nationally, nationally, or internationally. Emission trading systems also create resistance to changes in legislation that may reduce the value of emission permits from permit holders, such as a loosening of the cap over a given region. While they have their differences, emission trading systems and carbon taxes can be combined to provide a more stable price of carbon when permits for a cap are auctioned off. The carbon tax acts as a reserve price in the auction, maintaining a price floor and ensuring the incentive to reduce emissions does not weaken too much (Durning et. al., 2009).

When compared in practice, emission trading systems are more feasible at achieving a given level of reduction. Since the reduction level is defined by the cap placed on emissions, there is certainty in how much emissions will fall, and does not require any further knowledge than what level that cap should be. In contrast, emission taxes as a price instrument require information about what price level will correct the inefficiencies caused by GHG emissions. Such information is likely not available, and will be either very costly to obtain, or not possible to obtain at all. Since potential future damages are unknown, it is very difficult to set a price per unit of emissions to cover these damages. As more research has been done on the economic damages of climate change, the potential damage costs have increased over time, indicating that the price set by a tax is likely to underestimate the future costs of damages. While emission taxes may be easier to implement, and may provide some benefit, they are likely to be less effective than emission trading systems due to the additional information required.

CHAPTER 3: FAILURES OF EMISSION TRADING SYSTEMS

Leakage

One failure of emission trading systems is leakage of emissions. Leakage refers to emission sources moving from an emission constrained location to one with either less strict or no regulations whatsoever. This issue arises from unequal policies enacted by different regions, and greatly undermines the effectiveness of emission trading systems. Due to the relative mobility of firms enabled by the advances in transportation that have occurred in the past few decades, it has become more difficult to enact heavy regulations on firms within a specific region. While tariffs and border taxes help increase the cost of a firm producing in a different country than its primary market, they are ineffective at differentiating between products and firms from that country. Leakage of emissions is very similar to firms moving to developing countries to exploit looser labour regulations and cheap labour, while exporting the products back to developed countries.

Developed countries, such as Annex B countries with emission level restrictions under the Kyoto Protocol, have been criticized of “exporting” their emissions to less developed countries without emission regulations, such as China. Even if production within a domestic region does not move to another region, if a large percentage of consumption is on goods imported from a foreign region with no emission regulations, the increased demand of imports causes as much of an issue as if emissions were increased in the domestic region. While the issue of leakage and the exportation of emissions cannot be remedied without full global regulations on emissions, they can be greatly reduced by regulating key emitters throughout the world. The Paris Agreement, which allows for all countries to volunteer emission reduction targets, is a good first step toward this. Further, expanding the scope of regulations and emission trading systems is likely to increase efficiency and reduce these issues.

Manipulation of Emission Trading Systems

Similar to many other markets, there is the potential for participants to manipulate a permit trading system to either increase or decrease permit prices for their benefit. This concern is especially strong when there are few market participants, in which case collusion between agents becomes easier to carry out. Manipulation of an emission trading system would undermine the effectiveness of reducing total emissions, as well as potentially harming the operations of other agents by unfairly increasing their costs to an unsustainable level. If emission trading systems are to become widely used as a tool to reduce emissions, there must be some measures taken to protect against such manipulations. While measures can be taken to reduce the risk of manipulation, there does not exist an efficient system that agents are willing to participate in that is unable to be manipulated (Shin and Suh, 2007). An example of manipulation provided by Shin and Suh are agents misrepresenting their production technologies, in effect falsely reporting their actual amount of emissions. While this may be avoided by having emissions monitored by regulators, as the number of emission sources being monitored increases, so do the costs of monitoring them. As the monitoring costs increase, the effectiveness of an emission trading system to reduce the costs of abatement decreases.

Level of the Emission Cap

Another potential source of failure for emission trading schemes comes from the level that is set for the cap on emissions. Choosing a cap is a complex issue that is more political in nature than it is economic, and as such there are wide ranging levels among emission trading systems implemented around the world. It should be emphasized here that emission trading systems are merely a way to efficiently achieve a capped emission level; however, the level of such a cap is economically arbitrary. What this means is that emission trading systems *do not reduce emissions in and of themselves*. Instead, they are a mechanism to achieve a given reduction target at the lowest cost. Since such caps are set by regulators, political pressure from firms and lobbyists may lead to regulators setting a cap that does not lead to any meaningful reductions in emissions. Thus, if the emission cap is insufficient to avert environmental damage, emission trading systems will be of no use with regard to helping combat climate change.

Additionally, a cap that is set too low can potentially strangle the economy within the region the cap is implemented. Emission reducing technologies can achieve a certain amount of reductions, and a cap set below this level would require a reduction in output in addition to implementing greener technologies. As the cap is set lower and lower, production will continue to fall to meet it, which would reduce the level of consumption within the region. The effect may be that consumers pressure regulators to increase output, or emission leakage as producers move to other less constrained regions. Both of these pressures work against the need for lower emissions, and as such regulators face a difficult decision on the level of the emission cap to implement, which defines the ability of an emission trading system to reduce emissions. It seems to be that climate scientists should set the required cap on emissions at a level which their models deem sufficient to reduce the threat of warming average global temperatures, however it is unlikely that this will happen due to the nature of global political processes.

CHAPTER 4: CONCLUSION

Emission trading systems and other market based mechanisms have been proposed as a means to reduce pollution and to help internalize the externalities present in the usage of public goods. There is strong theoretical evidence that emission trading systems can be an effective means of finding a least-cost solution for achieving a level of emissions proposed by a regulatory body. They achieve this through a reduction in administrative costs, and by incentivizing those with a lower cost of reducing emissions to do so and sell their excess reduction capacity to others with a higher cost. In addition to theory, there is strong empirical evidence that such systems can be successful, so long as they are well designed with an emission cap that achieves the reductions sought after. When compared to other market based reduction strategies such as emission taxes, emission trading systems tend to be more effective due to setting the quantity of reductions outright and letting the market determine the price, as opposed to setting the price and allowing the market to determine the quantity reduced. This second method requires much more information on what price will achieve the desired reductions, and is more likely to be affected by market imperfections and stochastic shocks. The drawback of emission trading systems however is that they do not in and of themselves cause a reduction in emissions, but rather rely on the defined emission cap. Since this cap is set by regulators, there are non-economic factors that may influence it to be non-optimal, in which case the system will never achieve the optimal reductions. Even though, emission trading systems remain a powerful administrative tool that reduce the costs of reductions necessary to help prevent future environmental damages and disaster.

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