A COMPARATIVE COST ANALYSIS OF TWO INTERNATIONAL CARBON DIOXIDE EMISSION REDUCTION STRATEGIES

by

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DEDICATION

To Anne

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ABSTRACT

The average world temperature in 1998 was 58.946° Fahrenheit, the highest temperature ever recorded on Earth. Numerous scientists have proposed that this record high in particular and the warming trend over the past 130 years in general was caused by an increase in carbon dioxide emitted through artificial processes. This thesis will outline the most efficient way to undertake an emission reduction program. This thesis will also analyze the costs of two ways in which 157 nations can reduce their emissions of carbon dioxide: allowing the trade of emission permits, and not allowing trade. It is hypothesized that the trade of permits will cost less than a program that does not allow trade. There is a large cost savings potential with the trade of permits, but whether or not permits are traded, reducing carbon dioxide emissions is relatively cheap. It is also surmised that costs of reducing emissions will decrease as more countries are included in a trading program.

1 INTRODUCTION

1.1 Nature of the Problem

In 1827 the French mathematician and scientist, Jean Baptiste Fourier, observed that certain gases trapped heat in the atmosphere. He termed this process the greenhouse effect (Brown 1996). He described the atmosphere like the glass in a greenhouse. It lets in the sun's rays and warmth but also provides a barrier that prevents the heat from escaping. Some gases in the atmosphere, particularly carbon dioxide, act like those panes of glass. In June, 1988, atmospheric scientist James Hansen of NASA's Goddard Institute for Space Studies reported to a United States Senate committee that he was 99% confident that the rise in global temperatures over the last decade was not a random event, but a sign of a warming trend (World Resources Institute 1990). The popular term for this trend is global warming. Global warming is the enhanced greenhouse effect caused by the introduction to the atmosphere of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs) through artificial processes. These artificial processes include the combusting of fossil and biomass fuels, coal mining, cement production, enteric fermentation, application of ammonia-based fertilizers, rice cultivation, the clear-cutting of forests, and the use of air conditioners, aerosols, and other refrigerants (Brown 1996; Braatz et al. 1996).

Since the 19th century, the earth's temperature has risen between .3°C and .6°C. According to Dr. Tim Johns of the Hadley Centre in Berkshire, the global temperature will continue to increase at a rate of .2°C per decade (Brown 1996). Figure 1 shows how the world's mean surface air temperatures have risen since 1865. (It should be noted that average temperatures in Arizona are expected to increase by 3°F to 4°F in the spring in

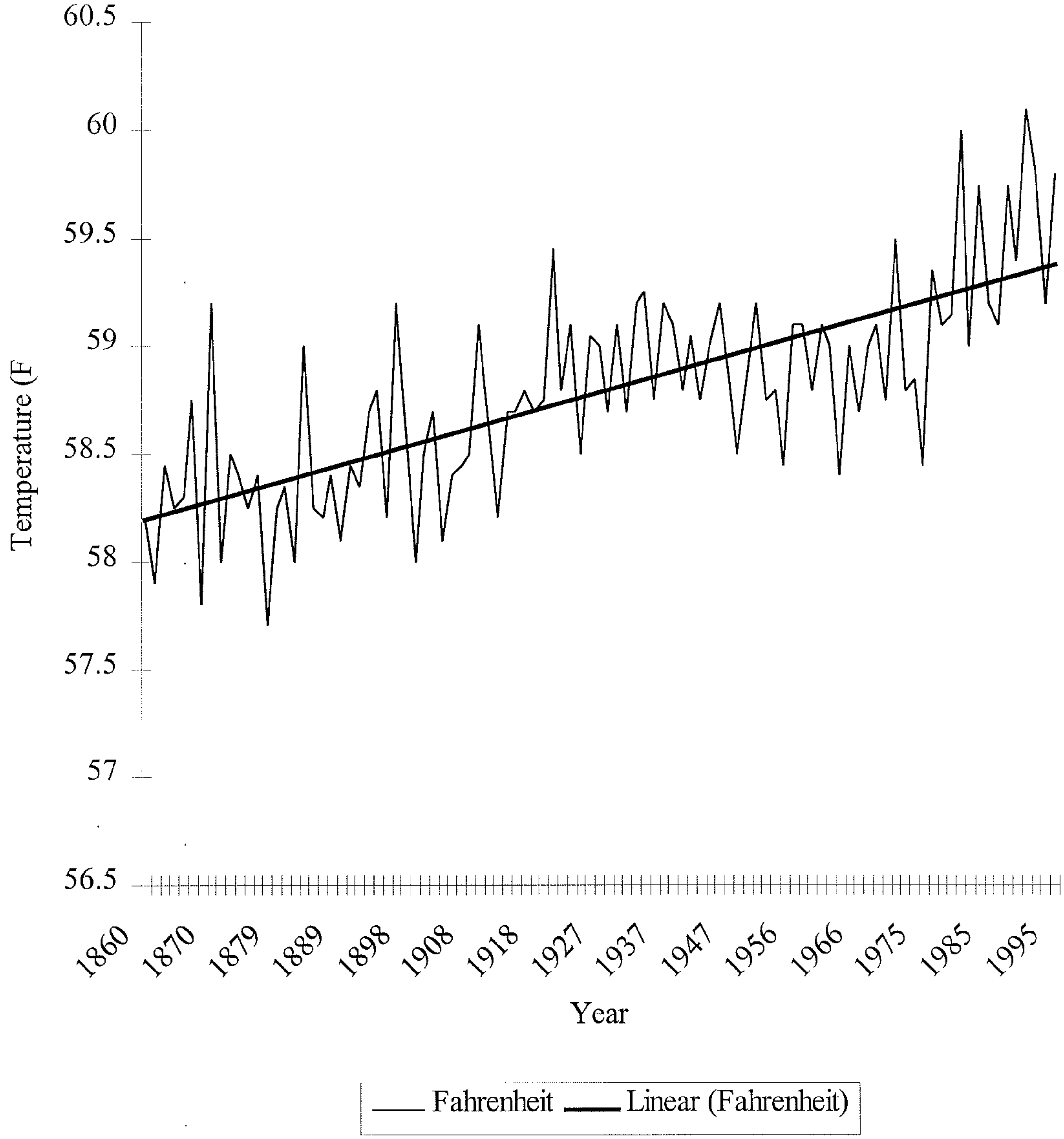

Figure 1 Global Mean Surface Temperatures, 1865-1995

Source: University Corporation for Atmospheric Research, 1997 fall seasons and by 5°F in the winter and summer seasons by 2100.) The trend line fitted to the data substantiates this rise. The effects that global warming could have are far-reaching and potentially catastrophic. These impacts include regional temperature and rainfall changes, sea level rise, and an increased frequency and severity of natural disasters. Some areas particularly susceptible to a temperature rise are the irrigated semi-arid areas of northern mid-latitudes, the lowland areas and island countries of the humid tropics in Asia, the Pacific, and the Caribbean, the arid and semi-arid zones of Africa, south Asia, west Asia and North Africa, rainfed upland and highland regions, extreme northern latitudes, and the mid-latitude temperate forests in the northern hemisphere. The sea level rise would increase the risk of flooding, increase beach and coastal erosion and encourage salt-water intrusion, lead to the disappearance of some islands and coastal strips, and cause the loss of coastal fisheries, fish farms, and wetlands (Barbier and Pearce 1990).

Global warming is no longer considered a problem concocted by preservationists searching for a means of safeguarding our planet. Rather, world and industry leaders are joining the cause to reverse global warming. In 1990, before the United Nations, Margaret Thatcher, former British Prime Minister, spoke of global warming being the greatest threat facing the human race (Brown 1996). Vice-president of the United States, Al Gore, wrote a book partly devoted to global warming. Representatives of British Petroleum, the world's third largest oil company, announced concern about human activity changing the Earth's climate (Stevens 1997). In October of 1998, British Petroleum, General Motors, and Monsanto joined with the environmental organization, The World Resources Institute, to call for actions to reduce the risk of climate change. In acknowledging the problem, these four entities agreed that "the climate challenge provides business and industry an opportunity to lead and innovate, by offering products and services that take advantage of markets driven by climate policy" (UNFCCC 1998A). Al Gore, speaking at the 3rd Conference of the Parties in Kyoto, Japan stated, "Last week we learned from scientists that this year, 1997, will be the hottest year since records have been kept. Indeed, nine out of ten of the hottest years since measurements began have come in the last 10 years. The trend is clear" (UNFCCC 1998A).

There have been numerous gatherings of world leaders to address global warming. The First World Climate Conference was held in 1979. It explored how climate change could affect human activities. At the conference, scientists endorsed a World Climate Program under the auspices of the World Meteorological Organization, the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions (UNEP 1998). A number of intergovernmental meetings have been held recently, including the Toronto Conference in 1988, the Ottawa Conference in 1989, the Noordwijk Ministerial Conference in 1989, the Second World Climate Conference in 1990, the Earth Summit in Rio de Janeiro in 1992, and the Climate Conferences of the Parties (COP) in 1995, 1996, 1997, 1998, and 1999 in Berlin, Geneva, Kyoto, Buenos Aires, and Bonn respectively.

In 1992, in Rio de Janeiro, over 150 nations created the Intergovernmental Panel on Climate Change (IPCC). The IPCC developed the United Nations Framework Convention on Climate Change (UNFCCC). The supreme body of the UNFCCC is the COP. The role of the COP is to "promote and review implementation of the Convention" (UNEP 1997). The ultimate objective of the Convention is to stabilize greenhouse gas concentrations at a level that would prevent interference with the climate system (Braatz et al. 1996). Since its origination, over 150 nations have ratified or acceded to the Convention. Although the primary goal of the Convention is the stabilization of all greenhouse gases, this thesis focuses on the stabilization and subsequent reduction of (CO_2).

1.2 Why Attack Carbon Dioxide Emissions?

Reduction in carbon dioxide emissions is the best strategy for halting global warming. CO_2 accounts for the greatest percentage of instantaneous warming (the relative impact upon warming per unit of concentration) and total warming potential of all greenhouse gases (Nordhaus 1991b). Carbon dioxide contributes 53.2% and 80.3% of instantaneous and total warming potential, respectively; while methane contributes 17.3% and 2.2%, CFCs 11 and 12 contribute 21.4% and 8.8%, and nitrous oxides contribute 8.1% and 8.7% (Nordhaus 1991b). Second, the most information regarding emissions covers CO_2. No adequate means exist to quantify the importance of the other sources (Swart 1993). Third, reductions of CO_2 emissions would be the easiest to achieve. Forty three percent of CO_2 emissions come from the United States, the former Soviet Union, and the European Community. Of those emissions, 99% are derived from the burning of fossil fuels (Cline 1992).

1.3 Tradable Emission Permits

In 1972 W.D. Montgomery developed the idea of creating a market for pollution (permit trading). Montgomery proposed two types of tradable emission permits, a system of pollution licenses that define allowable emissions in terms of pollutant concentrations at a set of receptor points, that can be bought and sold, and emission licenses that establish the right to emit pollutants up to a specified rate (Joeres and David 1983). Much work has been devoted to showing the advantages of trading programs over programs based upon taxes, subsidies, and standards (Haites 1991; Hahn and Hester 1989; Tietenberg 1985; 1992a; Dwyer 1992).

In the 1970s, the EPA created emissions trading programs based on bubbles, banking, offsets and netting. In 1975, the bubbles approach was adopted in response to industry pressures for greater flexibility in attaining pollution reduction goals. Much of the pressure came from older firms that could not meet the standards authorized by the original Clean Air Act. The bubbles policy allows swapping of emission rights within plants, across plants, and across firms provided that total emission levels are not increased.

In 1977, offsets were created to allow a firm to increase emissions if other firms offset the increase with a simultaneous equivalent decrease. Offsets generally are employed when a new firm begins operations and begins to pollute. Existing firms must offset the resulting increase in pollution. This policy is intended to accommodate economic growth while considering environmental objectives. An example of a successful offset occurred in Pennsylvania and involved the Volkswagen Company. To attract Volkswagen to Pennsylvania, the state curtailed hydrocarbon emissions from existing sources so that Volkswagen's hydrocarbon releases from painting and other plant activities would not lower the state's air quality (Field 1992).

In 1979, the banking policy was created to allow firms to accumulate credit for past reductions of emissions. Banking facilitates the transfer of credits from one firm to another. Netting was created in 1980. Netting is an intra-firm transaction. If a planned enlargement of a firm could increase pollution emissions, the firm can expand only if they cut emissions by an equal amount within the firm (Field 1992).

In 1982, these four provisions were integrated into a single emission trading program. Unfortunately, this program was voluntary. It had numerous detractors. State governments were unwilling to initiate trading programs because they feared they would be compromising economic competitiveness and the policy would be difficult to administer. Environmentalists were skeptical because they thought trading programs would be open to many loopholes and lead to less compliance. Due to the inactivity of state governments, bubbles, offsets, bankings, and nettings occurred rarely. From 1975 to

1986 there were approximately 2000 offsets, 130 bubbles, 110 bankings and 8500 nettings transactions nationwide (Hahn and Hester 1989). The primary reason for the 8500 nettings was that for expanding firms, nettings were cheaper than time-consuming permitting procedures that applied to new sources of emissions.

Under a tradable emission permit system, firms are allocated a number of permits to pollute, and the firms are allowed to do what they please with the permits. The price of a unit of pollution is set by the market. This price is based upon the marginal cost of abating pollution for each firm. For example, assume two firms in the market, currently emitting 40 tons of sulfur dioxide. The government wishes to cut emissions in half. Ten permits are allocated to each firm, each valued at one ton. If firm A's marginal pollution abatement costs are less than firm B's, it would be in firm A's interest to sell permits to firm B as long as the price of a permit is greater than firm A's marginal abatement cost. It would be in firm B's best interest to buy permits from firm A as long as the price of a permit is less than firm B's marginal abatement costs.

Trading of permits will occur until the marginal abatement costs of the firms are equated. In figure 2 this occurs at the point of intersection of the two marginal abatement cost curves. At the most efficient level, firm A is emitting 5 tons and firm B is emitting 15 tons. The efficiency gains from the trade of emissions could be as great as the area bounded by the left of the point of intersection of the two cost curves, right of the reduction called for by standards (10 tons/month), above firm A's marginal cost curve, and below firm B's marginal cost curve.

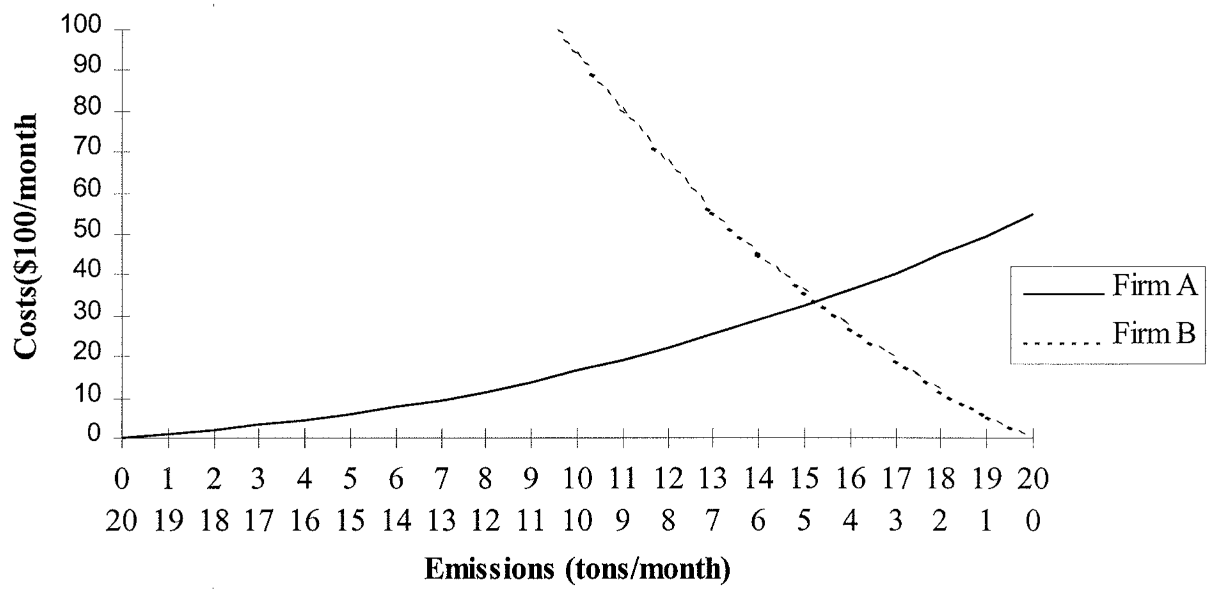

Figure 2 A Simple Two Firm Trading Model

Tradable pollution permits have four particular strengths. First, emission permits give firms the incentive to invest in research and development of pollution control. Firm pollution control technology will advance, lowering marginal abatement costs and releasing more permits for sale. Second, this program is less costly than an emission reduction policy based upon standards. Third, in most cases, any entity can purchase permits. It is common that an environmental organization will buy permits, thus removing them from the market. Fourth, pollution permits satisfy the equi-marginal principle. Economic efficiency has been achieved because firms are abating emissions to the point where their marginal abatement costs are equal.

There are three weaknesses inherent to a tradable emission permit program, each related to the infancy of the concept. First, the government may play a major role in the development of a permit program. The more initially intrusive the government, the more rules there will be governing trading procedures. The more rules there are, the less willing firms will be to actively participate. Second, as research and development advances, in what way should the additional permits be valued? Conceivably, if all firms are investing in research and development, eventually there will be a glut of emission permits on the market. If the administering agency removes the permits from the market, the incentive to invest in research and development is also removed. The final weakness of tradable emission permit programs is the general uncertainty involved with initiation, implementation, trade and possible price effects. As experience with trading markets increases, these weaknesses should dissipate.

The purpose of an emission trading program is to limit aggregate emissions at the least total cost to all participating entities. Numerous studies have documented the cost savings from an emission trading program compared to an abatement program using command and control techniques. Atkinson and Lewis (1984) found that the costs of command and control methods employed in the reduction of particulates in the St. Louis metro area would be six times more expensive than permit trading. Seskin, Anderson, and Reid (1983) found that the costs of a nitrogen dioxide trading program in Chicago would be 7% of the cost of a command and control program. McGartland (1984), in a study on the reduction of particulates in Baltimore, found that the costs of command and control methods would be 4 times the cost of an emission trading program (Tietenberg 1985). Van Horn (1993) estimated $1.7-3.0 billion yearly cost savings from the U.S. Acid Rain Program. The United States' NO_x and SO_x Regional Clean Air Incentives Market (RECLAIM) was forecast to reduce overall control costs by $58 million per year from 1994-1999 (Hall and Walton 1996). In a simulation of an international carbon emission trading program, Manne and Richels reported a total cost savings of $12 billion if credit trading was used instead of a command and control program (Manne and Richels 1992). Cost savings also exist for bubbles, nettings, offsets and banking transactions. The total cost savings for the 130 bubbles transactions was $435 million. General Motors in Defiance, Ohio saved $12 million in capital costs and had an additional emission reduction of 34.8 pounds per hour of TSP (Tietenberg 1985). Narragansett Electric in Providence, Rhode Island had fuel savings of $3 million and an additional reduction of 317 pounds of SO_2 emitted per hour (Tietenberg 1985). Cost savings from nettings were estimated at $25 million to $300 million in permitting costs, and $500 million to $12 billion in control costs. Cost savings for offsets and bankings were considered difficult to quantify, but they are thought to be large for offsets and small for bankings (Tietenberg 1985).

1.4 Organization of the Thesis

This project will compare the costs of an emission trading program for CO_2 with the costs of standards. The thesis will develop a blueprint for an international CO_2

emission trading program, judge its feasibility, and conduct a comparative cost analysis first for CO_2 reductions for the 38 developed nations that comprise the Kyoto Protocol's Annex I, and later for 157 nations divided into three groups (Annex I, Middle Income, and Low Income) with and without the trade of emissions. Issues to deal with in the blueprint include initial allocation choices, carbon sinks, equitable pollution control technology development and transfer, incentives for participation, monitoring and enforcement culpability, allocation within each country, number of phases, and the percent of emissions to be abated.

Impact on global warming will depend on the reduction of CO_2 emissions under each alternative. Economic efficiency estimation considers the costs (benefits) of reduction and how these costs (benefits) are allocated among participating countries. A trading model will simulate the effects of different marginal pollution abatement costs and total emissions for each country. A trading model will be developed for trade among the 38 Annex I nations as well as between Annex I nations, the 50 country middle income nation group, and the 69 country low income nation group[1]. The middle income nation group is composed of those nations that are not Annex I nations, but that have annual per capita gross national products greater than $1,000. The low income nation group is composed of all other nations. One hypothesis is that reduction of CO_2 emissions with the trade of emissions would be less costly than reducing CO_2 emissions without trade,

[1] Every country in the world will not be represented here due to a lack of data.

while achieving the same reduction in emissions. A second hypothesis is that the level of trading will increase with the addition of poorer nations.

The project will be organized as follows: chapter two will analyze four different tradable emissions programs, the U.S. Lead Trading Program, the Fox River Transferable Discharge Permit Market, Southern California's Tradable Emissions Program, and the U.S. Acid Rain Control Allowance Trading System. Chapter three will develop the blueprint for the international tradable emission permit device for carbon (INTREPD). Chapter four will derive the INTREPD simulation model for the nation groups and discuss the results of the simulation. Chapter five presents the conclusions.

2 THE FOUR PROGRAMS

Tradable emissions programs have not been complete successes. Still, compared to alternative abatement policies, they have provided participants with cost savings. The real world has presented problems that simulations were either unable to detect or hide. Most of these problems were due to the infancy of tradable emission programs. As these growing pains are mollified, cost savings will increase.

2.1 The United States Lead Trading Program

In terms of abatement and realized cost savings, the lead trading program has arguably been the most successful tradable emission permit program in the United States. The trade of lead between oil refiners in the United States began in 1982 and ended in 1987. Credits were initially allocated based upon average lead content in current production (Heggelund 1991). Over 50% of all U.S. refineries participated in the program. The price of a lead credit rose over time from 3/4 of a cent at the program's inception to 4 cents at the program's conclusion.

The EPA's initial estimate of cost savings of $228 million was more than likely exceeded, although data on actual cost savings was not collected because the volume of trades was higher than initially expected. In addition to cost savings, emissions were reduced. At the program's inception, there were an estimated 1.1 grams of lead per gallon of gasoline. By 1987, lead concentration had plummeted to 0.1 grams of lead per gallon of gasoline (Solomon 1995).

2.2 The Fox River Transferable Discharge Permit Market

The Fox River Transferable Discharge Permit Market was the least successful emission permit program. In 1981, the Lower Fox River, extending 22 miles between Lake Winnebago and Green Bay, was deemed "water quality limited" by the Wisconsin Department of Natural Resources due to the discharge of oxygen demanding wastes by ten pulp and paper mills and four municipalities (O'Neill et al. 1983).

It was initially anticipated that reducing dissolved oxygen levels to a safe level of 6.2 parts per million would cost $16.8 million under a transferable discharge permit program and $23.6 million under a central directive program (O'Neill et al. 1983). The savings of almost $7 million were never realized. Numerous trade restrictions placed upon the participating entities, the small number of participants, and the oligopolistic structure of the United States pulp and paper industry meant that only one trade occurred over the six-year span of the program (O'Neill et al. 1983). One trading restriction did not allow firms to purchase permits solely on the basis of reducing the costs of compliance. Another restriction required any permit transfer to last for at least one year (Heggelund 1991). The market created was too restrictive to allow a free market program like tradable emission permits to flourish, and the program failed.

2.3 Southern California's Tradable Emissions Program

The Southern California Tradable Emissions Program is drawn from the EPA's Regional Clean Air Incentives Market (RECLAIM). Southern California's high level of air pollution coupled with the glut of regulatory approaches makes this area a unique test case. Violation of air quality standards occurred on 184 days in 1991 (Hall and Walton 1996). To meet EPA mandated air quality standards by 2010, firms in the South Coast Air Basin needed to further reduce emissions.

RECLAIM is an emissions trading program for NO_x and SO_x emissions from sources that produce more than four tons a day of either pollutant (Hall and Walton 1996). In the early stages of the program, few trades occurred because initial allocations of permits exceeded emissions. As the EPA-mandated depreciation of RECLAIM trading credits began, demand for the credits increased. The costs associated with this program are estimated to be 40% of the costs associated with direct regulation.

RECLAIM extends earlier attempts at establishing markets for pollution. This program includes numerous industries, a set level of emissions reductions, allows firms to trade freely, increases the incentive for technological innovation in pollution control by including it as an objective, and allows firms to trade before gaining regulatory approval (Hall and Walton 1996). The Program is meeting the two criteria for a successful trading program: pollution is being reduced, and the cost is less than the cost of a direct regulation program.

2.4 The U.S. Sulfur Dioxide Trading Program

In late 1987, at a Columbia University conference on the future of environmental policy, Daniel Dudek, an Environmental Defense Fund economist, presented a plan for a sulfur dioxide emissions trading program. Over the next three years, this idea gained many proponents in Congress. In 1990, transferable discharge permits reached the form of marketable allowances with the signing of the Clean Air Act amendments. The allowances deviated from the traditional method of controlling interstate pollution through direct regulation. Although the marketable allowances were opposed by Robert Byrd, chairman of the Senate Appropriations Committee, and by environmentalists who preferred standards, the program was still included in Title IV of the amendments to the Clean Air Act (Cason 1995).

The goal of the sulfur dioxide trading program in phase one of the two phase program is to reduce annual emissions from 18.9 million tons (MT) to 8.9 MT by the year 2000. The first phase runs from 1995-2000 and will contain 110 electric utility plants located in 21 Eastern and Midwestern states. Those plants that emitted 2.5 or more pounds of sulfur dioxide per British Thermal Unit (BTU) used were included in the program. The number of permits allocated to each plant was based upon the following formula:

Number of Permits = Average BTUs of fuel used 1985-1987(in millions) X 2.5 pounds of sulfur dioxide/million BTUs.

The initial allocation of permits was approximately 5.5 million, each valued at one ton of sulfur dioxide.

Phase II begins in January of 2000. The formula for Phase II allocation substitutes 1.2 pounds of sulfur dioxide emitted for the 2.5 pounds used in the Phase I allocation formula. Fifty seven percent of the permits allocated in Phase I went to electric utilities in Ohio, Indiana, Georgia, Pennsylvania and West Virginia, partly appeasing Senator Byrd. Further political support for the program was gained in Illinois, Indiana and Ohio by granting these states an additional allocation. The EPA also holds in reserve 3.5 million permits to accommodate growth in electricity producing sectors (Solomon 1995).

In addition, the EPA included a provision calling for a yearly auction of permits. The auction is held in March on the Chicago Board of Trade. Within this yearly auction is a spot auction for allowances allocated for the current year, and an advance auction for allowances effective in seven years. Between 1993 and 1999, the number of allowances auctioned yearly varied from 150,000 to 250,000. In Phase II of the program, the annual number of allowances auctioned will be 200,000 (Solomon 1995).

The EPA employs a call-market auction to sell the permits. Potential buyers and sellers submit sealed bid and ask offers stating maximum willingness to pay and minimum willingness to accept. Buyers with the highest ask offers are matched with sellers with the lowest bid offers. The allowances are then purchased at the ask price. Allowance Holdings Corporation of Washington D.C. purchased the greatest number of allowances at the 1993 and 1994 auctions, 122,946 allowances. Carolina Power and Light of North Carolina purchased the second greatest amount, 85,103 (Solomon 1995).

Thus far, trading of allowances between utilities has been active, with roughly 500,000 allowances traded per year. Illinois Power Company has been involved in many of the largest trades. They have purchased 75,000, 80,000 and 90,000 allowances from Wisconsin Electric Power, Central Illinois Public Service and Southern Indiana Gas and Electric Company, respectively. The Ohio Power Company has been involved in the sale of large numbers of allowances on three occasions, selling 20,000 to Mississippi Power, 80,000 to Carolina Power and Light and 112,000 to South Carolina Electric and Gas Company. Although initial price projections ranged from $400 to $1000, the current allowance price is now under $200. This probably shows the banking of surplus allowances by utilities, the role of technological development, and the maturity of the market (Solomon 1995).

2.5 Lessons from the Trading Programs

There are numerous lessons to be learned from each of the aforementioned trading programs. Each program introduced new complexities that simulations could not have predicted. Success of the Lead Trading Program occurred because an unrestricted, competitive market for permits was created among refiners (Heggelund 1991). In addition, initial allocation was non-controversial, leading to a sense of contentment among refineries. Other advantages included use of an easily defined unit (a gram of lead), running the program over a finite time period, employing an enforcing agency that communicates well with participants, unambiguous rules, and independent audits (Nussbaum 1992).

Two major lessons were learned from the Fox River Trading Program. First, include as many entities in the market as possible. One reason the Fox River program failed was the inclusion of too few participating entities (ten pulp and paper mills) because the goal of the project was too narrow--decrease water pollution along a 22 mile stretch of the lower Fox River. The second reason the Fox River program failed was the preponderance of rules created by the administering agency. These rules hampered the effectiveness of the program because they greatly restricted trading freedom.

The Southern California trading program also supplies practical lessons for use in the design of an INTREPD. The Southern California program included multiple sources from a myriad of industries generating pollutants (Hall and Walton 1996). The Southern California program will therefore be very similar to an INTREPD because unlike SO_2, CO_2 is emitted from many different sources. In the United States, electrical utilities account for 70% of sulfur dioxide emissions, but only 36% of carbon dioxide emissions (Solomon 1995). Therefore, a trading program that only included electrical utilities would be discriminatory and inefficient.

One facet of the Southern California trading program is the depreciation of trading credits at a set rate over time. By including depreciation of credits in the program, program administrators hope to offset the sometimes exorbitant drop in prices that has occurred in trading programs that do not depreciate their credits. By depreciating the value of credits, program administrators hope to maintain demand for credits, and in turn maintain the incentive for a firm to continue to invest in research and development to lower costs of abatement. Constant depreciation of trading credits represents an alternative to removal of trading credits from the market "x" years into the program. It is not known which method is more successful at maintaining the research and development incentive.

In which industrial sector the cost savings occur could have an impact on whether an INTREPD comes to fruition. The RECLAIM program could have yearly cost savings of $58 million. Of those annual savings, $27 million and $25 million would be enjoyed by petroleum processing plants and utility operations, two powerful industries. Under direct control, the costs of abatement would be $73 million yearly for petroleum processing plants and $34 million yearly for utility operations (Hall and Walton 1996). These cost savings represent a large percentage decrease in abatement costs compared with direct control.

One problem the Southern California program was unable to solve was that older and dirtier sources of pollution have advantages over newer and cleaner sources. Since initial allocations of trading credits are often based upon historical emissions, entities that have polluted the most will be allocated the greatest number of permits. Under this allocation method, there is a cost to being environment-conscious before a trading program's enactment. In addition, sources of high amounts of pollution can often adopt cheap technologies immediately after a program's enactment, thus freeing up for sale trading credits. This concept could have direct application to an INTREPD. Wealthy countries with high levels of CO_2 emissions can easily adopt cheap technologies and free up credits for sale.

Lessons from the SO_2 trading program include the efficiency losses from the auction system, the use of the legal system to shackle the trading program, allocation issues, and the measurement of emissions. The EPA employed a variant of the call-auction system to sell the EPA's reserve allowances, and to allow participants to buy and sell among each other in an auction environment. The EPA determines the allowance price as all bids to the auctions are ranked on the basis of bid price (Cason 1995). The EPA will allocate and sell all the allowances in the auction sub-account on the basis of this ranking.

When all allowances are sold, the EPA will match contributed allowances offered for sale with any remaining bids. Specifically, the EPA proposes to match the offer to sell that stipulates the lowest minimum price with the highest remaining bid. This matching process will continue until all allowances are consumed, or until the EPA can no longer match bids with allowances because sellers have set their minimum price higher than any remaining bids (Cason 1995).

This auction creates a strong incentive for sellers to understate their true costs of emission control. Cason, using a symmetric Nash model of the seller side, found that increased competition would only make this incentive problem worse because sellers would be even more likely to understate their true costs of emission control. Cason and Plott stated that a uniform price call auction would be a viable alternative to the discriminative sealed-bid call auction. The uniform price call auction is more efficient, it induces more truthful revelation of underlying values and costs, provides more accurate price information, and recovers more quickly from changes in underlying market conditions (Cason and Plott 1996). A system of trading that also includes a reserve of allowances will be integral to the INTREPD to account for uncertainties involved with initial allocation. It will be necessary to employ a system other than the discriminative sealed-bid auction to distribute reserve allowances within the INTREPD.

The EPA's SO_2 emission trading program had two unforeseen legal counteractions: lawsuits and threats of restrictive state laws (Mostaghel 1995). One lawsuit was filed by New York State regulators against the EPA to limit trades perceived to be transferring pollution from one area to another. One New York company, Long Island Lighting Company (LILCO), sold an option to buy SO_2 allowances to Amax Energy Inc. of Greenwich, Connecticut. Amax then planned on selling some of these allowances to utilities in the Midwest. Concern within New York arose because pollution would drift east from the Midwest, coming to rest in New York.

New York Department of Environmental Conservation Commissioner Thomas Jorling outlined New York's position: "Unless the market approach is connected to achieving reductions in acid deposition, the trading of allowances could result in utilities in the Midwest purchasing credits and continuing to emit massive loadings of sulfur to the atmosphere at the expense of environmentally sensitive areas of New York and other northeastern states and Canada" (Mostaghel 1995, p. 208). Some of Jorling's statement is hyperbole because the trading program will have reduced total SO_2 emissions by 50% by 2000. But there is some truth. The free-market mechanism gives utilities the option to purchase allowances or cut back emissions. As a result, in some areas air quality may not improve at all, although overall air quality will be improved.

Another legal problem for the SO_2 trading program is the threat of restrictive state laws. Wisconsin and New York are attempting to enact legislation that would hamper the sale of allowances to upwind sites. The Wisconsin legislation would call for the disclosure of any purchase or sale to the public, mandate that the Wisconsin Department of Natural Resources judge the environmental impacts of proposed trades, and give the Wisconsin Public Service Commission the right to approve or deny any trade (Mostaghel 1995). This legislation could lead to stagnation of the allowance market.

For a trading program to work effectively, all allocation issues must be resolved before the enactment of the program. Allocation lobbying is likely to occur on a grand scale when determining initial allocation of CO_2 rights among countries in the international trading program. When debating the initial SO_2 distribution, the EPA managed to keep total allowances at 8.9 million units. The utility industry had lobbied for an extra allocation of 2 to 5 million allowances, but were allocated only an extra 200,000 in Phase I and 50,000 in Phase II (Solomon 1995). To mitigate the impacts of the program on the 3 to 5 thousand high-sulfur coal miners, Title XI made $50 million available each year from 1991 to 1995 for all workers laid off as a result of the trading program (Solomon 1995).

To measure emissions, the EPA required all utilities to employ the very precise continuous emission monitoring (CEM) system. Precision of CEM systems has been estimated to be 96-97% (Solomon 1995). There are two problems with extending the CEM system to the INTREPD program. First, CEM systems are very costly--$50,000 per unit in capital expense (EPA 1999a). The price of a CEM has dropped dramatically since the early 90s though as they did cost $300,000 with an additional $80,000 in annual operation and maintenance costs (ICF 1992). Second, CEM systems would only indicate CO_2 emissions from electric power plants. Other measurement systems would be necessary to measure emissions from other sources.

2.6 Conclusion

The purpose of chapter 2 was to describe and rate four real world applications of tradable emission permits, and discuss their contributions to a worldwide tradable carbon dioxide emission program. Due to its relative scope and success, the United States sulfur dioxide emissions trading program provides more teaching tools for the development of a worldwide trading program than the other three permit programs. The sulfur dioxide program shows that the mechanism by which carbon dioxide emissions can be reduced most efficiently is tradable carbon dioxide emission permits. It also provides a concrete example of tradable permit programs to show that the trade of emission permits is a practical tool.

3 THE INTERNATIONAL CARBON DIOXIDE EMISSION TRADING PROGRAM

The first worldwide accord on greenhouse gases, the Kyoto Protocol to the United Framework Convention on Climate Change, devotes certain sections to the trade of emissions. Article 16 bis states, “The parties included in Annex B (the 38 participating countries) may participate in emissions trading for the purposes of fulfilling their commitments under Article 3 of this Protocol.” (UNFCCC 1998A, p.17) Details on the critical elements necessary for this Protocol to function, such as compliance and the rules for trading, are yet to be determined. This chapter will incorporate sections of the Kyoto Protocol with the work of other authors to provide a blueprint of the INTREPD. The chapter considers the worldwide level of allowable emissions, alternatives for equitable allocation, sources of CO_2 emissions to include in the agreement, the role of carbon sinks (forestry offsets), technology exchange, allowable trades, administration of the program, and issues for monitoring and enforcement.

3.1 International Environmental Meetings and Allowable Emissions

This section will describe a successful international environmental agreement, the Montreal Protocol, and provide a description of the four Conferences of the Parties. Agreements for allowable emissions reached at the third Conference of the Parties, held in Kyoto, Japan in December 1997, will be applied to the INTREPD blueprint.

3.1.1 The Montreal Protocol

The only international agreement to address environmental problems is the Montreal Protocol on Substances that Deplete the Ozone Layer, signed in 1987. The signatory nations hoped that developed country chloroflorocarbons (CFCs) would undergo a complete production phaseout by 1996. Halon production would be banned by 1994. Production of hydrochloroflorocarbons (HCFCs) would cease by 1996, and a 35% cut in consumption would occur by 2004, rising to 65% by 2010, 99.5% by 2020, and a total phaseout by 2030. The Protocol also called for a production freeze in methyl bromide by 1995 (Tietenberg 1992a).

The requirements set for developing countries were much more lenient. No limits were set for the production of methyl bromide or HCFCs. For halons and CFCs, developing countries are to begin their phaseout in 1999 and complete it by 2010. The Multilateral Environmental Fund was established (in 1990) to ease the economic pains from reductions of ozone depleting gases (Connolly and Keohane 1995).

The budget from 1994-1996 was $510 million per year. The United States was decreed responsible for 25% of the budget and other developed countries are responsible for the remaining 75%. Presidential candidate Al Gore believes that responsibilities for taking the initiative, for innovating, catalyzing, and leading such an effort, fall disproportionately on the United States (Gore 1992). The Fund was partly created to entice China and India to agree to the Montreal Protocol. China and India did agree, even though it will cost China $1.4 billion to implement the conditions in the Protocol (Sims 1995).

Thus far, the Montreal Protocol has been a success. Levels of methyl chloroform, a substance found in methyl bromide, CFCs, and HCFCs, have been declining since 1991 (Connolly and Keohane 1996). The Montreal Protocol thus serves as a model of cooperation for nations working toward a common environmental goal.

3.1.2 Conference of the Parties One and Two

The Conference of the Parties comprises all countries that have ratified the UNFCCC. The first meeting, COP1, was held in 1995 and resulted in the "Berlin Mandate". The Berlin Mandate launched talks on new commitments by developed countries for the post-2000 period (UNEP 1997). COP1 also launched the concept, "activities implemented jointly" (AIJ). Any country could participate in the pilot phase of cuts if the country so chooses. COP2, held in 1996, measured the progress of the Berlin Mandate and the review process for national communications. The 1995 Second Assessment Report of the IPCC was endorsed as "the most comprehensive and authoritative assessment of the science of climate change, its impacts and response options" (UNFCCC 1998A).

3.1.3 Conference of the Parties Three

Over the last 5 years, numerous non-binding agreements have been struck between countries. Many countries have recommended stabilizing emissions at their 1990 levels by the year 2000. At the 1995 Berlin Conference of the Parties (COP1), John Gummer, the British environment secretary, stated: "agreement on a figure in the range of 5 to 10 per cent reductions below 1990 levels by 2010 would seem to be a credible and achievable outcome of the negotiating process" (Brown 1996, p.27). By the conclusion of COP1, 70 nations, including China, had signed an agreement for 20 per cent reductions of CO_2 emissions by 2005, a proposal promoted by the Association of Small Island States (AOSIS) (Brown 1996).

The third Conference of the Parties (COP3) was held in Kyoto, Japan in 1997. At the conference, international negotiators reached an historic agreement. Industrialized countries agreed to legally-binding limits on greenhouse gases. This agreement, the Kyoto Protocol, replaces the voluntary agreement reached at the Rio Climate Conference in 1992. Under this agreement, 38 industrialized countries, referred to as Annex I countries, agreed to limit emissions by some percentage of 1990 emissions by 2012 (NRDC 1997). Table 1 shows the CO_2 reduction commitments of the Annex I nations as a percentage of 1990 emissions. Six Annex B countries--Australia, Iceland, New Zealand, Norway, the Russian Federation, and the Ukraine--will be allowed to increase emissions above their 1990 emissions (UNFCCC 1998A). The United States insisted on the trade of emissions because they felt their limitations could not be met without excessive costs.

Country	Emission Limitation	Country	Emission Limitation
Australia	108.00	Lichtenstein	92.00
Austria	92.00	Lithuania	92.00
Belgium	92.00	Luxembourg	92.00
Bulgaria	92.00	Monaco	92.00
Canada	94.00	Netherlands	92.00
Croatia	95.00	New Zealand	100.00
Czech Republic	92.00	Norway	101.00
Denmark	92.00	Poland	94.00
Estonia	92.00	Portugal	92.00
Finland	92.00	Romania	92.00
France	92.00	Russian Federation	100.00
Germany	92.00	Slovakia	92.00
Greece	92.00	Slovenia	92.00
Hungary	94.00	Spain	92.00
Iceland	110.00	Sweden	92.00
Ireland	92.00	Switzerland	92.00
Italy	92.00	Ukraine	100.00
Japan	94.00	United Kingdom	92.00
Latvia	92.00	United States	93.00

Table 1 Annex I Emission Limitations

Source: United Nations Framework Convention on Climate Change, 1998

Two groups highly critical of world progress on global warming problems were The Natural Resources Defense Council (NRDC) and the Environmental Defense Fund (EDF). They offered tempered praise to the accord. Greg Whetstone, the director of NRDC's legislative program stated, "While this is only the first step on a long road, and we know that later agreements must produce far more aggressive action if we are to succeed, the accord reached here today marks a historic turning point in the effort to protect the planet." (NRDC 1998) Fred Krupp, EDF's executive director stated, "The Kyoto Protocol represents a watershed moment in the history of environmental protection and international diplomacy, but there's still more work to be done to assure that the Protocol's targets are met... The agreement represents a challenge to governments to turn the Protocol's good intentions into political reality. The Protocol is a good start on protecting the Earth, but it must be looked at as part of a longer process. Efforts to strengthen the Protocol, including increasing participation by developing countries, will be needed from the international community for years to come" (EDF 1998).

3.1.4 Conference of the Parties Four

Conference of the Parties Four was held in Buenos Aires, Argentina from November 2 through November 13, 1998. Much of the early discussion dealt with national reporting requirements for greenhouse pollution, issues surrounding allowances to "trade" pollution control obligations, encouraging the protection and growth of forests and other CO_2 absorbing areas, financial mechanisms for the accord, and efforts to promote clean development (UNFCCC 1998b).

Later, the talks dealt with the "Clean Development Mechanism" (CDM), a way for developing nations to reduce their CO_2 emissions by promoting the use of solar power. Before the Kyoto Protocol, many developing nations were skeptical as to what CDMs would offer them. Now they are much more anxious to adopt these strategies. If the trade of pollution emissions is allowed, the CDMs have the potential to increase the permits that developing countries can sell (UNFCCC 1998b).

Argentine President Carlos Menem announced that his country would establish goals for CO_2 emissions and within a few years, declare a commitment to these goals. President Menem stated that Argentina would implement the emissions limitations beginning in 2008. According to Menem, "The emerging countries also share the responsibility to assume their own initiatives to face and solve every challenge of the 21st century." (Stevens 1998, pg.A5) Later, delegates from Kazakhstan announced that they too would commit to emission limitation goals.

The limitation commitments by the two developing countries have additional value because as more developing nations agree to CO_2 limits, the likelihood of the United States Senate ratifying the Kyoto Protocol will increase. Members of the Senate have stated that unless developing countries also agree to undertake emission reductions or limitations they will not agree to the reduction commitments established in the Kyoto Protocol. Near the end of COP 4, the United States' delegate, Under Secretary of State for Economic, Business and Agricultural Affairs, Stuart Eizenstat, signed the Kyoto Protocol. The U.S. government also renewed their commitments to accelerate efforts to increase energy efficiency, and to set new appliance efficiency standards (Allen 1998).

The Conference of the Parties concluded with the adoption of the Buenos Aires Action Plan. The Action Plan established deadlines for finalizing topics discussed in Kyoto. The Action Plan has a year 2000 deadline for the development of financial mechanisms, rules for development and transfer of technologies, rules governing the Kyoto Mechanisms with priority given to the Clean Development Mechanism, and discussion of ceilings, long-term convergence and equity (UNFCCC 1998b).

3.1.5 The Equitable Initial Allocation

Equity issues are paramount to the success of the INTREPD. There is no supranational institution that can force a greenhouse gas agreement, and appeals to economic efficiency will not be sufficient to rally countries together, given the wide disparities in welfare and the welfare changes implied by efficient policies. Some ways of allocating permits are more equitable than other ways. Allocation could be based on population, per capita emissions, GDP, current emissions, willingness to pay, value added of production, or unilateral reductions in OECD countries (Larsen and Shah 1994, Heggelund 1991, OECD 1992, Swart 1992).

3.1.6 Allocation Methods

Three methods of allocating emission permits are distribution by current emissions, distribution by value added of production, and distribution according to industry benchmarks. Distribution of permits by current emissions appears to be the most equitable option if current emission control efforts are distributed so that marginal costs are equal across sources (Heggelund 1991). Equating marginal costs across all sources would sacrifice free market incentives to develop less costly pollution control technologies, one of the main advantages of emission trading programs over programs based upon direct regulation. Two drawbacks to this initial distribution are that firms are not rewarded for their environmental consciousness before the program's enactment, and a firm on the brink of large growth is hampered because allocation will be based upon emissions prior to expansion.

Some believe that an equitable trading system must be based upon per capita emissions. Solomon (1995) recommends allocating permits based upon 80-150% of historical per capita emissions, decreasing allocations to high per capita emitters over time, and increasing allocations to low per capita emitters. This method would encourage countries to plan for the long-term, and encourage them to invest in pollution control technologies. This method would be difficult to justify administratively due to the numerous allocation phases required. One other problem is that the allocation is not based solely on emission levels. It is also based upon population, and over time would reward those countries that are most densely populated.

The initial allocation will be based upon the binding agreement reached in Kyoto. The Kyoto Protocol uses 1990 as its base year and the United Nations as its source. The INTREPD will apply 1992 as its base year, and the World Resources Institute as its primary data source because data for CO_2 emissions from industrial processes are more current and more complete. There are three Annex I nations--Lichtenstein, Luxembourg, and Monaco--for which emissions will need to be estimated, due to a lack of data for each country. Their contributions to world CO_2 emissions from industrial processes are negligible, .05%. This data problem can be considered slight.

Emissions will not be frozen at 1992 levels because that is infeasible. Instead, the yearly change in emissions was estimated for each country group based upon the average yearly change for each country group from 1992 to 1995. The average yearly change in emissions until the program's inception in 2000 will be as follows: Annex I emissions will remain stable, emissions of middle income nations will increase 1.36%/year, and emissions of low income nations will increase 2.63%/year.

3.2 Initial Allocation Methods

Table 1 showed the binding reduction commitments agreed to by the 38 Annex I countries. If these commitments were attained, there would be a 5.3% reduction of emissions borne by Annex I countries, and a 3.4% reduction in worldwide emissions. To achieve a CO_2 emission freeze at 1992 levels, the remaining 119 possible entrants into the trading program would be allowed to increase emissions beyond their 1992 levels.

These countries are divided into two groups: those with yearly per capita gross national product (GNP) less than 1,000 U.S. dollars, and those with yearly per capita GNP greater than $1,000, but not an Annex I nation. These countries are broken into two groups to introduce equity concerns. To maintain emissions at 1992 levels, the lowest income group is allocated permits 10.5% greater than 1992 emissions, and the middle income group is allocated permits 7.2% greater than their 1992 emissions.

A more progressive method would be for each Annex I country to commit to an additional 2% reduction beyond their Kyoto Protocol commitments. This would lead to a reduction of emissions within Annex I nations of 7.3%. Under this allocation, the low income group would be granted permits 13.5% greater than their 1992 levels, and the middle income group would be granted permits 11.0% greater than their 1992 levels. Total emissions for each country group under the different allocation scenarios are illustrated in Table 2.

	1992 Emissions	**Low Equity**	**High Equity**
Annex I	13,379,356	12,664,274	12,396,687
Middle Income	3,594,313	3,852,005	3,988,928
Low Income	4,356,271	4,813,661	4,944,325
Total	21,329,940	21,329,940	21,329,940

Table 2 Emission Levels under Different Allocation Scenarios

Source: Author's calculations from data from World Resources Institute, 1997

The second column in Table 2 shows 1992 CO_2 emissions. The third and fourth columns show total emissions for each country group under the two equity scenarios. Annex I country emissions are lowest under the high equity allocation scenario. Emission allocations for the other two country groups are highest.

Non-Annex I countries are most likely to agree to a trading program when the initial allocation is most equitable. However, this allocation might be a deterrent for Annex I countries; many of whom agreed only grudgingly to the Kyoto Protocol commitments. The majority of the Annex I countries signed the agreement without concern as to whether they would be allowed to trade emissions. Therefore, it is possible that the Annex I countries would be more likely to agree to further allocation reduction if two incentives were included: the right to trade emissions, and the inclusion of the additional 119 potential trading partners. In fact, the United States stance on the subject is that they will not be able to meet their commitments unless the trade of emissions is allowed.

3.3 The Sources of CO_2 Emissions

Although artificial CO_2 emissions account for only 4% of total CO_2 emissions, their effects have had far-reaching and deleterious impacts. These artificial processes can be divided into two groups: industrial and land use change. Within industrial processes, CO_2 can be emitted from the burning of fossil fuels. Cement manufacture represents another important source of CO_2 emissions. In 1992, total CO_2 emissions from industrial processes were 22.3 million Gg. Of this total, fossil fuel burning accounted for 21.7 million Gg and cement manufacture was responsible for 0.6 million Gg. Table 3 shows 1992 CO_2 emissions (in Gg) for each continent (World Resources Institute 1997). Much of the world's CO_2 emissions come from three continents: Europe, North America, and Asia. The developing regions of the world, Africa, South America, and Oceania are responsible for the smallest amount of CO_2 emissions.

Continent	Solid	Liquid	Gas	Gas Flaring	Cement	Total
Africa	271,744	274,430	77,054	65,659	26,905	715,792
Europe	2,486,141	2,509,400	1,659,895	49,248	161,817	6,866,501
North America	1,897,472	2,480,550	1,262,197	18,833	56,418	5,715,470
South America	67,883	375,413	116,962	17,367	27,407	605,032
Asia	3,660,255	2,382,934	642,021	97,048	336,062	7,118,320
Oceania	160,864	90,589	42,982	0	2,810	297,245
Total	8,588,416	9,050,080	3,828,880	249,152	626,544	22,343,072

Table 3 Continental Sources of CO_2 Emissions

Source: World Resources Institute, 1997

Industrial processes account for 84.5% of worldwide CO_2 emissions from artificial sources (World Resources Institute 1997). Land use change accounts for the other 15.5%. Table 4 documents CO_2 emissions from land use change in 1991.

Continent	Land Use Change
Africa	730,000
Europe	11,000
North America	190,000
South America	1,800,000
Asia	1,300,000
Oceania	38,000
Total	4,100,000

Table 4 Continental CO_2 Emissions from Land Use Change

Source: World Resources Institute, 1997.

In 1991, South America and Asia were most responsible for CO_2 emissions as a result of land use change. By country, Brazil and Indonesia contributed the greatest amount of CO_2 to the atmosphere: 1,100,000 and 410,000 Gg, respectively. Brazil and Indonesia also have the highest rates of deforestation[2].

Other considerations in the design of a trading program are forestry offsets. Forests and oceans act as carbon sinks. A carbon sink converts CO_2 to other forms of carbon, thus limiting CO_2 release into the atmosphere (Cubbage, Regan and Hodges 1990). It has been estimated that one hectare of forest could sequester 5.67 metric tons of carbon each year (Dixon et al. 1993). The earth's trees, shrubs, and soils hold roughly 2.3 billion Gg of carbon (Dixon et al. 1993).

There are many difficulties associated with the economic analysis of emission reduction programs and forestry offsets. The Council of Economic Advisors (1998, p.40) outlined them: "First are the uncertainties that still remain over the operational considerations of the treaty, necessitating assumptions on which the analysis is predicated. Second are the inherent limitations of available models to analyze the costs of abating emissions. Third, it is extremely difficult to quantify the long-term economic benefits of climate change mitigation, although such benefits are the motivation of the Kyoto Protocol." The Council of Economic Advisors (1998) also believes that numerous other estimates can not plausibly be attained at this juncture. Among these estimates are the value of carbon sinks, and the costs and benefits related to reforesting land that was previously farmed. Estimates of the costs of reforesting land are available, but foregone

[2] Emissions from land use change were unavailable for 59 of the 130 countries examined in the World Resources Institute report.

benefits from the loss of farming income are not included in the estimates. Many of the reforestation studies estimate the costs of reforesting marginal land, not viable farmland.

Dixon et al. (1993) found that as much as 1.8 billion hectares of deforested or degraded tropical latitude land is technically viable for reforestation projects. Given prevailing conditions, Trexler, Faeth and Kramer (1990) determined that 462 million hectares is a more practicable amount of deforested or degraded tropical land that can be reforested. This amount would surely increase if reforestation projects became economically viable. Planting and maintaining 121 million hectares of trees by the year 2000 would absorb approximately 710,000 Gg of carbon every year.

Solomon (1995) estimated the costs of forestry projects at between $1-12/metric ton (Mt) of carbon reduced or offset. In an analysis of 8 forestry projects, Dixon et al. (1993) found that carbon could be sequestered at a cost of $1-60/megagram (Mg) with a median cost of $10 (1 Mg is equal to 1 Mt). Prices that can be charged for carbon emission permits have varied depending upon the simulation and the level of reduction sought. Larsen and Shah (1994) derived a permit price of $58/Mt of carbon. Manne and Richels (1992) derived a price of $150/ton. Therefore, in a trading program, it would be in a country's interest to reforest to increase their permits. Projects in progress in the Czech Republic, Costa Rica, and Belize are expected to achieve total carbon reductions of 3,400 Gg over their life spans.

3.4 Technology Exchange

To entice more countries to participate, an open exchange of information and ideas is needed. Article 2 of the Kyoto Protocol has a section devoted to the exchange of technology. The provision calls for all Parties to "share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness." (UNFCCC 1998a, p.3) Article 10 also discusses the transfer of technology: "(c)ooperate to promote, facilitate, and finance the transfer of environmentally sound technologies pertinent to climate change, and in the creation of an enabling environment for the private sector; cooperate in scientific and technical research and promote systematic observation systems and development of data archives to reduce uncertainties related to the climate system; and cooperate in and promote education and training programs, including personnel to train experts in this field, in particular for developing countries" (UNFCCC 1998a, p.11). The article mentions the importance of the transfer of *publicly* owned technologies, or those within the *public* domain, but makes no mention of the transfer of privately owned technologies. By allowing private firms to maintain ownership of pollution control technologies, administrators of the INTREPD will also maintain the incentive for firms to invest in research and development.

3.5 Rules of Trade

A profusion of regulations impedes the fluidity of the free market. The INTREPD should keep regulations to a minimum, while trying to reduce emissions of CO_2 at the least total cost. The INTREPD will allow two types of trade--between countries, and between emission sources. Trade between sources is a vexing issue. To achieve cost-effectiveness, trade between sources should include only larger CO_2 producers: electric and gas utilities, independent power producers, aluminum, cement and lime manufacturers, and refineries. For trade between countries, a simple tracking system can record country of origin, year of issue, tonnage, and serial number (Tietenberg 1992b). The INTREPD would add a fifth element; price per credit, and substitute credits for tonnage. Before the trade of emissions occurs the selling country must prove to the governing body that they have a surplus of credits. This underlines the importance of accurate emission measuring equipment. To remove any incentive for countries to collude, or practice other types of biased behavior, a clearinghouse strategy will be employed. With this strategy, a country that wishes to sell permits will put the order through the clearinghouse, and the clearinghouse will find a buyer of the permits.

3.6 Monitoring

Emissions monitoring can be accomplished by national self-reporting systems or private monitoring. The role of an international monitoring authority is small (Tietenberg

1992b). Perhaps the United Nations could be that monitoring authority, cataloguing each country's CO_2 emission data. The Kyoto Protocol calls for each country included in Annex I to "have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol." (UNFCCC 1998a, p.7)

One monitoring device for stationary emissions is the Continuous Emissions Monitoring System (CEMS). The EPA is currently employing CEMS to measure electric utility sulfur dioxide emissions. CEMS can also be employed to measure carbon emissions. The EPA estimates the potential error of these systems to be 3-4%. Due to economies of scale, the price of CEMS is dropping (Solomon 1995). In 1995, CEMS for CO_2 cost $300,000. By 1999, they cost less than $50,000 (EPA 1999a).

The main issues in the monitoring of CO_2 emissions are data collection, data management, and measurement (Dudek and Tietenberg 1992). To track mobile emission sources, vehicle miles traveled (VMTs) can be estimated. Many OECD member countries already use this type of tracking device. This system of monitoring would be relatively inexpensive.

3.7 Enforcement

To guarantee the greatest efficiency of emission reductions, effective sanctions or penalties should be imposed on countries that under-report emissions or fail to abide by rules set forth by the governing body. Tietenberg (1992a) proposes a model based upon the use of the legal system, incorporating provisions of the 1957 Rome Treaty. First, "letters of formal notice" are sent by the commission to member countries believed to be in violation of a rule. Then the country is given the opportunity to respond to the notice. In step three, the monitoring body accepts the offending country's position and dismisses the case, or confirms the rule infringement. If the rule infringement continues, the monitoring authority has the right to initiate legal proceedings against the offending country.

The process of filing and publicizing complaints is by itself a powerful force for compliance. A country with shoddy emission reports will be less sought after as a trading partner than a country with accurate reports. Shoddy reports could potentially cost a country because of the decrease in trade of emission permits, and increase in emission reductions.

Under the 1986 Emergency Planning and Community Right-to-Know Act, emission data for approximately 20,000 United States pollution emitters was made public. The publication of these previously restricted reports has had an effect on numerous chemical companies. Partly because of the Right-to-Know Act, Monsanto, Dow, and DuPont all pledged to reduce emissions of carcinogens by at least 35% (Tietenberg 1992a). This method of enforcement, enforcement by shame, will enhance public awareness of CO_2 emissions, but alone will probably not convince countries to abide by the rules of trade.

Enforcement in the form of economic sanctions would more likely convince participating countries to adhere to the rules of trade and reporting. A cost-minimizing country will weigh the costs of compliance against the costs of noncompliance (Heggelund 1991). The value of the sanctions should be flexible, increasing with emission reductions. Historically, the application of penalties has led to protracted court battles, and in some cases, penalties were not implemented for fear of creating friction between the governing body and the offending party (Heggelund 1991). The INTREPD should not dissuade developing countries from participating because they still will benefit from the operation.

3.8 Conclusion

This chapter discussed the veritable menagerie of ideas that must be considered before a program of this scope is to commence. These topics include equitable methods of allocation of emission permits, the sources of carbon dioxide emissions, technology exchange, rules for the trade of emissions, monitoring of an international program, and the enforcement of penalties for entities that violate the rules of trade. The most equitable method of allocation appears to be one that links the reductions in emissions called for in the Kyoto Protocol for Annex I nations with historical emissions in developing countries.

4 EMPIRICAL APPLICATION OF THE INTREPD

The INTREPD must deal with allocation issues, rules of trade, monitoring, enforcement, the sources of emissions to include, and equity. This chapter will discuss the two levels of equity to pursue with the allocation of permits among 157 countries in the trading program. The second section discusses two growth scenarios for carbon dioxide emissions. The third section will describe the cost curve for carbon controls, and how it will be varied between country groups and over time, depending upon technology advance.

4.1 Carbon Dioxide Emission Growth Scenarios

Table 5 shows the 1992 emissions of the Annex I nations according to World Resources Institute data. Total CO_2 emissions for Annex I nations in 1992 was 13.4 million Gg, 63% of the world's CO_2 emissions. The United States is by far the greatest contributor to the total: 4.9 million Gg. The World Resources Institute (1999) recently published the world's CO_2 emissions for 1995. Emissions of Annex I nations increased by 0.8% from 1992 to 1995. Emissions for the rest of the world increased by 4.8%.

To estimate future emissions, two growth scenarios, slow and fast, have been chosen. These growth scenarios are based upon the results of a regression that determines the dependent variables for per capita CO_2 emissions for 120 nations. Per capita CO_2 emissions are a function of per capita GNP, per capita consumption of commercial

Country	Emissions (Gg)	Country	Emissions (Gg)
Australia	267,937	Liechtenstein a	208
Austria	56,572	Lithuania a	22,006
Belgium	101,768	Luxembourg	11,343
Bulgaria	54,359	Monaco	71
Canada	409,862	Netherlands	139,027
Croatia	16,210	New Zealand	26,179
Czech Republic	135,608	Norway	60,247
Denmark	53,897	Poland	341,892
Estonia	20,885	Portugal	47,181
Finland	41,176	Romania	122,103
France	362,076	Russian Federation	2,103,132
Germany	878,136	Slovakia	36,999
Greece	73,859	Slovenia	5,503
Hungary	59,910	Spain	223,196
Iceland	1,777	Sweden	56,796
Ireland	30,851	Switzerland	43,701
Italy	407,701	Ukraine	611,342
Japan	1,093,470	United Kingdom	566,246
Latvia	14,781	United States	4,881,349
		Total	13,379,356

Table 5 Carbon Dioxide Emissions for Annex I Nations

Source: World Resources Institute, 1997

Note: The emissions of Liechtenstein, Lithuania, and Monaco were not estimated by the World Resources Institute study. Their UN estimates were applied. The UN was chosen as the second data source because their data most closely matched that of the World Resources Institute's for CO_2 emissions from European countries. This data inaccuracy should be viewed as minor because these three countries are responsible for only .17% of total Annex I nation CO_2 emissions.

energy, and the distribution of GDP borne by industry. The level of each growth scenario will vary between country groups because the variances as well as the average yearly increase of each variable are different. Table 6 presents the results of the regression that determines the factors causing the emission of CO_2. The R^2 for the regression was 0.78.

VARIABLES	*Coefficients*	*Standard Error*	*T Statistic*	*P-value*
Intercept	-2.29E+06	7.70E+05	-2.97	3.62E-03
Per Capita GNP	112.90	42.46	2.66	8.95E-03
Per Capita Consumption Commercial Energy	3.89E-05	3.46E-06	11.23	3.34E-20
GDP Distribution Industry	1.14E+07	2.59E+06	4.41	2.29E-05

Table 6 Regression Analysis of Carbon Dioxide

Each variable is highly significant, with per capita consumption of commercial energy having the greatest significance. Consumption of commercial energy has the greatest influence on CO_2 emissions because, in general, the consumption of energy leads to the emission of fossil fuels. Per capita consumption of commercial energy has the smallest coefficient because its values are the largest.

Slow growth is defined as the point where 25% of the distribution of each variable lies, and fast growth is defined as the point where 75% of the distribution of the variable lies. To determine the growth scenarios, per capita GNP, per capita commercial energy consumption, and percent of the GDP distribution borne by industry were derived for each country group. For the Annex I nations those values were $14,467.97, 1.736E+11 joules, and 37.85%, respectively.

To determine the effects of a change in variable values, variances and standard deviations were found for the three variables and for each country group. To find the change in the variable values under each scenario, the following formula was employed:

% change = average change X_i -.675(standard deviation) for slow growth,

% change = average change X_i +.675(standard deviation) for fast growth,

where % change is the increase or decrease in variable X_i, average change X_i represents the yearly average change of each of the three independent variables, and ± 0.675 is the t value with a confidence interval of 50%. Table 7 shows the variance, standard deviation, and the yearly average % change of each variable. The yearly average % change for each variable was based upon data taken from the World Bank's *1998 World Development Report*.

	Per Capita GNP	**Per Capita Energy Consumption**	**GNP Industry**
Variance	3.01	0.07	11.39
Standard Deviation	1.74	0.26	3.37
Average Change	1.29%	-0.24%	-0.44%

Table 7 Estimation Results for Annex I Nations

Under the slow growth scenario, per capita GNP will increase 0.1%/year, commercial energy consumption per capita will decrease 0.4%/ year, and GDP from industry will decrease 2.7%/year. Under slow growth, CO_2 emissions for Annex I countries will decrease 1.4%/year. Under the fast growth scenario, per capita GNP will increase 2.4%/year, commercial energy consumption per capita will decrease 0.1%/year, and GDP from industry will increase 1.8%/year. Under the fast growth scenario, emissions will increase 1.1%/year.

The middle income group is comprised of 49 countries. Their 1992 CO_2 emissions vary from 332,852 Gg in Mexico to 264 Gg in Belize. The group total is 3,594,313 Gg. Average per capita GNP is $3,145, average per capita commercial energy consumption is 4.578E+10 joules, and 36% of GDP is borne by industry. Table 8 shows the variance, standard deviation, and annual average change for the middle income country group.

	Per Capita GNP	Per Capita Energy Consumption	GDP Industry
Variance	12.23	28.26	17.15
Standard Deviation	3.50	5.32	4.14
Average Change	1.73%	3.51%	-0.42%

Table 8 Estimation Results for Middle Income Group

Under slow growth, per capita GNP will decrease 0.6%/year, per capita commercial energy consumption will decrease 0.08%/year, and GDP from industry will decrease 3.2%/year. Under the slow growth scenario, emissions of CO_2 will decrease 2.9%/year. Under fast growth, per capita GNP will increase 4.1%/year, per capita commercial energy consumption will increase 7.1%/year, and GDP from industry will increase 2.3%/year. Emission levels under the fast growth scenario will increase 6.0%/year. Under normal growth conditions, emissions will increase 1.7%/year.

The low income country group is comprised of 68 countries. Their carbon dioxide emissions vary from 2,667,982 Gg in China to 15 Gg in Somalia. The total emissions for the low income country group is 4,356,271 Gg. China's emissions constitute 61% of the total. India's emissions constitute 18% of the total. Because their independent variable values are quite dissimilar from the other 66 countries in the low income country group, China and India were excluded from the derivation of variances and standard deviations of the three independent variables. Average per capita GNP is $397, average per capita commercial energy consumption is 1.44E+10 joules, and 34 percent of GDP is borne by industry. Table 9 contains the results of the derivations.

	Per Capita GNP	**Per Capita Energy Consumption**	**GDP Industry**
Variance	9.87	41.46	23.22
Standard Deviation	3.10	6.44	4.82
Average Change	-1.10%	5.19%	1.20%

Table 9 Estimation Results for Low Income Group

Under slow growth, per capita GNP will decrease 3%/year, per capita commercial energy consumption will increase 0.8%/year, and GDP from industry will decrease 2%/year. When slow growth of CO_2 emissions exists, emissions will decrease 3.4%/year. Under fast growth, per capita GNP will increase 1%/year, per capita commercial energy consumption will increase 9%/year, and GDP from industry will increase 4%/year. CO_2 emissions will increase 10.1%/year. Under normal growth, emissions will increase 3.3%/year.

As expected, the Annex I country group has the smallest disparity and the low income country group the widest disparity between CO_2 emission growth scenarios. For the Annex I nations, there existed a disparity of 2.4%. For the middle income country group the disparity was 8.9%. For the low income country group the disparity was

13.6%. The primary reason for these differences in disparities is the relative stability of each country group. It is unlikely that any independent variable for the Annex I nations will increase or decrease radically. Most of the Annex I nations have stable governments. Many countries in the other two groups are newly democratized, and struggling with a new system (capitalism). The variances and standard deviations of the two lower income country groups reflect this instability. Table 10 illustrates the difference in size of the variances of the three country groups for each variable. The only variable that does not have a decreasing variance moving from the low income group to middle to Annex I is per capita GNP. Some countries in the middle group are enjoying phenomenal economic growth, while others remain laggards.

Variance	Per Capita GNP	Per Capita Commercial Energy Consumption	GDP Industry
Low Income Group	9.87	41.46	23.22
Middle Income Group	12.23	28.26	17.15
Annex I Group	3.01	0.07	11.39

Table 10 Comparison of Variances Between Country Groups

4.2 The Cost Function

To estimate costs of pollution control, a log linear cost curve was derived from marginal cost and CO_2 data. The cost function was obtained by Nordhaus (1991a) by fitting an equation to nine different cost estimates for CO_2 reduction. Larsen and Shah (1994) used the same cost function. They employed it because country-specific cost functions are unavailable for the majority of countries, and the cost functions that do exist for specific countries are based on different models and assumptions.

The function was chosen because it combines numerous studies covering a wide variety of countries under a broad range of circumstances. The function (relating marginal cost of CO_2 reduction to percent reduction of emissions) takes the form:

$$\ln(MC) = \alpha + \beta \ln(R)$$

where MC equals the marginal cost of reduction in US$/ton, and R equals the percent reduction of emissions from an uncontrolled path. Table 4.7 shows the results of the regression of the natural log of reduction of emissions on the natural log of marginal cost. Both values have very low standard errors, low P-values, and very high t statistics. The R^2 is .9818.

	Coefficients	**Standard Error**	**t Stat**	**P-value**
Intercept	-0.6297	0.0998	-6.3069	1.5834E-07
Reduction	1.4586	0.0250	58.3204	4.4888E-41

Table 11 Regression Analysis of Reduction on Marginal Cost

Figure 3 shows the slope of the marginal cost function. The slope increases at an increasing rate. The costs of reducing CO_2 emissions increase at a rate faster than the level of emission reductions. If this were not the case, there would be no incentive for trading emissions.

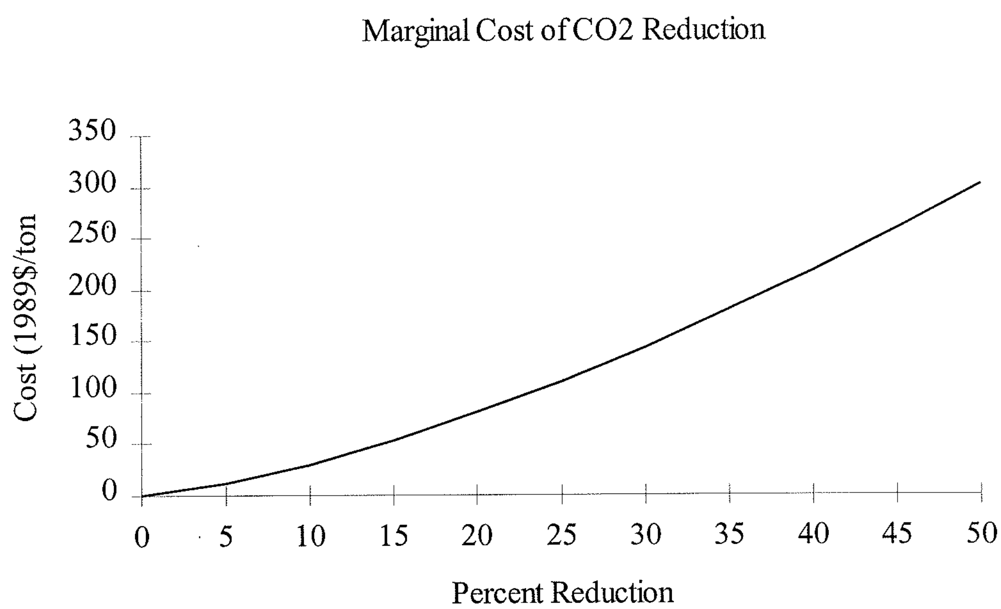

Figure 3 The Marginal Costs of Reducing CO_2 Emissions

The total cost of reducing CO_2 emissions is the integral of the marginal cost curve. Taking the anti-log of the log linear marginal cost function yields the following equation:

$MC = \exp^{\alpha} + R^{\beta}$

Integrating the marginal cost function yields the total cost function:

$TC = \exp^{\alpha} + (R^{\beta+1})/\beta+1$, which equals:

$TC = \exp^{-0.62971} + R^{2.45861}/2.45861$.

Figure 4 shows the total cost function. Total costs of CO_2 reduction increase at an increasing rate. If total emissions are 100 tons, it will cost $22 to reduce emissions by 5%, $643 to reduce emissions by 20%, $6,116 to reduce emissions by 50%, and $33,615 to reduce emissions completely.

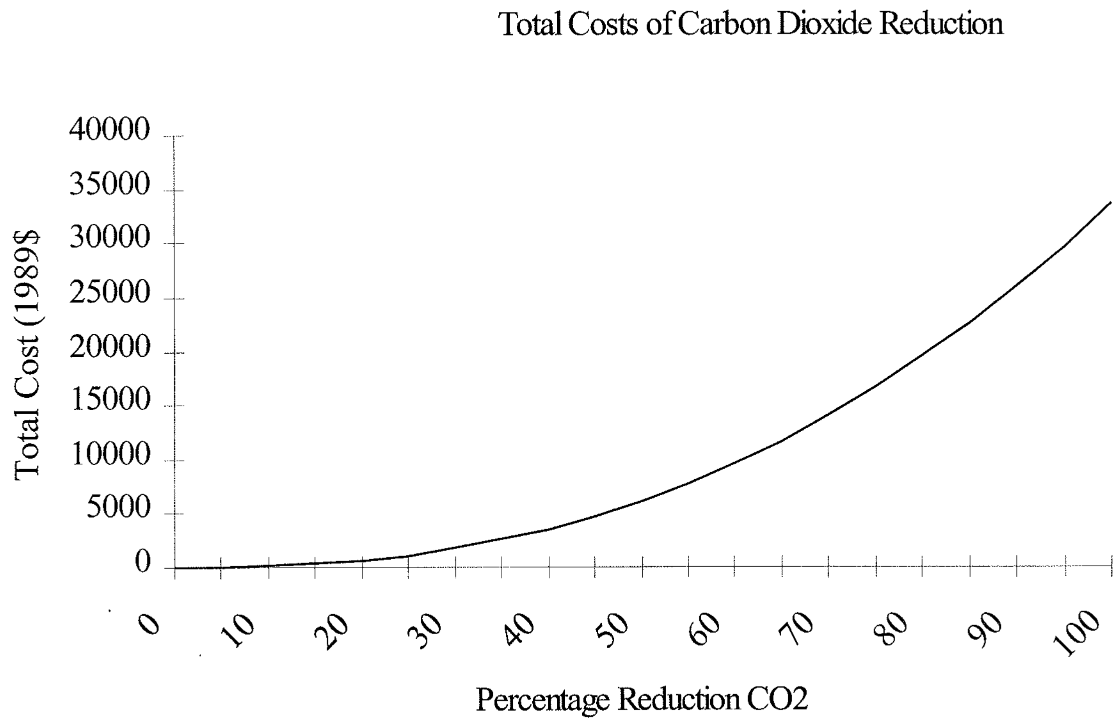

Figure 4 Total Cost of CO_2 Reduction (Cost per ton CO_2)

4.3 Varying the Cost Function

A tradable emission program creates a market for pollution, and thus provides the incentive for competition between nations in the development of new pollution control technologies. The Kyoto Protocol includes a provision for the transfer of all *publicly* owned pollution control technologies between nations, but makes no provision for the transfer of privately owned technologies. Firms that can lower costs of pollution abatement will free up permits for sale (UNFCCC 1998a).

Few studies have been released in which the marginal costs are varied over groups of countries. Wealthier countries are at a comparative advantage because they can devote more to research and development and hence further lower abatement costs. In Dean and Hoeller's (1992) analysis, GDP costs associated with the carbon emission stabilization were much lower for the OECD regions and Russia than for China and the rest of the world. Perroni and Rutherford (1993) simulated a worldwide trading program in which the poorer nations were allocated carbon emission rights at a level that offset the reductions sought in OECD nations partly because of the higher costs associated with reducing emissions in developing nations.

The use of one marginal cost function implies that pollution abatement technologies are identical across nations. This removes some efficiency from a trading

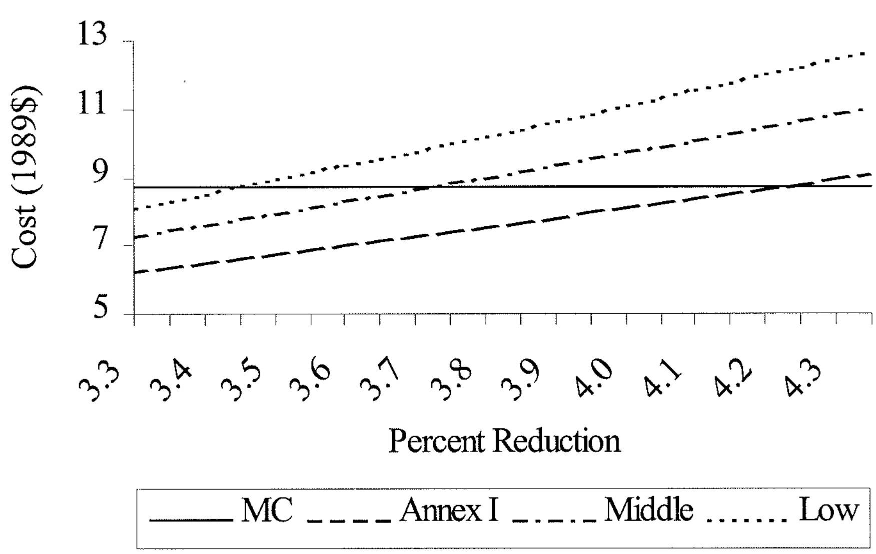

Figure 5 Varying the Marginal Cost Function Between Nation Groups

program because one of the primary goals of an emission trading program is to supply a market-based alternative to reducing pollution emissions. Employing a single marginal cost function assumes that more efficient technologies will not be developed over time. In reality, marginal costs of pollution abatement vary across nations.

In the final scenario, marginal abatement cost functions are varied between country groups. For middle income countries, the beta value was increased from 1.46 to 1.6; for low income countries, the beta value was increased to 1.7. These are hypothetical situations, but it is a fair assumption that the Annex I nation country group will have the cheapest methods of abating CO_2 emissions.

When the cost functions are varied, Annex I nations will have lower relative costs of emission reduction. Therefore, it is conceivable that not all Annex I nations will be buyers of emission permits. Alternatively, not all low income nations will be sellers of emission permits. Table 12 shows the total costs (1989$) of emission reductions when

% Reduction	TC Annex I	TC Middle	TC Low
5	22	26	29
10	117	154	186
20	643	929	1,207
30	1,742	2,665	3,605
40	3,534	5,629	7,838
50	6,116	10,055	14,318
75	16,572	28,853	42,787
100	$33,615	$60,958	$93,033

Table 12 Total Costs of Emission Reduction under Different Cost Functions

the cost function is varied for the middle and low income country groups. As the table shows, the costs of reducing 100 tons of carbon 100% is almost 3 times more expensive for low income countries and 2 times more expensive for middle income countries.

4.4 The Comparative Cost Analysis

Two CO_2 emission reduction strategies are trading and not trading CO_2 emission permits. The multiple permutations of the costs and reduction methods pursued by the three nation groups for which accurate CO_2 emission data exists will include the growth scenarios, progressive and less progressive reduction strategies, and varied cost functions among nation groups.

4.4.1 The Costs of Reducing Emissions for Annex I Nations

The total cost of reducing CO_2 emissions comes from integration of the marginal cost curve. Taking the anti-log of the log linear marginal cost function yields the following equation:

$$MC = \exp^{\alpha} + R^{\beta}$$

Integrating the marginal cost function yields the total cost function:

$$TC = \exp^{\alpha} + (R^{\beta+1})/\beta+1 = \exp^{-0.62971} + R^{2.45861}/2.45861.$$

Table 13 outlines the costs (1998$) for selected countries under the fast growth scenario, without the trade of emissions. Without the trade of emissions, the United

States will bear the greatest cost of the emission reduction program, $254 million per year.

Country	**Total Yearly Cost (1998$)**	**Yearly Reduction (Gg)**	**% Reduction**
Australia	653,246	888	0.33%
Canada	18,258,484	6,920	1.69%
Czech Republic	8,178,416	2,545	1.88%
France	21,836,530	6,795	1.88%
Germany	52,959,720	16,479	1.88%
Greece	4,454,381	1,386	1.88%
Italy	24,588,140	7,651	1.88%
Japan	48,711,774	18,462	1.69%
Netherlands	8,384,614	2,609	1.88%
Poland	15,230,565	5,772	1.69%
Romania	7,363,940	2,291	1.88%
Russian Federation	32,087,921	23,219	1.10%
Spain	13,460,782	4,188	1.88%
Ukraine	9,327,371	6,749	1.10%
United Kingdom	34,149,868	10,626	1.88%
United States	253,798,622	87,029	1.78%
Total (All Annex I)	**$593,950,740**	**216,999**	**1.62%**

Table 13 Yearly Costs, Reductions and Percent Reductions of CO_2 Without Trade

The total cost for Annex I nations of the emission reduction program for one year would be $594 million.

Table 14 outlines the total costs of the emission reduction program for Annex I nations without trade under three different discount rates. The primary discount rate, 6%, was based upon the real yield of Treasury debt. The other two rates provide a sensitivity analysis of plus or minus 2% to capture possible variability in real yields (Lyon 1990). As the discount rate is decreased, costs increase. At an 8% rate, total costs are approximately $4.3 billion.

Year	4%	6%	8%
0	593,950,740	593,950,740	593,950,740
1	571,106,481	560,330,887	549,954,389
2	549,140,847	528,614,044	509,217,027
3	528,020,045	498,692,495	471,497,247
4	507,711,582	470,464,618	436,571,525
5	488,184,214	443,834,545	404,232,894
6	469,407,898	418,711,835	374,289,716
7	451,353,748	395,011,165	346,564,552
8	433,993,988	372,652,042	320,893,104
9	417,301,912	351,558,531	297,123,244
Total	**$5,010,171,455**	**$4,633,820,902**	**$4,304,294,440**

Table 14 Total Cost of Reduction under Different Discount Rates Without Trade

In a tradable emissions permit program, efficiency will be attained when marginal costs of pollution abatement are equated among participating entities. In the Annex I trading program, under the high growth scenario, this point occurs when marginal cost is $2.56. Since only one marginal cost function is employed, the level where marginal costs are equated will also yield the same percent reduction for each country, 1.6%.

Table 15 shows the cost and reduction responsibility for selected countries if the trade of permits occurs. Costs are lower when the trade of emissions is allowed. The total, non-discounted cost with the trade of emissions is $61.0 million (10.3%) less than the program that does not allow trade. With the trade of emissions, the United States still bears the greatest cost of emission reduction, $194 million. The total non-discounted cost of emission reduction is $533 million.

Country	Total Yearly Cost (1998$)	Yearly Reduction (Gg)
Australia	10,673,387	4,346
Canada	16,327,030	6,648
Czech Republic	5,402,004	2,199
France	14,423,455	5,872
Germany	34,980,929	14,242
Greece	2,942,205	1,198
Italy	16,240,947	6,612
Japan	43,558,851	17,735
Netherlands	5,538,201	2,255
Poland	13,619,416	5,545
Romania	4,864,026	1,980
Russian Federation	83,779,175	34,111
Spain	8,891,110	3,620
Ukraine	24,353,074	9,915
United Kingdom	22,556,655	9,184
United States	194,450,655	79,170
Total (All Annex I)	**$532,972,451**	**216,999**

Table 15 Yearly Costs and CO_2 Reduction with Trade

Table 16 outlines the total costs of the emission reduction program for Annex I nations with trade under three different discount rates. As the discount rate is decreased, costs increase. At an 8% rate, total costs are approximately $3.9 billion.

Margo Thorning compiled ten estimates of the impact of stabilizing CO_2 emissions on U.S. GDP growth. The estimates varied from 4.2% to .01% of GDP (Thorning 1998). The EPA recently published the results of a trading model for Annex I nations and "key" developing countries. The costs to the United States would be 0.11% of the GDP in the US in 2010 (EPA 1999b). The estimated costs of the trading model here would be .003% of GDP. This estimate is much lower because the emission

Year	4%	6%	8%
0	532,972,451	532,972,451	532,972,451
1	512,473,510	502,804,199	493,493,010
2	492,762,990	474,343,584	456,937,972
3	473,810,568	447,493,947	423,090,715
4	455,587,085	422,164,100	391,750,661
5	438,064,505	398,268,019	362,732,095
6	421,215,869	375,724,547	335,863,050
7	405,015,260	354,457,120	310,984,306
8	389,437,749	334,393,509	287,948,431
9	374,459,374	315,465,574	266,618,917
Total	**$4,495,799,361**	**$4,158,087,050**	**$3,862,391,609**

Table 16 Total Cost of Reduction under Different Discount Rates with Trade

reduction program simulation runs for ten years, while the Kyoto Protocol expects all participating nations to begin the program in 2008 and end in 2012. If this program were to run for five years, annual reductions would increase at an increasing rate, placing costs within the range of estimates compiled by the American Council for Capital Formation and Policy Research.

4.4.2 Analysis of the Emission Reduction Programs for Annex I Nations

Table 17 compares the total costs over the ten year span of the trade and non-trade programs at 4%, 6%, and 8% discount rates. Total costs with the trade of emissions are 10% less than a program without the trade of emissions.

	4%	6%	8%
No Trade	$5,010,171,455	$4,633,820,902	$4,304,294,440
Trade	$4,495,799,361	$4,158,087,050	$3,862,391,609

Table 17 Total Costs of Two Reduction Programs

The cost savings would be even greater if the marginal cost function for CO_2 abatement was to vary between countries. Table 18 compares pollution abatement and cost for selected Annex I nations with and without the trade of emissions. For some

Country	Yearly Cost No Trade	Yearly Cost Trade	Yearly Reduction No Trade (Gg)	Yearly Reduction Trade (Gg)
Australia	653,246	10,673,387	888	4,346
Canada	18,258,484	16,327,030	6,920	6,648
Czech Republic	8,178,416	5,402,004	2,545	2,199
France	21,836,530	14,423,455	6,795	5,872
Germany	52,959,720	34,980,929	16,479	14,242
Greece	4,454,381	2,942,205	1,386	1,198
Italy	24,588,140	16,240,947	7,651	6,612
Japan	48,711,774	43,558,851	18,462	17,735
Netherlands	8,384,614	5,538,201	2,609	2,255
Poland	15,230,565	13,619,416	5,772	5,545
Romania	7,363,940	4,864,026	2,291	1,980
Russian Federation	32,087,921	83,779,175	23,219	34,111
Spain	13,460,782	8,891,110	4,188	3,620
Ukraine	9,327,371	24,353,074	6,749	9,915
United Kingdom	34,149,868	22,556,655	10,626	9,184
United States	253,798,622	194,450,655	87,029	79,170
Total (All Annex I)	**$593,950,740**	**$532,972,451**	**216,999**	**216,999**

Table 18 Abatement Levels and Costs of Reducing Emissions under Two Programs

countries there exists a massive difference in costs and emission reduction between the two programs. The United States and Russian Federation experienced the greatest difference. The United States would buy 7,900 Gg worth of emission permits from other countries. The Russian Federation would sell 10,900 Gg worth of emission permits.

Each country experiences cost saving from the trading program. Each country could potentially experience the same percentage cost savings, 10.3%, but the dollar magnitude depends upon the level of emissions and the difference in emissions between the two programs. For example, Australia's cost of pollution control is just $653,000 when there is no trade of permits, but almost $11 million with the trade of permits. This does not mean that Australia would pay more for pollution abatement if emissions were traded. Rather, Australia would sell permits valued at a total price greater than ($10,673,387-$653,246). Similarly, the United States costs of CO_2 abatement drop from $254 million to $194 million. The United States' total yearly cost for reducing emissions of carbon dioxide is roughly $227 million. The United States purchases $33 million worth of emission permits, and cuts abatement at a cost of $194 million. Their total yearly saving when the trade of emissions is allowed is approximately $26 million. Table 19 provides a breakdown of the trading program, and compares its total costs to those of the program that does not allow trading. The first numerical column lists the cost incurred from reducing emissions. The second numerical column lists the costs incurred, or monies received from the purchase or sale of permits. The third numerical column is the sum of the first two columns, and is the total cost of the trading program. The fourth numerical column is the total yearly cost when the trade of permits is not allowed.

The Russian Federation would be the greatest yearly seller of emission permits, followed by the Ukraine and Australia. These three nations are net sellers of emission permits.[3] Approximately 18,000 CO_2 emission permits are bought and sold when trade is allowed, roughly 8.3% of all emissions. When emission permits are not traded marginal

[3] As per the Kyoto Protocol, the emissions of Iceland, New Zealand, and Norway are also not greatly limited, but for the sake of space, they do not appear in table 19. They are net sellers of emission permits as well.

costs vary from $0.96 to $4.00. When the trade of permits is allowed, marginal cost is $3.37.

Country	Reduction Costs	Trading Costs or Benefits (-)	Total Trade	Total No Trade
Australia	10,673,387	-10,087,426	585,961	653,246
Canada	16,327,030	50,830	16,377,860	18,258,484
Czech Republic	5,402,004	1,934,034	7,336,038	8,178,416
France	14,423,455	5,163,914	19,587,368	21,836,530
Germany	34,980,929	12,523,939	47,504,869	52,959,720
Greece	2,942,205	1,053,374	3,995,580	4,454,381
Italy	16,240,947	5,814,615	22,055,562	24,588,140
Japan	43,558,851	135,611	43,694,462	48,711,774
Netherlands	5,538,201	1,982,798	7,520,999	8,384,614
Poland	13,619,416	42,400	13,661,816	15,230,565
Romania	4,864,026	1,741,428	6,605,454	7,363,940
Russian Federation	83,779,175	-54,996,310	28,782,865	32,087,921
Spain	8,891,110	3,183,211	12,074,321	13,460,782
Ukraine	24,353,074	-15,986,422	8,366,652	9,327,371
United Kingdom	22,556,655	8,075,777	30,632,432	34,149,868
United States	194,450,655	33,206,708	227,657,364	253,798,622
Total (All Annex I)			**$532,972,451**	**$593,950,740**

Table 19 Costs within the Trading Program and Total Costs of Each Program

4.5 Emission Reduction Programs With Inclusion of All Nation Groups

Including all three nation groups, emission estimates in the year 2000 were based upon recent yearly changes in emissions. Because of the change in emissions from 1992 to 2000, an additional reduction is necessary for the two lower income groups. The emissions of the middle income nation group were estimated to increase 1.36%/year over the 10 year duration of the program. The emissions of the low income nation group were estimated to increase 2.63%/year.

4.5.1 Feasible Growth Scenarios

The first growth scenario causes each group to increase their emissions at a faster pace. Under the fast growth scenario, the emissions of Annex I nations would increase 1.1%/year, middle income nations' emissions would increase 6.0%/year, and the emissions of the low income group would increase 10.2%/year.

Another feasible CO_2 emission growth scenario is for the emissions of the two lower income groups to grow at a fast rate and those of the Annex I nations to grow at a slow rate. Slow growth for Annex I nations would be a yearly decrease in emissions of 1.4%. Technological advance would affect per capita consumption of commercial energy, the variable with the greatest contribution to carbon dioxide emissions. In a semi-competitive emission reduction program, it would be unlikely that Annex I nations would transfer all of their technologies to the other two nation groups. Hence, the emissions of the other two nation groups would continue to increase.

The final growth scenario is fast growth for the two wealthiest nation groups and slow growth for the low income nation group. Under this scenario, yearly emissions for Annex I nations would increase 1.1%, yearly emissions for the middle income group would increase 6.0%, and yearly emissions for the low income group would decrease

3.4%. This scenario appears plausible because developing nations are generally unstable economically and politically.

4.5.2 Cost Analysis

As table 20 shows, costs of the programs over ten years when the emissions are not allocated progressively, and are growing at a fast pace, vary wildly: $174 billion - $1,040 billion.

Country Group	Total Cost No Trade	Total Cost Trade	Yearly Reduction No Trade (Gg)	Yearly Reduction Trade (Gg)
Annex I	6,091,232,315	108,845,976,542	217,039	608,901
Middle Income	108,856,507,857	29,241,056,780	240,495	163,579
Low Income	925,467,553,320	35,439,865,048	513,201	198,256
Total	**$1,040,415,293,492**	**$173,526,898,370**	**970,735**	**970,735**

Table 20 Costs and Reductions With and Without Trade, All Fast Growth, Not Progressive

Table 21 presents the total costs over the ten year span of the programs at a 6% discount rate, and the yearly reductions when emissions are allocated progressively.

Country Group	Total Cost No Trade	Total Cost Trade	Yearly Reduction No Trade (Gg)	Yearly Reduction Trade (Gg)
Annex I	6,915,322,594	111,746,150,482	250,223	614,373
Middle Income	89,997,107,873	30,020,177,457	227,838	165,049
Low Income	848,450,469,420	36,384,151,427	501,399	200,038
Total	**$ 945,362,899,887**	**$ 178,150,479,365**	**979,459**	**979,459**

Table 21 Costs and Reductions With and Without Trade, All Fast Growth, Progressive

Costs increase dramatically as an entity attempts to reduce emissions. With the progressive allocation, over the ten year span of the pollution control program, Annex I nations are allocated 2.0% fewer permits to emit CO_2, and the middle income and lower income nation groups are allocated 3.7% and 3.0% greater permits to emit CO_2, respectively.

The revised allocations affect the costs of reducing emissions. Over the duration of the program, when the trade of emissions is not allowed, a progressive allocation costs Annex I nations $0.9 billion more, but costs are reduced by $18.9 billion for middle income nations, and by $77.0 billion for low income nations.

Table 22 presents the marginal costs and the reduction of emissions necessary when trading is not allowed, and for all nations when trading is allowed. Marginal costs and necessary emission reductions vary greatly from nation group to nation group. When trade is not allowed, the necessary reductions for the Annex I nations are much less than those of the other two nation groups. Likewise, the marginal costs of reduction are much less for the Annex I nation group.

But when trade is allowed, marginal costs are equated. The marginal costs have risen for the Annex I nation group, but plummeted for the other two nation groups. Costs of reducing emissions have risen for the Annex I nation group because they have sold permits to the other groups. When emissions are not allocated progressively, Annex I nations must reduce emissions an additional 2.9%. The cost of the additional reduction is more than offset by the sale of the permits. The middle income and low income nation groups are now responsible for lesser percentage reductions. They have purchased the right of further emissions for a price less than the cost to reduce emissions.

Country Group	Percent Reduction No Trade	Percent Reduction Trade	MC No Trade	MC Trade
Annex I (NP)	1.62%	4.55%	3.37	12.71
Middle Income (NP)	6.69%	4.55%	21.77	12.71
Low Income (NP)	11.78%	4.55%	48.81	12.71
Annex I (P)	1.87%	4.59%	3.98	12.87
Middle Income (P)	6.34%	4.59%	20.18	12.87
Low Income (P)	11.51%	4.59%	47.20	12.87

Table 22 Percent Reduction and Marginal Costs, Fast Growth for All[4]

Tables 23, 24, and 25 present the results of the emission reduction programs when the growth of emissions is slow for Annex I, but fast for the other nation groups.

Country Groups	Total Cost No Trade	Total Cost Trade	Yearly Reduction No Trade (Gg)	Yearly Reduction Trade (Gg)
Annex I	0	26,967,789,695	-115,112	400,557
Middle Income	108,856,507,857	7,244,793,926	240,495	107,608
Low Income	925,467,553,320	8,780,616,958	513,201	130,420
Total	**$1,034,324,061,177**	**$42,993,200,579**	**638,585**	**638,585**

Table 23 Costs and Reductions With and Without Trade, Slow Growth Annex I, Not Progressive

Tables 23 and 24 show that costs are only marginally less when the emission reduction program does not allow trade, but drastically lower when trade is allowed. When trade of emissions is allowed, Annex I nations stand to benefit economically and

4 NP denotes not progressive, and P denotes progressive.

environmentally from a reduction beyond targets because they can sell their reductions as permits.

Country Groups	Total Cost No Trade	Total Cost Trade	Yearly Reduction No Trade (Gg)	Yearly Reduction Trade (Gg)
Annex I	0	28,194,289,019	-81,889	406,054
Middle Income	89,997,107,873	7,574,288,295	227,838	109,085
Low Income	848,450,469,420	9,179,960,801	501,399	132,210
Total	**$938,447,577,293**	**$44,948,538,115**	**647,348**	**647,348**

Table 24 Costs and Reductions With and Without Trade, Slow Growth Annex I, Progressive

Annex I nations emit 0.9% and 0.6% less than their yearly allocations under the non-progressive and progressive allocations, respectively. The Annex I nations can sell the surplus permits. The other nation groups will purchase permits from the Annex I nations. Buying and selling occurs until the marginal costs are equated across groups. This occurs at $7.22 when emissions are not allocated progressively and $7.35 when they are.

Country Group	Percent Reduction No Trade	Percent Reduction Trade	MC No Trade	MC Trade
Annex I (NP)	-0.86%	2.99%	0	7.22
Middle Income (NP)	6.69%	2.99%	21.77	7.22
Low Income (NP)	11.78%	2.99%	48.81	7.22
Annex I (P)	-0.61%	3.03%	0	7.35
Middle Income (P)	6.34%	3.03%	20.18	7.35
Low Income (P)	11.51%	3.03%	47.20	7.35

Table 25 Percent Reduction and Marginal Costs, Slow Growth Annex I

A dramatic difference between the cost of cutting emissions with and without the trade of permits also occurs when the low income group has slow emission growth. Tables 26, 27, and 28 present the results of this scenario.

Country Group	**Total Cost No Trade**	**Total Cost Trade**	**Yearly Reduction No Trade (Gg)**	**Yearly Reduction Trade (Gg)**
Annex I	4,636,042,142	5,366,915,424	217,039	237,611
Middle Income	108,856,507,857	1,441,801,375	240,494	63,833
Low Income	0	1,747,448,683	-78,723	77,365
Total	**$113,492,549,999**	**$8,556,165,482**	**378,809**	**378,809**

Table 26 Costs and Reductions With and Without Trade, Slow Growth Low Income, Not Progressive

As when slow growth occurred in the Annex I group, emissions are reduced beyond the necessary amount for the low income nation group. When permits are not allocated progressively, the cost of reducing emissions when the trade of permits is allowed is $105 billion less than the cost of reducing emissions without the trade of permits. The low income nation group is a net seller of emission permits while the other nation groups are net buyers.

Country Group	**Total Cost No Trade**	**Total Cost Trade**	**Yearly Reduction No Trade (Gg)**	**Yearly Reduction Trade (Gg)**
Annex I	6,915,322,594	5,731,975,638	250,262	165,273
Middle Income	89,997,107,873	1,539,873,410	227,838	65,310
Low Income	0	1,866,310,998	-90,527	79,155
Total	**$96,912,430,467**	**$9,138,160,046**	**387,573**	**387,573**

Table 27 Costs and Reductions With and Without Trade, Slow Growth Low Income, Progressive

When permits are allocated progressively, the cost of reducing emissions when the trade of permits is allowed is $88 billion less than the cost of reducing emissions without the trade of emissions. Once again, the low income nation group is a net seller of emission permits while the other two groups are net buyers. Because of the progressive allocation, the low income group has an even greater amount of permits.

Country Group	Percent Reduction No Trade	Percent Reduction Trade	MC No Trade	MC Trade
Annex I (NP)	1.62%	1.78%	3.37	3.75
Middle Income (NP)	6.69%	1.78%	21.77	3.75
Low Income (NP)	-1.81%	1.78%	0	3.75
Annex I (P)	1.87%	1.82%	3.98	3.84
Middle Income (P)	6.34%	1.82%	20.18	3.84
Low Income (P)	-2.08%	1.82%	0	3.84

Table 28 Percent Reduction and Marginal Costs, Slow Growth Low Income

The most efficient level of emissions for each nation group is a yearly decrease of 1.78% under a non-progressive allocation, and 1.82% under a progressive allocation. Marginal cost is $3.75 when permits are not allocated progressively, and $3.84 when permits are allocated progressively.

4.5.3 Varying the Cost Function

The costs of containing emissions with and without trade when the cost function is altered is the most realistic cost analysis. It is likely that the wealthier nations have less expensive pollution control technology. When the marginal cost is $13.90, the Annex I nations are reducing emissions 4.86% per year, the middle income group is reducing emissions 4.23% per year, and the low income group is reducing emissions 3.88% per year. Without the trade of emissions, the Annex I nations would have to reduce emissions 1.62% per year, the middle income group would have to reduce emissions 6.69% per year, and the low income group would have to reduce emissions 11.78% per year.

Table 29 shows costs are greater with and without emission trading when the cost function is varied. The two poorer groups purchase a greater number of emission permits. It has become proportionally less expensive for the Annex I nations to cut emissions, so they are willing to sell a greater amount. There is a much greater percentage saving with the trade of permits when the cost function is varied. The cost of reducing emissions with trade is only 9.7% the cost of reducing emissions without trade.

Country Group	**Total Cost No Trade**	**Total Cost Trade**	**Yearly Reduction No Trade (Gg)**	**Yearly Reduction Trade (Gg)**
Annex I (Same)	6,091,232,315	108,845,976,542	217,039	608,901
Middle Income (Same)	108,856,507,857	29,241,056,780	240,495	163,579
Low Income (Same)	925,467,553,320	35,439,865,048	513,201	198,256
Total (Same)	**$1,040,415,293,492**	**$173,526,898,370**	**970,735**	**970,735**
Annex I (Diff)	4,957,582,200	135,565,954,234	217,039	649,636
Middle Income (Diff)	134,164,665,924	21,226,414,064	240,495	151,932
Low Income (Diff)	1,523,509,415,743	32,415,791,315	513,201	169,167
Total (Diff)	**$1,662,631,663,867**	**$189,208,159,613**	**970,735**	**970,735**

Table 29 Comparison of Costs and Reductions With and Without Varied Cost Function

Table 30 presents the percent reduction and marginal costs when emission permit trading is allowed. When the function is varied the Annex I nations take on a greater reduction responsibility because they have the lowest reduction costs of the three nation groups. Marginal costs are greater because it is now more expensive for the middle and low income nation groups to reduce emissions.

Country Group	Percent Reduction Same Function	Percent Reduction Different Function	MC Same Function	MC Different Function
Annex I	4.55%	4.86%	12.71	13.90
Middle Income	4.55%	4.23%	12.71	13.90
Low Income	4.55%	3.88%	12.71	13.90

Table 30 Percent Reduction and Marginal Cost Comparison, Trade

Over eight percent of all eligible permits were traded in the Annex I trading program. If the cost function is varied, more trades on a percentage basis occur. In addition, when more countries are present in a trading program and they have different initial allocations, more trades on a percentage basis occur. When all countries are included, and growing at a fast rate, under the non-progressive allocation, approximately 392,000 permits, or 40.4%, of all tradable permits are actually traded. When all countries are included and growing at a fast rate under the non-progressive allocation, 433,000, or 44.6%, of all permits are actually traded. Therefore, not only will the percentage trade of permits increase when more entities with different initial allocations are involved, it also increases when the cost function is varied.

4.6 Conclusion

Trading CO_2 emissions is less costly than reducing CO_2 emissions without trade. If the emission reduction program has a greater number of participants, the costs of a trading program are a much smaller percentage of the costs of a program without trade. With the inclusion of all 157 nations, the costs of the trading program are only 17% those of the non-trading program. When only the Annex I nations are involved, the costs of the trading program are 90% those of the non-trading program.

When the marginal cost function is varied, the percentage cost saving of trading programs is greater then when the cost function is the same for all countries. With the same cost function, the costs of the trading program are 17% those of the non-trading program. When the cost function is varied, the costs of a trading program are 10% those of the non-trading program. It was also shown that the percent of trades occurring will increase if the cost function is varied, and if the number of participants increases. The percentage of permits traded increased almost five-fold when the cost function was varied and all 157 nations were included in the trading program. Finally, the cost of the CO_2 emission control program would be relatively inexpensive, whether or not trade of emissions is allowed given that the world's GDP was almost $288 trillion in 1998 (World Bank 1998).

The two growth scenarios were arranged in numerous feasible combinations. The growth scenarios were drawn from existing data for each country. The levels of progressiveness are also practicable. The low progressiveness case was drawn directly from the Kyoto Protocol and is based upon an achievable level of emission reductions. The high progressiveness allocation was simply a slight monotonic transformation of the low progressiveness case. Annex I nations were given a slightly greater responsibility for emission reductions.

The cost function's derivation makes practical sense because the data from which the function was derived came from pollution control studies of CO_2 abatement. The changes in the beta values to steepen the cost functions for the low and middle income country groups were not drawn from real world data, but make intuitive sense. Comparing the costs of trade and no trade pollution abatement programs when the beta values are varied should be viewed as illustrative. As was seen in the previous section, cost savings for the tradable emission permit program will be even greater when the cost function is varied between nation groups.

5 CONCLUSION

On November 12th of 1998, at the Conference of the Parties 4 in Buenos Aires, the United States signed the agreement reached in 1997 in Kyoto. President Clinton is not expected to submit the treaty for ratification to the Senate until he sees meaningful participation by developing countries (UNFCCC 1998a). As this thesis has shown, including more countries would lead to a greater cost efficiency for the Protocol, and the costs would be a small percentage of the world's GDP.

The National Aeronautic and Space Administration (NASA) announced earlier this year that 1998 was the warmest year on record. The average world temperature in 1998 was 58.496° Fahrenheit. The previous record high, recorded in 1995, was 58.154° Fahrenheit. The National Oceanic and Atmospheric Administration, in a separate announcement, agreed with NASA's assertion (Schmid 1999).

The trade of greenhouse gas emissions has already begun on an international individual firm basis, and is in the final proposal stages in certain parts of the world. This past March, Suncor Energy of Canada purchased 100,000 metric tons of greenhouse gas emissions reductions from Niagara Mohawk Power of New York, and an option exists for the exchange of an additional 10 million tons over a ten year period. The European Commission and the G-8 have also discussed enacting trading programs. As this thesis has shown, including as many entities as possible will lead to the greatest economic efficiency (World Resources Institute 1999b).

5.1 Problems Encountered in the Composition of the Thesis

Most of the problems encountered were related to inadequate data. Data inadequacies occurred with the measurement of the level of emissions, the cost of reducing emissions, measurement of carbon sinks, and historical and future data related to GDP, GNP derived from industry, and commercial energy consumption.

The most recent data presented by the World Resources Institute in the 1998-1999 World Development Report presents emission data for only 155 nations. Also, the CO_2 emissions of some nations have been greatly underestimated, especially China (Hertsgaard 1998). In situations where the data was not underestimated, it was more often than not incomplete. In the Americas, 22 nations reported emissions from fossil fuel burning in 1995. Of those 22 nations, only 9 reported what can be viewed as complete data.

The yearly emission growth values would have been more convincing if incomplete historical values were not needed to derive future values. It is almost impossible to predict GDP growth one year into the future. It is impossible to predict GDP five or more years into the future. Over a period of five months in 1998, for example, the International Monetary Fund (IMF) decreased their GDP growth forecasts from 0.0% to –2.5% in Japan, from –0.8% to –7.0% in Korea, from –5.0% to –15.0% in Indonesia, and from 2.5% to –6.4% in Malaysia. Likewise, it is not possible to estimate the future levels of GNP that will be derived from industry in each country, and commercial energy consumption (IMF 1998a and 1998b).

The estimates would have been more realistic if cost data existed for all countries. Employing the same cost function for all 157 nations was a hindrance. Randomly varying the cost function for the lower income groups was illustrative, but incomplete. Finally, inclusion of carbon sinks in the trading program was not possible because the level of CO_2 emissions offset by carbon sinks was unavailable for many Annex I nations and for all the developing countries. In addition, a wide range of emission offset levels was given for many of the nations for which data existed.

5.2 Problems Extending Beyond the Thesis

One problem that may hamper the development of a CO_2 emission reduction program is the United States political system. In the early 1990s, it appeared that the United States was on a pro-environment course. Bill Clinton had chosen environmental advocate Al Gore as his running mate. In *Earth in the Balance* (1992), Gore went so far as to say that the rescue of the environment had to become "the central organizing principle for civilization." Gore relished his role as the environment's Winston Churchill, standing up for his beliefs despite the existence of numerous detractors and hurdles. Weeks after the 1992 election, environmental guru Lester Brown referred to Gore as "Mr. Environment".

But shortly after, events took a sharp turn. Clinton's initial budget package included a provision for a BTU tax, intended to lower air pollution and greenhouse gas emissions. Under pressure from Senators from coal and oil states, Clinton was forced to change the BTU tax plan. He "amended" the tax from its initial value of 50 cents per gallon of gasoline to 4 cents per gallon of gasoline. Additionally, subsidies for mineral rights and other public lands were not stricken. In 1995, Clinton signed into law a bill that allowed unlimited clear-cutting of national forests. This action pales in comparison to the "goals" sought by the Administration at Kyoto. A few months before the Kyoto conference, Clinton unveiled his climate change policy. In it, he pledged to not allow CO_2 concentrations in the Earth's atmosphere to exceed 550 parts per million, a doubling of pre-industrial levels. But this pledge resulted in no concrete action (Hertsgaard 1998).

5.3 Other Problems with Enacting an Emission Control Program

The primary problem associated with enacting an emission control program derives from those with political voices who claim that the costs are going to be astronomical. Conservative leaning research organizations have derived estimates of costs to the United States ranging from 0.9% to 4.2% of US GDP. These organizations also state that the price of gasoline will need to increase by as much as 53%, and the price of electricity will increase by as much as 86% to attain the stabilization goal called for by the Kyoto Protocol (Thorning 1998). In contrast, 2000 economists from academia, industry, and government signed a letter in 1997 that stated, "Economic studies have found that there are many potential policies to reduce greenhouse gas emissions for which the total benefits outweigh the total costs... The most efficient approach to slowing climate change is through market-based policies" (Global Change 1997). Clearly, this issue is going to continue to incite controversy (Fialka 1999).

5.4 Areas for Future Study

One area that stands to profit from future study is the accurate determination of CO_2 emissions. Developed nations are attempting to include developing nations in a worldwide emission reduction program, but data on the CO_2 emissions of many of these nations are non-existent or inaccurately estimated. Before a worldwide emission reduction program can commence, a comprehensive set of emission data must be compiled. Cost data needs also to be examined. Perhaps the cost of reducing emissions is greater for less developed nations, but there has yet to be a conclusive study done on the subject. If each nation knew their reduction costs for CO_2 emissions, the trading program would run in a much more efficient manner.

Carbon sinks should be included in the joint international CO_2 emission reduction effort. Further study is needed on the costs of reforestation, the emissions sequestered by each type of forest, and the world's inventory of forested land. Carbon sink data are incomplete for almost all countries. Many data inconsistencies exist within and between the Annex I nations. Of the Annex I nations, only 14 reported data on CO_2 emissions and removals through land-use change and forestry. The base year varies from 1985 to 1990.

Some countries include the sequestration from changes in forest and other woody biomass stocks, and abandonment of managed lands, but others do not.

Over-reporting of sinks is also a problem. The Russian Federation reported a removal of almost 800,000 Gg of CO_2. Their emissions through energy use and industrial processes were approximately 2.4 million Gg. Much of the 800,000 Gg was removed because of "managed forest". The United States reported neither emissions nor removals from land-use change and forestry, and yet reported a net decrease in CO_2 emissions of 436,000 Gg. Clearly there is much room for improvement in the compilation of carbon sink data (World Bank 1998).

Will nations continue to develop with little regard for the environment? Will countries approach the CO_2 emission problem by employing an inefficient stopgap measure of an emission reduction program that utilizes standards? As this thesis has shown, the global warming problem is not getting any better, and an INTREPD is the most economical way to solve it.

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