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Joint Implementation - Optional or Necessary Policy?

by

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ABSTRACT

Joint Implementation (JI) was included in the Framework Convention on Climate Change (FCCC) to offer country's with high costs of abatement the opportunity to purchase reductions in greenhouse gas (GHG) emissions from countries with lower costs. Despite the potential for JI to provide a more cost effective deployment of global resources to combat climate change, disagreement over abatement responsibility has given the impression that JI is an optional policy in international negotiations.

This thesis was written to refocus the debate over JI. Using a Cournot model of oligopoly, it is shown that in some cases JI is a necessary policy. Without JI, it is possible that the gradual participation of developing countries in undertaking GHG commitments will be threatened, eliminating the opportunity for the effective mitigation of global climate change. This research supports the development of a legal framework which will allow JI projects to count as credits towards developed country's abatement commitments.

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CHAPTER ONE

INTRODUCTION

Since the 1980's, world wide attention has been drawn to the issue of rising global greenhouse gas (GHG) emissions and the potential for catastrophic climate changes. In 1992, the signing of the Framework Convention on Climate Change (FCCC) was a major milestone towards the development of international GHG abatement commitments.

The FCCC assigned the lead in combating climate change to the developed nations and countries whose economies are in transition. [1,2] The aim for these countries, established by the FCCC, was to reduce their emissions of carbon dioxide and other GHGs to 1990 levels by the year 2000. All nation signatories, including developing countries, were to commit to provide GHG inventories, publish regular updates on programs to control emissions and promote cooperation and education about the issues related to climate change.

Presently, only two developed countries Britain and Germany, are expected to meet their existing target of stabilizing emissions at 1990 levels.[3] Even if every country achieved its stabilization target, these combined commitments fall far short of what scientists estimate as required. In 1990, the Intergovernmental Panel on Climate Change (IPCC) suggested that a 60 to 80% reduction in emissions would be necessary to mitigate the threat of future climate change.[4] This level of abatement is only possible if both developed and developing countries adopt GHG targets.

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[1] Keating [1993], pg 64

[2] For the ease of exposition, the terms developing and developed countries are used to imply Annex I and non-Annexed countries.

[3] Science and Technology, The Economist [1997], pg 89

[4] Intergovernmental Panel on Climate Change [1992]

Presently the OECD countries account for approximately 39% of global GHG emissions.[5] The need for a system that somehow includes the developing countries is further exacerbated by the future growth and industrializing of the developing world. However, developing countries have been reluctant to commit to any GHG abatement targets. The primary issue over which there is much debate is one of responsibility.

Developing countries, which are at the beginning stages of development, feel they should not be unduly punished for GHG emissions. Their opinion is that developed countries have had opportunity to create affluent economies by borrowing the assimilative capacity of the atmosphere and therefore have the moral obligation to do the abating. It is the critical role which GHG emissions play in the industrialization process that is central in the debate over where and by whom GHG abatement should take place. However, if developed nations were to acknowledge that they have taken too much of the common airspace and undertake the responsibility for reducing GHG emissions, it would be at a substantial cost. Reports in the popular press suggest that overall global costs would be reduced by 70% if developed countries pursued reductions wherever it was cheapest to do so (i.e. in the developing countries).[6]

The concept of joint implementation (JI) was included in the FCCC to address the issue of cost-effectiveness. In theory, JI would permit countries which possessed high costs of abatement the opportunity to purchase GHG reductions from countries with lower costs. With JI, efficient emission reductions could be achieved without the necessity of world government regulation,

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[5] Barrett [1992], pg 15

[6] Science and Technology [1997], pg 89

allowing each country to maintain its autonomy.[7] However, the unresolved debate over GHG abatement responsibility has not permitted JI projects to count towards developed countries' commitments for the year 2000.

The literature offers limited analysis from which to draw to reconcile the views regarding the use of JI. From an economic perspective, the attractiveness of JI is its potential to develop into a system of fully tradeable permits, equivalent to attaining the socially optimal level of abatement. In most cases, the analysis of environmental policies has been from one of two perspectives. The first is the tendency to make comparisons between alternative policies for imposing full cooperation, assuming a cooperative consensus is already achieved. This ignores the very real possibility that full cooperation (100% participation) is never attained. Second is the tendency to evaluate the gains achieved from the socially optimal solution over a situation of non-cooperation. This ignores the probability that cooperation to reduce GHG emissions will develop gradually, as already witnessed with the signing of the FCCC.

Rentz [1995] argues that an international agreement on the implementation of a CO_2 entitlement system without introductory measures is quite improbable. If the participation of countries were to take place gradually, economic theory would suggest that each country's decision to participate would be determined by the incremental gains each expects to receive. As the bulk of the literature has been restricted to analysis of scenarios which involve no cooperation or full cooperation, it is not clear if there exists an incentive for small numbers of developing countries to join developed countries in undertaking GHG abatement commitments.

[7] Swisher [1992], pg 158

The contribution this thesis makes is to refocus the debate over JI. The controversy surrounding the use of JI is distracting because it tends to imply that JI is an optional strategy in the pursuit of international GHG abatement. In some cases, JI is required to gradually advance country participation. A Cournot model of oligopoly is used to identify the conditions which determine whether JI is optional and a means to minimize costs versus an absolutely necessary policy to advance cooperative GHG negotiations. It will be shown that, under certain conditions, JI is a necessary policy instrument and provides the incentive for the gradual participation of developing countries who are indispensable in the effort to mitigate the threat of global climate change.

1.1 Thesis Structure

In chapter 2, a brief background on the science of climate change, the necessity of broad global agreement and the current differences in views and circumstances of developed and developing countries is provided. The history of the FCCC and JI is summarized in Chapter 3. A short review of the theoretical work which motivates this study pertaining to JI, economic instruments, permit trading and cooperation follows in Chapter 4. Chapter 5 presents an illustrative two country Cournot model to introduce the method of analysis used to evaluate the necessity for JI. Chapter 6 builds on the model presented in Chapter 5, allowing for several countries and progressive stages of international cooperation between developed and developing countries. The final chapter draws conclusions on the models and makes suggestions for additional research and variations in the analysis presented that would be useful to enhance the understanding of the role of JI in furthering efforts to reduce international emissions of GHGs.

CHAPTER TWO

THE SCIENCE AND HISTORY OF CLIMATE CHANGE

2.1 The Greenhouse Effect and the Global Climate

In 1863, a British scientist, John Tyndall, described how water vapour in the atmosphere helps to keep the earth warm.[8] Since then, scientific research has identified a number of gases that contribute to the earth's atmosphere being 33 degrees higher than the space beyond. Four gases, carbon dioxide, nitrous oxide, methane and chlorofluorocarbons (CFC's), are primarily responsible for this well known warming effect referred to as the greenhouse effect. They keep the earth warm by reducing the return flow of solar radiation back into space. Table 1 outlines the principal anthropegenic sources of the various GHGs.

Table 1: Principal Anthropogenic Sources of GHG Emissions

	GHG	Principal anthropogenic sources
CO_2	Carbon dioxide	Fossil fuel burning Deforestation and land use changes Cement manufacture
CH_4	Methane	Rice paddy cultivation Ruminants (eg. cows, sheep) Biomass burning and decay Releases from fossil fuel production
CFC's	Chlorofluorocarbons 12	Manufactured for solvents, refrigerants, aerosol spray, propellants, foam packaging
N_20	Nitrous Oxide	Fertilizers Fossil fuel burning Land conversion for agriculture
NO_x	Nitrogen Oxides	Fossil fuel burning
CO	Carbon Monoxide	Fossil fuel burning and biomass burning
	Non-methane hydrocarbons	Evaporation of liquid fuels and solvents

Source: Grubb [1989] pg 6

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[8] MacLean [1992]

Since 1750, atmospheric concentrations of carbon dioxide have increased 27% (from 279 ppmv (1750) to 345 ppmv (1990).[9] The expectation is that these concentrations will continue to grow with increasing global populations and the industrializing of developing countries. Table 2 shows that emissions of carbon dioxide are forecast by the International Energy Agency (IEA) to rise 47.6% in a base case growth scenario over the next two decades.

Table 2 also provides some examples of the impact developing countries have in future GHG emissions. In 1990, CO_2 emissions from East Asia and China represented 4.6% and 11.1% of total world emissions respectively. Table 2 shows that these shares of world emissions are expected to increase as the base case forecast predicts emissions of CO_2 from East Asia and China to grow 167.8% and 109.3% with world emissions increasing only 47.6%. If this proves to be the case, by year 2010, East Asia's CO_2 emissions will represent 7.8% of world emissions and China, 15.8% of world emissions.

While it is true that the industrialization of developed countries is largely responsible for the current build up of GHG emissions in the atmosphere, developing countries have a critical role in the future growth of these emissions. Presently, China and India account for less than 10% of the world's energy demand, but this is changing rapidly as they plan to build what would amount to a quarter of the world's new capacity.[10]

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9 Climate Digest [1994], pg 7

10 Survey: Energy, The Economist [1994], pg 7

Table 2: World CO_2 Emissions (gigatonnes CO_2 per year) and Forecast Growth

		2010 Forecast Percentage growth over 1990		
Group of countries	**1990 gigatonnes**	Low growth	Base case	High growth
OECD	10.4	22.0%	28.4%	34.1%
Former Soviet Union and Central and Eastern Europe	4.8	-7.1%	-3.7%	3.2%
Latin America	1.0	66.5%	84.4%	108.3%
Africa	0.7	64.0%	81.5%	106.0%
Middle East	0.7	93.4%	117.7%	150.2%
East Asia	1.0	121.6%	167.8%	212.2%
South Asia	0.7	101.3%	148.8%	221.9%
China	2.4	69.5%	109.3%	130.4%
World	**21.6**	**33.6%**	**47.6%**	**61.5%**

Source: IEA, World Energy Outlook [1994] as reported by Selrod et al [1995] pg 2

Considerable concern in the 1980's over the expected change in GHG emissions resulted in the development of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC brought together thousands of leading scientists involved in the study of climate change, its expected impacts and necessary responses. When concentrations of carbon dioxide double over the levels present in the 1750's, the earth's average temperature increase is likely to lie inside the range of 1.5 to 4.5 degrees Celsius.[11] While there exists scientific debate over the precise impacts increased concentrations of GHGs will have on the global climate and the eco-system, a global temperature change in this range may be sufficient to generate a variety of serious potential climate scenarios.

Rising global temperatures, to the levels predicted, have been sufficient for climate models to predict the melting of the West Antarctic ice sheet raising the sea level, flooding coastal cities, the freezing of Western Europe from the discontinuous change in the oceans, and increased areas of desertification. Cline [1991] provides a synthesis of possible global warming impacts which

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11 Intergovernmental Panel on Climate Change [1992], pg 6

include substantial forest loss, more severe tropical storms, increased illness and mortality, increased drought and water scarcity and thawing of permafrost.[12]

Although the IPCC [1992] reported that the unequivocal detection of the enhanced greenhouse effect is not likely to occur for a decade or more, there are already some statistics which suggest a change in the earth's climate is occurring. The IPCC reported that the global mean surface temperature had increased by 0.3 to 0.6 degrees Celsius over the last 100 years.[13] The U.S. Department of Agriculture reported in 1992 that the seven warmest years in the past 100 years (based on average global temperatures) were 1990, 1988, 1987, 1983, 1981, 1980 and 1986 in that order.[14] According to Environment Canada, The MacKenzie Basin, a 1.7 million square kilometer watershed in Northwestern Canada, has warmed an average of 1.7 degrees Celsius over the last 100 years which is three times the global rate.[15] The Nigerian Environmental Protection Agency has reported that the Sahara desert is advancing 5 km annually.[16] The Climate Digest [1994] warned if desertification is not tackled, Africa and the rest of the world could face almost permanent famine as further areas of food-growing land are lost.

Faced with the uncertain and potentially catastrophic consequences of increasing GHG emissions, the IPCC put forth a recommendation to stabilize the atmospheric concentrations of GHGs as a precautionary target and suggested that a 60 to 80% reduction in emissions will be required to effectively mitigate the threat of future climate change.[17] Despite this recommendation, the strongest action taken to date has been the negotiation of the FCCC, requiring developed countries to commit to return emissions to 1990 levels by the year 2000.[18]

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12 Cline [1991], pg 915-916
13 IPCC Supplement [1992], pg 6
14 Whitmore [1992]
15 ECONET [1996]
16 Climate Digest
17 IPCC Supplement [1992]
18 Keating [1993], pg 64

2.2 Necessity for Broad Global Agreement

The IPCC recommendation of 60-80% reduction in emissions of GHG is not achievable without the broad participation of many countries. Table 3 illustrates the international distribution of GHG emissions.

Table 3 Global GHG Emission Shares, 1987[19]

	Percent of World Emissions	
	CO_2 Emissions*	CO_2+CH_4+CFC net emissions**
OECD	30%	39%
US	15%	17%
EC	9%	14%
Japan	4%	4%
ex-USSR	12%	12%
Eastern Europe	4%	3%
China	10%	6%
Brazil	15%	10%
India	3%	4%
Indonesia	3%	2%
Mexico	1%	1%
Myanmar	2%	1%

* includes emissions resulting from land use changes, including deforestation
** Estimates include CO_2, CH_4 and CFC emissions, weighted by their heat trapping potential

Notice that the OECD, as a group, only emits 39% of the world GHGs and is therefore unable to deliver independently the size of the reduction recommended by the IPCC. Furthermore, these emission shares are expected to change as a larger proportion of incremental emissions will come from newly industrializing countries. Given the relatively small contribution any one country, or even any one economic group of countries, makes towards international emissions of GHGs, the IPCC target will only be achieved with the participation of many countries which include both developed and developing nations.

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19 Barrett [1992] page 15: Table 1.1, compiled from World Resources Institute

2.3 Diversity Between Developed and Developing Countries

Abatement opportunities differ across countries as each economic region has a different existing technological base, energy market structure, availability of indigenous fuels and differences in labour costs.[20] These issues are recognized in the FCCC. Given the challenges in recognizing the diversity between all countries, the FCCC grouped signatories according to their economic classification (i.e. developed versus developing). The FCCC requested common commitments among signatories of a common group but differentiated the commitments between the groups. The reason for doing so was to assign the lead responsibility in combating climate change to the developed countries. However, the distinction is useful as developed and developing countries, in addition to their economic diversities, possess distinct differences in their costs and benefits of GHG abatement.

Consider the benefits to be derived from international GHG abatement. It is possible to argue that the marginal abatement benefit curve will be lower for developing countries, holding all else constant. Barrett [1992] makes the argument that poorer countries, by virtue of their lower incomes, have less to lose from the global warming than rich countries.[21] Furthermore, poorer countries probably discount the future at a higher rate than richer countries. The result of higher discounting is that poor countries will view the benefits from slowing global warming as smaller than richer countries which would be expected to discount the welfare of their future citizens at a lower rate.[22] Overall, it is expected that the developed country will attach a higher value to the benefits from GHG abatement, in comparison to developing countries.

With respect to the cost of GHG abatement it is more difficult to make generalizations. Abatement opportunities differ widely across countries, even within developed countries. However, it has been noted that lower cost opportunities for reducing GHG emissions may be

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20 Jackson [1995], pg 123

21 Barrett [1992], pg 21

22 This argument is made by both Barrett [1992] pg 21 and Wilman [1992], pg 4

found in developing countries from the removal of heavy fossil fuel subsidies and the use of known technology to improve currently fuel inefficient facilities.[23] Further, lower labour costs and low cost GHG sinks further contribute to costs of abatement in the developing world being less than those in the developed nations. Finally, the fact that pilot JI projects are being undertaken by developed country companies in developing nations provides evidence that developing countries are perceived to offer less expensive opportunities for GHG abatement. Walker and Franz [1994] see the recent development of JI as an "admission by the industrialized countries that the cost of GHG abatement within their own territory is not cheap despite previous claims by many environmentalists". The popular press suggests if developed nations were able to reduce emissions wherever in the world it was cheapest to do so, their costs could be reduced by 70%.[24]

Despite the diversity between participants to an international agreement to abate GHG emissions, comparison of countries suggests developed countries will possess higher costs of GHG abatement and higher benefits of GHG abatement. This implies developed countries may be characterized as high cost and high benefit countries and developing countries as possessing low costs and low benefits, with respect to the abatement of GHGs.

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23 This argument is made by Cox [1991], Wilman [1992], pg 5

24 Science and Technology [1997], pg 89

CHAPTER THREE

THE FCCC AND JI

3.1 Evolution of the FCCC

The discovery of the greenhouse effect and the primary gases took place hundreds of years ago. However, a multitude of scientific studies detailing climate modeling and forecasting impacts of growing concentrations of GHGs did not take place until the 1980's. In 1988, the United Nations Environment Programme and World Meteorological Organization created the IPCC to bring together several thousand leading scientists involved in the study of climate change, its expected impacts and necessary responses.

The conclusions of the IPCC became well-known after being presented to the second World Climate Conference in Geneva in 1990 at the Ministerial Declaration. In December of 1990, an Intergovernmental Negotiating Committee (INC) of government representatives was established under the United Nations to draft a legally binding climate treaty. Although the IPCC report had concluded that a 60-80% reduction of CO_2 emissions was needed to stabilize atmospheric concentrations, the strongest proposal considered by the INC was to freeze CO_2 emissions at 1990 levels by the year 2000.

The text of the climate treaty was carried forward for signature to the United Nations Conference on the Environment and Development at Rio de Janeiro in June of 1992 (Earth Summit). The principal aim of the so-called Earth Summit was to show the way to a new global strategy for reconciling development needs with environmental protection. One of the key results of the Summit was the signing of the FCCC. In June 1992, the FCCC was signed by 154 states and the European Community, to carry forth the convention's ultimate objective, the "stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

The common commitments which all signatories accept upon ratifying the FCCC are delineated in article 4.1 (a) to (j) and in summary reflect each states responsibility to adopt national programmes for mitigating climate change; to develop adaptation strategies; to promote the sustainable management and conservation of GHG sinks; to take climate change into account when setting relevant social, economic and environmental policies; to cooperate in technical, scientific and education matters; and to promote scientific research and the exchange of information.[25]

Differentiated commitments for categories of states were designed to assign the lead to developed nations for combating climate change. This provision recognized that the current concern over increased levels of atmospheric concentrations was the result of the historical development of the current industrialized countries. Every developed country and country with economy in transition (or Annex-I country) by ratifying the FCCC made the following two commitments as identified in Article 4.2 (a) and (b).[26]

> • ...[to] adopt national policies and take corresponding measures on the mitigation of climate change by limiting its anthropogenic emissions of GHGs and protecting and enhancing its GHG sinks and reservoirs...consistent with the objective of the Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of ... GHGs ... would contribute to such modification... These parties may implement such policies and measures jointly with other Parties and may assist other Parties in contributing to the achievement of the objective of the Convention and, in particular, of the subparagraph;
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> • ...[to] communicate, within six months of the entry onto force of the Convention for it and periodically thereafter ... detailed information on its policies and measures .... with the aim of returning individually or jointly to their 1990 levels of these anthropogenic emissions of ... GHGs ...[27]

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25 Framework Convention on Climate Change, as reprinted in Kuik, O. et al [1994]

26 Annex-I countries are OECD members and countries that are in transition to a market economy. Annex-II countries are strictly OECD members. This thesis utilizes the term "developed countries" for ease of exposition to refer to Annex-I countries.

27 Framework Convention on Climate Change, as reprinted in Kuik, O. et al [1994]

3.2 Joint Implementation

To improve the cost effectiveness of international GHG abatement and encourage nations to undertake GHG abatement commitments, the concept of "joint implementation" (JI) was incorporated into the FCCC. JI appears in Article 4.2 (a), and the concept enables states, which have made commitments under the FCCC, the option to partially meet their GHG targets by investing in net GHG reducing projects in separate states. Through JI, developed countries, possessing often the highest cost alternatives for GHG abatement, could achieve a portion of their target by investing in GHG reduction projects in other developed or developing countries. JI projects would maintain the FCCC objective to stabilize GHG emissions as carbon dioxide may be considered a perfectly mixed pollutant. This implies the earth's atmosphere is no better off if one tonne of carbon dioxide is removed from the atmosphere over Peru versus Canada.

Despite the inclusion of JI in the FCCC, it has been decided that JI projects will not be permitted to count towards the commitments which developed countries have already made for the year 2000. As there is little documentation in the FCCC to indicate how exactly JI is to be defined, by whom it will be carried out, or the means whereby it will ensure that the aim of cost-effectiveness is achieved, JI projects are not presently credited towards developed country's year 2000 commitments.[28] After the FCCC has had the opportunity to assess the results from a demonstration phase of pilot JI projects, its role in combating climate change will be reassessed. Presently, JI activities are being undertaken as pilot initiatives by a number of developed and developing countries in an effort to provide real world experience and to assist in establishing an empirical basis for considering JI projects as credits towards country commitments. The debate surrounding the use of JI and a current update of JI activities is discussed in Chapter 4 where a review of the theoretical literature is provided.

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28 Jackson [1995], pg 117

CHAPTER FOUR

REVIEW OF THE LITERATURE ON MARKET MECHANISMS, ECONOMIC COOPERATION AND JI

The foundation of the model presented in Chapter 5 is the literature pertaining to market mechanisms, economic cooperation and the implementation of JI between countries. The literature provides the basis for understanding the role sidepayment policies, such as JI, have in developing further international cooperation.

4.1 Market Mechanisms and Environmental Regulation

Traditionally, command and control regulation has been the dominant approach for protecting environmental quality. The cornerstones of the federal environmental policy in the United States, the Amendments to the Clean Air Act in 1970 and to the Clean Water Act in 1972 explicitly prohibited the weighing of benefits against costs in the setting of environmental standards.[29] However, the imposition of emission levels and/or specific technologies has not allowed firms to seek the lowest cost alternatives to meeting the regulations. Regulatory standards require all polluters to meet the same standard of emission control, regardless of the costs of control. In contrast, market based mechanisms such as emission taxes and tradeable emission allowances work through market prices, providing a clear signal to producers and consumers to control emissions at least cost to the community.

In 1991, Tietenberg provided a summary of empirical studies on the cost advantage of controlling air pollution with least cost methods over traditional command and control. This study found that least cost (market based) methods were 1.07 to 22 times more cost effective than command and control methods.[30] In an increasingly global economy, the costs associated with traditional

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29 Cropper and Oates, [1992], pg 675

30 Stavins [1994] points out that it would have been more appropriate to compare actual cost savings as opposed to potential

environmental regulation motivated the exploration of more flexible systems to allow firms to pursue cost effective, market based alternatives.

In theory, and under otherwise perfectly competitive market conditions, marketable emission permits are a fully equivalent alternative to unit taxes. Both policies confront polluting agents with a "price" equal to the marginal cost of the polluting activities to induce them to internalize at the margin the full social costs of their activities.[31] In the 1960's the idea of using transferable discharge permits to distribute the burden of pollution control was put forward by Crocker [1966] followed by Dales [1968]. Four years later, Montgomery [1972] rigorously proved that such a system could, in theory, provide an efficient policy alternative for pollution control. Today there is growing support for economic incentives, visible from favorable treatment in popular business and environmental press, and incorporated into core strategies of public environmental organizations.[32]

4.12 Market Mechanisms and GHG Abatement

Given the potential for an international carbon tax or a system of tradeable permits to achieve cost-effective emission reductions the examination of these concepts and their ability to contribute to reductions of GHGs has been widely discussed.

Price has long been recognized by economists as one of the most powerful tools available for affecting demand. However, there are many issues associated with establishing an environmental pricing and carbon taxes are no exception to this rule. Many have analyzed alternative operational structures for an international carbon tax and the factors that could adversely affect its ability to effectively control emissions, these include Grubb [1989], Pearce [1991], Shah and Larsen [1992] Cnossen and Vollebergh [1992], Bertram, Stroombergen and Terry [1993] among others. The troubling issue of energy taxes being largely regressive, disproportionately affecting the poor, has

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31 Cropper and Oates [1988]

32 Tietenberg [1991], pg 267

been discussed by Grubb [1989]. Despite ongoing debate, carbon tax proposals are rampant throughout the OECD and some countries have already imposed a carbon tax (including Finland, the Netherlands and Sweden).[33] New Zealand has undertaken extensive modeling of how a carbon tax can deliver environmental gains while preserving or enhancing the economy's performance.[34] However, as Barrett [1992] points out, all of these taxes are modest in comparison with the level of tax that would be required to make substantial reductions in CO_2 emissions.

While regional and national governments are most familiar with the imposition of taxes, Grubb [1989] questioned whether the application of carbon taxes is the way to reduce international emissions of GHG.[35] While the familiarity countries have with the imposition of taxes may make a carbon tax appear as one of the easiest agreements to negotiate, it presents a number of implementation challenges. General difficulties include resolving the social impacts associated with energy pricing as well as the presence of imperfect markets.[36] An agreement on carbon taxes, in a world of very different economic and political systems, which in many cases do not reflect real costs is another challenge. Further, handing over the control and allocation of the large funds collected from carbon taxes is in conflict with the country sovereignty. Given these difficulties, Grubb was one of the first to argue that by far the most promising approach is a tradeable permit system in which countries have an adult per capita entitlement to emit carbon. This is formalized via carbon permits which can be leased in return for technical assistance for aiding development. Grubb argued this is the most practical and ethical approach, as countries retain sovereign control over the nature of the associated transfers, thus reducing the need for an international bureaucracy.[37]

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33 Barrett [1992], pg 25
34 Bertram et al [1993]
35 Grubb [1989], pg 29
36 Grubb [1989], pg 30
37 Grubb [1989], pg 41

There is much debate over the equity and efficiency considerations in the distribution of GHG emission permits. In 1994, Larsen and Shaw examined the feasibility of four alternative tradeable permit distributions to stabilize global carbon dioxide emissions at 1987 levels by the year 2000. Their results suggested an allocation by population would likely be unacceptable to most middle income countries as well as to emerging market economies because of the large net costs involved. For example, OECD countries may be reluctant to a global treaty based on a permit allocation by population as their net costs were forecast to be 1% of GDP. Larsen and Shaw found the distribution which is most likely to induce the broadest participation is that which distributes permits to each non-OECD country equivalent to its projected baseline emissions, and to OECD countries, permits equal to the world emissions target minus the permit allocations to the non-OECD countries. Under this allocation, the net costs to the OECD countries would be only one-half of the costs of unilateral OECD reductions and OECD countries would still participate in GHG abatement.

While the literature continues to debate equity considerations in the distribution of GHG emission permits, equally important is an understanding of the factors which affect the efficiency of permit systems. The performance of marketable permit systems, in terms of their cost savings and impact on environmental quality, will be affected by several crucial factors, which are largely outside the scope of traditional economic analysis. Hahn and Hester [1989] found economic, political, institutional and technological factors all have the potential to have a major impact on both the structure and performance of permit markets. Papers that have discussed the ethical, monitoring and verification issues include among others Grubb [1989], Victor [1990, 1991], Oates and Portney [1991], Haites [1991] and Bertram [1992]. Most relevant to this thesis is the work by Stavins [1994] who incorporated the presence of transaction costs, which are typically assumed away, within a model of tradeable permit activity.

Stavins identified three potential sources of transaction costs in tradeable permit markets, i) search and information, ii) bargaining and decision and iii) monitoring and enforcement.[38] He showed that when these costs are associated with the exchange of permits, the trading levels are reduced, abatement costs are increased and in some cases the equilibrium permit allocations and associated aggregate control costs are sensitive to the initial permit distributions. Therefore, both the equity and efficiency of a permit system may be affected by the presence of transaction costs.

Furthermore, the analysis of tradeable permits typically begins with the assumption that cooperation is already achieved regarding the emissions cap and initial distribution. The 5 year history of international discussions regarding GHG abatement suggests that full cooperation or consensus is unlikely. The authoritarian approach of assigning global emission ceilings and an initial distribution of permits is contrary to the sovereign government of many countries.[39] While analysis continues in the area of tradeable emission permits, the impact of transaction costs and recognition of the challenges in generating consensus regarding emission permits and global emission ceilings naturally leads one to consider alternative forms of agreement with regards to international GHG abatement.

Grubb [1989] considered lesser forms of full global agreement in which smaller groups of countries reach consensus on abatement measures or targets. He reasoned these types of agreements would likely be much easier to achieve as far fewer countries would be involved, they might have much more in common both economically and politically and there might be existing institutions which could be used. These agreements would have the potential to lead eventually towards a global agreement. Furthermore, the overwhelming complexity of target-setting agreements would be greatly reduced if global negotiations were conducted among a few regional bodies, who would return from the negotiating table with overall targets to be allocated among

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38 Stavins [1994], pg 134

39 Swisher [1994], pg 158

member countries in separate discussions. Rentz [1995], has recently argued that an international agreement on the implementation of a CO_2 entitlement system without introductory measures is quite improbable and proposed introducing the use of JI in a step wise manner.

In the case of GHG abatement, real world experience has shown that international cooperation will develop gradually. The most recent step towards mitigating emissions of GHG has been to extract abatement commitments from developed countries through the signing of the FCCC. These commitments were obtainable, unlike a global consensus on emission caps and permit distribution.

4.3 Economic Cooperation

A number of papers have analyzed the challenges of establishing international consensus on targets to reduce GHG emissions. Theoretical ideas of cooperation which pertain to this thesis were developed and discussed by Olson [1977], Barrett [1991,1992,1994] and Wilman [1992] and form the basis for the models presented in this thesis.

Many of the basic ideas related to cooperation were discussed by Mancur Olson [1977], who showed that the existence of a large group with a common interest does not automatically give rise to cooperative action. Olson argued that the larger the group, the farther it will fall short of providing an optimal amount of the collective good.[40] As the size of the group increases, the share of the total benefit going to any one individual declines while transaction costs increase.[41] Therefore, only a separate and selective incentive will stimulate a rational individual in a large group to act in a group-oriented way.[42] These incentives need not be restricted to economic incentives as Olson sees individuals as being motivated by a wide range of social and psychological objectives. However, Olson considers social incentives important mainly only in small groups.

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40 Olson [1977], pg 35

41 Olson [1977], pg 48

42 Olson [1977], pg51

Barrett [1994] also examined the issue of group size amongst homogenous countries. His analysis showed that the fully cooperative outcome can be sustained by a large number of countries but only when the gains in terms of global net benefits from such action is small. If the abatement gains from cooperating are small, so are the net gains from deviating from the agreement. When the abatement gains from cooperation are large, cooperation can only be sustained by a few countries or possibly none at all as the incentives to free ride on the actions of others are great. With the use of diagrams, Barrett showed the abatement gains from cooperation are determined by the characteristic of the environmental problem in question.[43] His reasoning is illustrated in figures 1, 2 and 3

Barrett considered the potential abatement gain from cooperation to be the difference between the cooperative abatement level (Q^c) and the non-cooperative abatement level (Q^{nc}). Barrett identified the factor which determines the magnitude of the potential abatement gain as the ratio between the steepness of each country's marginal cost curve (c) and the steepness of the global marginal benefit curve (b). If the ratio of c/b is high, the difference between Q^c and Q^{nc} will be small and close to zero. This may be the case where there is a pollutant that is very costly to control and the abating of such a pollutant yields little or no benefits. In this case, little abatement will occur in the non-cooperative case and even with cooperation, abatement will be minimal. If c/b is low, there will be very little difference between Q^c and Q^{nc} as countries will be willing to abate large levels of the pollutant independently. This would reflect a pollutant being very inexpensive to control relative to the large benefits that accrue from controlling it. Barrett [1993] suggests that the issue of global warming is characterized by either a large c and small b or a large c and large b implying there are large gains from negotiating cooperative abatement.[44]

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43 Barrett [1993]

44 Barrett [1992], pg 35

Three scenarios depicted below in figures 1, 2 and 3, illustrate Barrett's theory. The abatement level which occurs in a situation of non-cooperation is determined by the point of intersection between each country's marginal cost curve and marginal benefit curve and is indicated in the diagrams with $\underset{\sim}{Q}^{nc}$. When countries cooperate, abatement will increase as each country will take into consideration the global benefits from undertaking abatement. In this case, each county's abatement level is determined by the intersection between its marginal cost curve and the global marginal benefit curve, indicated in the diagrams with $\underset{\sim}{Q}^{c}$.

Figure 1 Abatement Gains if c/b =1

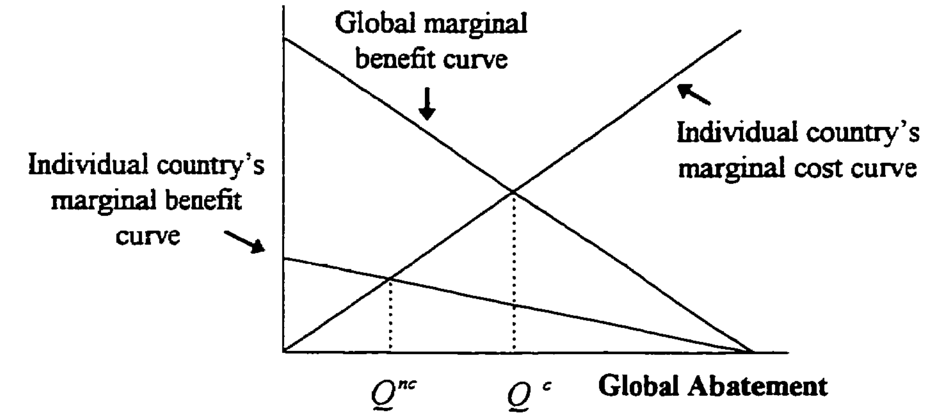


Figure 2 Abatement Gains if c/b is Small

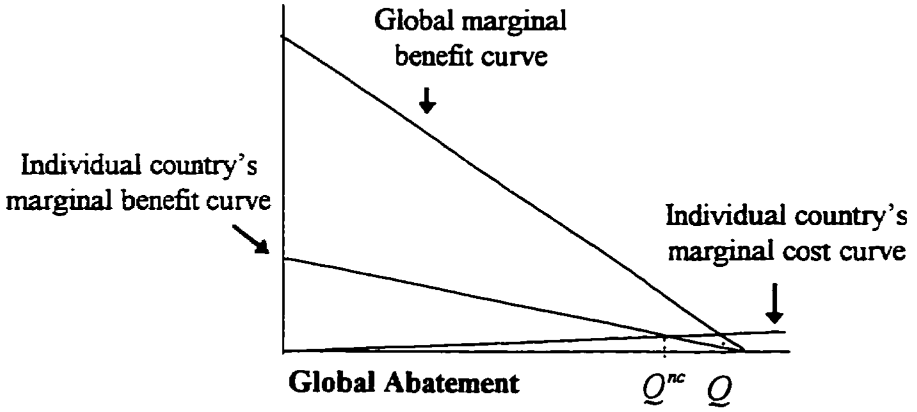
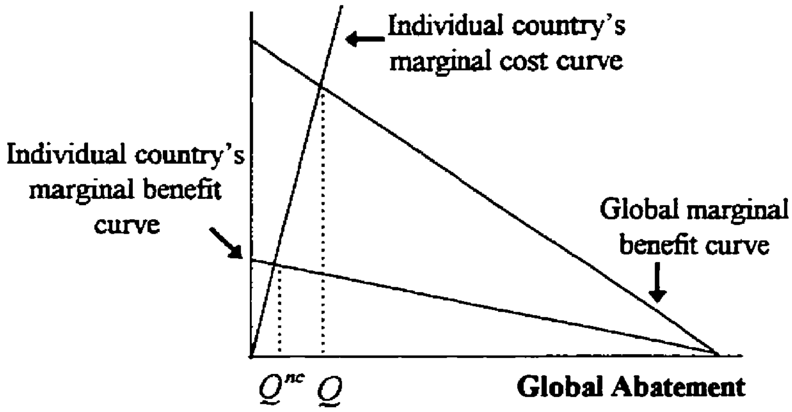


Figure 3 Abatement Gains if c/b is Large



However, this analysis assumes countries possess identical costs and benefits of abatement. If this same analysis is to be applied to the case of GHG emissions, the diversity between developed and developing countries must be incorporated.

Wilman [1992], relaxed the assumption of identical countries and in the context of a game theoretic approach, examined the problem of attaining international cooperation to reduce carbon dioxide emissions. Wilman differentiated between two groups of countries, one which was assumed to possess high costs and high benefits from abatement, the other which possessed low costs and low benefits of abatement. Starting from a non-cooperative Nash equilibrium, a tradeable permit system is introduced and countries must agree on an aggregate level of emissions reduction and the initial allocation of the permits. The analysis showed that the ease with which this agreement is obtained will depend upon how different the countries' benefits and cost functions are. Most relevant to this thesis is Wilman's conclusion that large differences between countries net benefits from abatement will result in no allocation of the public good abatement (Q^c) without sidepayments which will leave no country worse off. As it is possible to define JI as a form of sidepayment mechanism, Wilman's work provides the methodology for assessing the conditions under which JI is necessary to achieve the public good level of abatement presented in Chapters 5 and 6.

4.4 JI - Theory and Practice

One of the obstacles to generating international cooperation over reducing GHG emissions is the potentially high costs associated with abatement. JI was introduced to improve the cost effectiveness of international GHG abatement by allowing parties to the FCCC to pursue their abatement commitments with other signatories. In theory, countries which possessed high costs of abatement would have the opportunity to purchase GHG reductions from countries with lower costs. However, JI projects are not permitted to count towards country abatement commitments and given the intense debate which has developed over JI in international forums, it is not certain whether or not JI will survive as a mechanism for combating climate change.[45]

From an economic perspective, the attractiveness of JI is the potential for JI projects to become tradeable assets, leading into a system of fully tradeable emission permits. With a system of tradeable emission permits, market price signals provide the means to minimizing the costs of GHG abatement. However, there is much debate over whether JI projects should count as GHG reduction credits towards the abatement commitments of developed countries. Most central to the debate over JI is the issue of responsibility. Developing countries, which are at the beginning stages of development, feel they should not be unduly punished for GHG emissions. It is the opinion of many developing countries that the problem of atmospheric GHG emissions is due to developed countries having utilized too much of the airspace. Therefore, the developed countries should be required to do all the abatement. However, developing countries will be largely responsible for future emissions growth and from a global perspective, GHG abatement costs would be minimized if developed countries are able to pursue abatement opportunities wherever it was cheapest to do so.

While the debate over JI ensues, a number of international developments which support the development of JI and tradeable GHG allowances have evolved independent of the FCCC. In

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[45] Tattenbach [1997], pg 2

1993, it was reported that a major U.S. based electricity generating corporation (New England Power) had invested funds in controlling the process of logging forest in Malaysia to reduce the environmental damage and carbon release due to logging.[46] Funds were allocated for training crews in reduced-impact logging techniques and for applying these techniques to the Forest Reserves in Sabah, Malaysia. Since April 1993, Sweden has dispensed more than $39.64 million U.S. in environmental aid to the Baltic States.[47] The funds have been allocated to converting heavy fuel oil-burning boilers to biomass and to finance the application of energy efficient technologies in apartment buildings and heating plants. Despite no formal international credits for projects which yield net reductions in GHG emissions, developed countries are continuing to pursue investments in developing countries which offer a low cost means to reducing emissions of GHGs.

In addition to emergence of pilot JI projects, support for the development of tradeable GHG allowances has been furthered with the first trade involving carbon dioxide, the sale of carbon permits by the Costa Rican Government to Centre Financial and the inauguration of a Policy Forum on GHG Emissions Trading. In January 1995, one of the first trades involving carbon dioxide took place between Arizona Public Service Company (APS) and Niagara Mohawk Power Corporation. Under the agreement, APS traded 25,000 sulfur dioxide allowances to Niagara Mohawk in exchange for 1.75 million tons of carbon dioxide reductions recorded with the U.S. Department of Energy.[48] In May 1997, the Cost Rican Government began issuing Certifiable Tradable Offsets (CTO's) to the international market.[49] Each issued CTO represents the reduced emission into the atmosphere of one metric ton of carbon. Centre Financial made the first U.S. purchase of CTOs in the amount of 1,000 metric tons of carbon (equaling the average annual carbon emissions of 900 U.S. cars) and plans to trade the CTOs on the Chicago stock exchange. In

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46 Putz and Pinard [1993]

47 Lofstedt, Sepp and Kelly, [1996], pg 18

48 Environmental Manager [1995]

49 Earth Council [1997]

hopes of preserving and regenerating its national environment, the Costa Rican Government intends to sell approximately 15 million metric tons of CTO's. Recently, in June 1997, 50 senior policy makers and corporate executives from different regions of the world met to inaugurate a Policy Forum on GHG emissions trading.[50] The Forum will assist interested countries to examine the technical issues and practical steps involved in setting up a limited-scale international GHG trading system, possibly starting with a few interested countries.[51] The target date for launching the emissions market is set for early 2000. The combined initiatives undertaken by private companies, policy groups and select governments are the driving force behind the development of tradeable GHG allowances.

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50 United Nations Conference on Trade and Development [1997]

51 Joshua [1997]

CHAPTER FIVE

AN ILLUSTRATIVE TWO COUNTRY MODEL

A two country Cournot model, with one developed and one developing country, is presented to illustrate a methodology for assessing the gains from achieving the socially optimal level of abatement and determine whether a policy of JI is necessary to achieve these gains. The net benefit functions have been derived from Barrett [1992, 1994] while the analysis and approach is based on work developed by Wilman [1992]. It is assumed countries will choose to cooperate when cooperation results in a positive change in net benefits over non-cooperation. This model does not address the issue of free-riding - one country reneging its commitments assuming the other country will continue to abate.

5.1 The Model

Let the following functions, NB_A, NB_{NA} be representative of one developed and one developing country's net benefits of GHG abatement.[54] [55]

Equation 1: $$NB_A = \frac{b(aQ - \frac{Q^2}{2})}{N} - \frac{cq_A^2}{2}$$

Equation 2: $$NB_{NA} = \frac{\delta b(aQ - \frac{Q^2}{2})}{N} - \frac{\delta c q_{NA}^2}{2}$$

where N=2 and a is a positive parameter. The variable b reflects the steepness of the global marginal benefit curve and c reflects the steepness of each country's marginal cost curve. developed and developing abatement is represented by q_A, q_{NA} respectively and Q represents total

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[54] The derivation of the net benefit functions is provided in Appendix A

[55] The parameter subscripts, A and NA refer to Annex I and non-Annexed countries. For ease of exposition, the text utilizes the terms developed and developing to refer loosely to Annex I and non-Annexed countries.

abatement where $Q = q_A + q_{NA}$. The parameter δ reflects the ratio between the developed and developing country's costs of abatement and benefits of abatement. It is assumed the developed costs and benefits of abatement always equal or exceed the developing costs and benefits of abatement such that $0 \le \delta \le 1$.[56]

5.2 Solving the 2 Country Model[57]

If no cooperation exists between the two countries, each country is assumed to act according to the Cournot model of oligopoly. Each country will select its abatement (q_A^{nc} or q_{NA}^{nc}) to maximize its own net benefits, taking the other country's abatement as given, with $\gamma = c/b$. The Nash equilibrium, two-country non-cooperative aggregate abatement level, Q_2^{nc}, is:

$$\text{Equation 3:} \qquad Q_2^{nc} = \frac{a}{(1+\gamma)}$$

There is also a socially optimal level of GHG abatement which is derived by assuming the countries maximize their collective net benefits. The socially optimal level of GHG abatement is shown in Equation 4:

$$\text{Equation 4:} \qquad Q_2^{c} = \frac{a(1+\delta)^2}{2\delta\gamma + \delta^2 + 2\delta + 1}$$

To determine whether JI is necessary to induce the cooperation required to achieve Q_2^c, a benchmark, Q_2^{max}, is used. The amount q_A^{max} is the level of abatement by the developed country which will give it the same net benefit level as at the non-cooperative equilibrium, while holding the aggregate abatement at Q_2^c (see Figure 4). The amount q_{NA}^{max} is determined similarly for the developing country. The aggregate abatement Q_2^{max} is the sum of q_A^{max} and q_{NA}^{max}. It can be

56 For reference, see the discussion entitled "The Diversity Between Developed and Developing Countries" in Chapter 2

57 The derivation of all equations associated with the two country model is provided in Appendix B

greater, equal to, or less than Q_2^c. In Figure 4, $Q_2^{max} > Q_2^c$. Given the parameters specified in the two country model, Q_2^{max} can be derived as:

Equation 5:

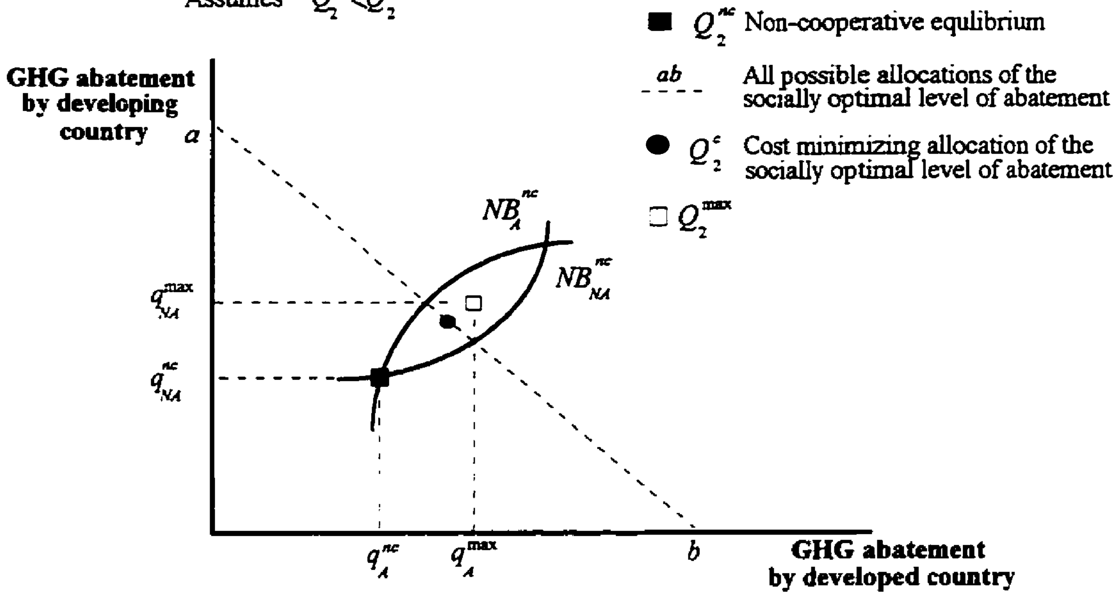
$$Q_2^{max} = 2\sqrt{\left(\frac{b}{c}\right)\left(\frac{\alpha^2\delta^4 + 4\alpha^2\delta^3\gamma + 4\alpha^2\delta^3 + 8\alpha^2\delta^2\gamma + 6\alpha^2\delta^2 + 4\alpha^2\delta\gamma + 4\alpha^2\delta + \alpha^2}{2[2\delta\gamma + (1+\delta)^2]^2}\right) - \left(\frac{2\alpha^2 b(1+2\gamma) - \alpha^2 c}{4c(\gamma+1)^2}\right)}$$

If the value of Q_2^c exceeds Q_2^{max}, a policy of JI is considered necessary to achieve the socially optimal level of abatement. Without JI, any allocation of Q_2^c would leave one country worse off than if they were not to cooperate. Only when neither country is made worse off will both countries consider cooperating to achieve the socially optimal level of abatement.

Figure 4 illustrates the two country model for a case where countries are identical and $Q_2^c < Q_2^{max}$. The diagram reflects the non-cooperative abatement levels (q_A, q_{NA}),the maximum abatement allocations of Q_2^c for each country (q_A^{max}, q_{NA}^{max}) and the non-cooperative levels of net benefits, NB_A, NB_{NA}. The line "$\xrightarrow{ab}$" reflects all possible allocations of the fully cooperative level of abatement between the developed and developing countries while the symbol ● represents the cost minimizing allocation of Q_2^c. The solutions for Q_2^{nc}, Q_2^{max} are also labeled.

The lens formed by the intersection of the net benefit functions contains the allocations of abatement which constitute a Pareto Improvement over the non-cooperative equilibrium. A Pareto Improved allocation of abatement is a level of abatement which leaves both countries better off from achieving it. If one of the possible allocations of the socially optimal level of abatement (represented by the line $\xrightarrow{ab}$) lies within the lens of Pareto Improvements, Q_2^{max} will exceed the value of Q_2^c and the use of JI to achieve Q_2^c is not necessary. If all possible allocations of the socially optimal level of abatement lie outside the lens, $Q_2^c > Q_2^{max}$ and a policy of JI is necessary to achieve Q_2^c. Figure 5 shows a case where δ =0.25 and $Q_2^c > Q_2^{max}$.

Figure 4 **Illustration of the Two Country Model**
Assumes $Q_2^c < Q_2^{max}$



5.3 Evaluating the Model

Specifying values for the model parameters permits analysis of the gains from cooperation and the role JI play in attaining these gains. It is assumed the values for a, b, c are those specified by Barrett [1992] where a=100, b=1 and c=35. Aside from the knowledge that δ, which measures the differences between countries abatement net benefits, will be less than 1, its precise value is not known. However, there is evidence to suggest that abatement costs are lower in developing countries. The fact that developing countries are already hosting pilot JI projects undertaken by companies in developed countries is an indication that developing nations offer relatively less expensive opportunities for GHG abatement. Further, one may expect the developed country's marginal cost curve to rise more quickly as there exist fewer low cost alternatives for GHG abatement. For the purpose of evaluating the model it is assumed δ=0.25. This implies the abatement costs in the developing country are ¼ of the abatement costs in the developed country and the abatement benefits in the developing country are ¼ the abatement benefits in the developed country.

The ratio between the steepness of the marginal cost function, c, and the steepness of the global marginal benefit curve, b, is represented by γ. Barrett [1992] proposed for the case of GHG abatement, that γ will be large and assumed a value of 35 with $b = 1$ and $c = 35$. The argument for γ being greater than 1 is strong. An additional argument for γ being large is that abatement costs are incurred today while abatement benefits, which are received in the future, are discounted.

Table 4 summarizes the solutions to the two country model evaluated with these assumptions. The table shows that the socially optimal level of abatement (Q_2^c) is almost three times the level of abatement expected for the non-cooperative outcome (8.20 versus 2.78). In addition, the table shows Q_2^c is not achievable without JI as $Q_2^c > Q_2^{\max}$ (8.20 exceeds 8.14). There is no allocation of 8.20 units of abatement between the two countries that will leave both with at least the net benefits they had at the non-cooperative equilibrium. This is partially illustrated by table 4 with the net benefits for the developing country being negative.

The developing country's net benefits are reduced 115.66 units (25.80- (-89.96)) from moving to the cost minimizing allocation of the socially optimal level of abatement (q_A^c, q_{NA}^c). It is assumed the developing country will not cooperate if it is made worse off. Thus, the question becomes whether there exists an alternate allocation of Q_2^c which leaves neither country worse off. If $Q_2^c < Q_2^{\max}$, such an allocation exists. If $Q_2^c > Q_2^{\max}$, no reallocation of Q_2^c will leave both countries no worse off and JI is necessary to induce cooperation. With the parameter values assumed, the value of Q_2^c exceeds $Q_2^{\max}$ and in this case, a policy of JI is necessary to induce the cooperation to achieve the socially optimal level of abatement.

Table 4 **Two Country Model [δ=0.25, γ=35]**

	Case	
	No Cooperation	**Socially Optimal**
ABATEMENT		
developed	1.399	1.64
developing	1.399	6.56
TOTAL	Q_2^{nc}=**2.78**	Q_2^{c}=**8.20**
		Q_2^{max}=**8.14**
BENEFIT		
developed	135.03	376.24
developing	34.24	98.26
TOTAL	**169.27**	**474.50**
COSTS		
developed	33.76	47.03
developing	8.44	188.12
TOTAL	**42.20**	**235.15**
NET BENEFITS		
developed	101.27	329.21
developing	25.80	-89.86
TOTAL	**127.07**	**239.35**

5.4 Illustrating the Model

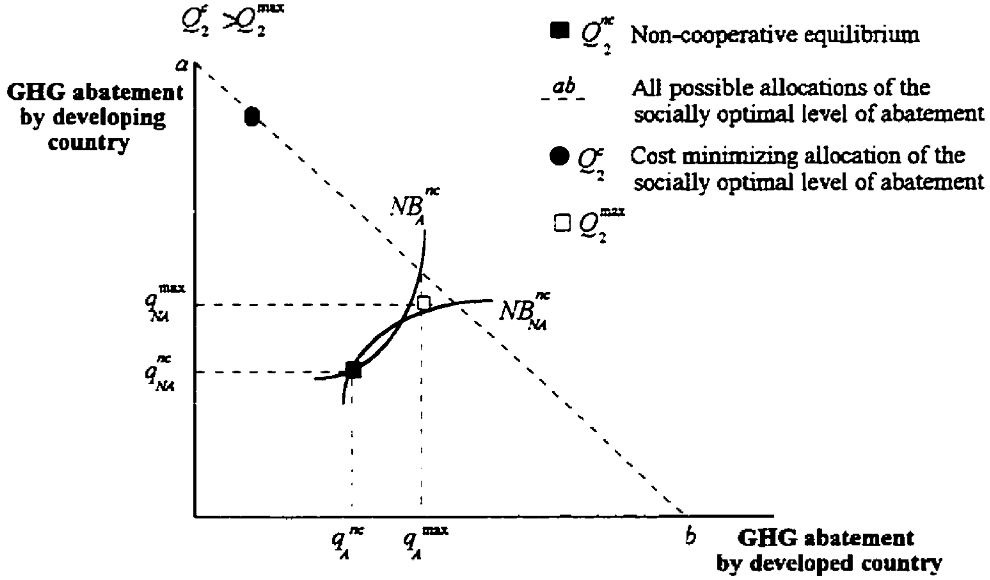
Figures 5 and 6 provide an illustration of the two country model. Figure 5 represents the model results summarized in table 4. Figure 6 presents an alternate scenario of the two country model, assuming a larger value for δ. (δ=0.25 in figure 5, δ=0.50 in figure 6).

Figure 5, with $\delta = 0.25$, implies the developing country's costs of abatement are ¼ the size of the developed country's costs and the developing benefits of abatement are ¼ the size of the developed country's. In this scenario, table 4 shows $Q_2^c > Q_2^{max}$, implying all possible allocations of the socially optimal level of abatement (line $\xrightarrow{ab}$) lie outside the lens of Pareto Improvements. As it is assumed no country will consider cooperating if it is made worse off than it would be without cooperating, Q_2^c will not be achieved by any sharing of the abatement burden between the two countries. Only if the use of JI is permitted will it be possible to abate the socially optimal level Q_2^c.

Table 4 shows that the cost minimizing allocation of the socially optimal solution, has the developing country abating 6.56 units and the developed country abating 1.64 units. If the developing country were to undertake these levels of abatement it would be made worse off than if it were not to cooperate (net benefits are reduced from 25.80 when not cooperating to -89.86 at the cost minimizing allocation of $\underset{\sim}{Q}_2^c$). Thus, it would be expected the developing country would not agree to deliver 6.56 units of GHG abatement. If the value for $\underset{\sim}{Q}_2^c > \underset{\sim}{Q}_2^{max}$ (8.20 versus 8.14), all possible allocations of $\underset{\sim}{Q}_2^c$ will lie outside the lens of Pareto Improvements and it will not be possible to define any allocation of the socially optimal level of abatement $\underset{\sim}{Q}_2^c$ (line $\xrightarrow{ab}$) in such a way as to leave neither country worse off. Only if JI is permitted so that the developed country is able to compensate the developing country for undertaking greater levels of abatement, will $\underset{\sim}{Q}_2^c$ be attainable. The higher cost developed country will pay less for abatement and the lower benefit developing country will receive larger gains.

Figure 5 **Two Country Case with δ =0.25**

$\underset{\sim}{Q}_2^c > \underset{\sim}{Q}_2^{max}$



Whether JI is necessary will depend on the extent of the differences between countries (represented by δ). This is illustrated where the differences between the developed and developing countries are not as great, with $\delta = 0.50$. Table 5 summarizes the solutions to the two country model with the change in the assumed value of δ.

Table 5 **Two Country Model Summary** [δ=0.50, γ=35]

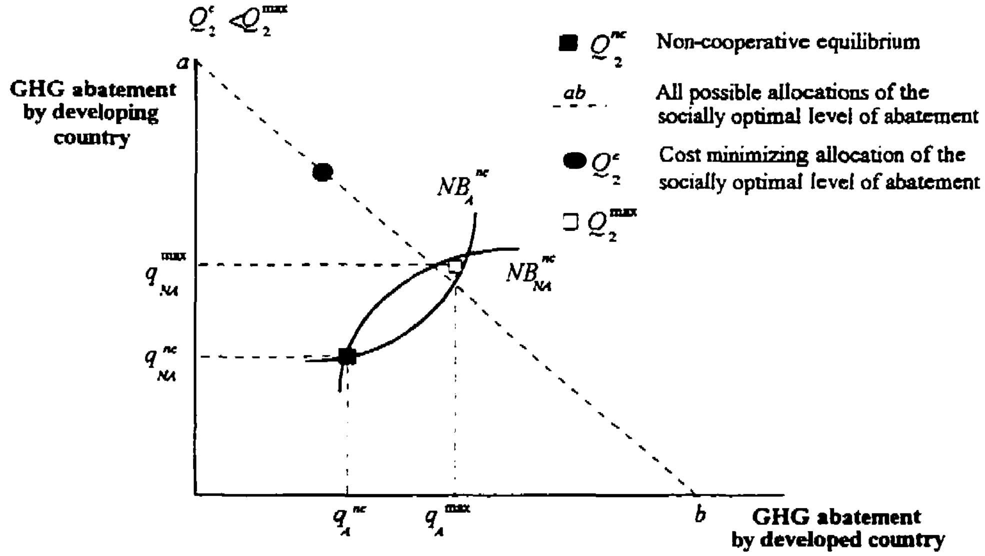
	Case	
	No Cooperation	**Socially Optimal**
ABATEMENT		
developed	1.399	2.013
developing	1.399	4.027
TOTAL	Q_2^{nc}=2.78	Q_2^c=6.040
		$Q_2^{\max}$=6.585
BENEFIT		
developed	135.03	283.77
developing	68.48	146.45
TOTAL	**203.51**	**430.22**
COSTS		
developed	33.76	70.94
developing	16.88	141.89
TOTAL	**50.64**	**212.83**
NET BENEFITS		
developed	101.27	212.83
developing	51.60	4.56
TOTAL	**152.87**	**217.39**

In table 5, the socially optimal level of abatement Q_2^c = 6.040 units. The cost minimizing allocation Q_2^c has the developed country abating 2.013 units and the developing country abating 4.027 units. At this cost minimizing allocation, the developing country is made worse off, evidenced by the loss in net benefits (reduced from 51.60 units at the non-cooperative solution to 4.56 units at the cost minimizing allocation). However, as the value of $Q_2^c < Q_2^{\max}$, there does exist a reallocation of Q_2^c which will leave both countries better off and JI will not be necessary to achieve the socially optimal level of abatement.

The reallocation would require that more abatement be undertaken by the developed country since it is the developing country which is made worse off. For example, if Q_2^c were to be divided equally between the developed and developing country, (each abating 3.020 units), both the developed and developing country would be made better off than at the non-cooperative equilibrium. The developing country's net benefits would increase from 51.60 to 66.64 and the developed country's net benefits would increase from 101.27 to 124.16 units. However, at this allocation, the cost of achieving $\underset{\sim}{Q}_2^c$ would not be minimized. Figure 6 provides an illustration of the case where $\delta = 0.50$.

In figure 6, $\underset{\sim}{Q}_2^c < \underset{\sim}{Q}_2^{\max}$ and there is an allocation of $\underset{\sim}{Q}_2^c$ which lies in the lens of Pareto Improvements. Therefore, there exists an allocation of $\underset{\sim}{Q}_2^c$ which will leave neither country worse off without the use of JI, but the socially optimal level of abatement will no longer be achieved at the cost minimizing allocation. In the case of $\delta = 0.50$, the use of JI would enable the aggregate net benefits to be maximized, but it is not necessary to induce cooperation.

Figure 6 **Non-Uniform Countries, assumes $\delta = 0.50$ $\underset{\sim}{Q}_2^c < \underset{\sim}{Q}_2^{\max}$**



Figures 5 and 6 illustrate that a critical determinant affecting whether JI is necessary is the value of δ. The smaller the value of δ, the more likely that all possible allocations of the socially optimal level of abatement will be outside the lens and hence, $\underset{\sim}{Q}_2^c > \underset{\sim}{Q}_2^{\max}$.

5.5 Sensitivity Analysis

The assumed parameter values determine both the size of the gains from cooperation as well as whether JI is necessary to achieve these gains. As there exists uncertainty regarding the "true" parameter values, this section derives the abatement gains (Q_2^c - Q_2^{nc}) and the determinant for JI (Q_2^c - Q_2^{max}) in terms of the model parameter values and evaluates these differences over a reasonable range of parameter values.

Consider the discrepancy between Q_2^c and Q_2^{nc}, which represents the abatement gains from cooperation. In Barrett's analysis of uniform countries, the size of this discrepancy was found to depend on the value of γ. In this model of differentiated countries, the size of the discrepancy depends on the magnitude of the differences between countries, represented by δ, as well as the value of γ. The abatement gain is equal to:

Equation 6: $$Q_2^c - Q_2^{nc} = \frac{a\gamma(1+\delta^2)}{(1+\gamma)\left[2\gamma\delta + (1+\delta)^2\right]}$$

The value of γ which maximizes the abatement gain from cooperation is determined by:

Equation 7: $$\gamma = \sqrt{\frac{(1+\delta)^2}{2\delta}}$$

Utilizing this equation, table 6 calculates how the maximum abatement gains from cooperation varies with δ.

In the case of uniform countries (δ=1), the model predicts the abatement gain from negotiating the public good solution will be the greatest when γ =$\sqrt{2}$ or close to 1 . To explain this result, consider the case where γ is large. This scenario exists when harmless pollutants (for which b is small) are increasingly costly to control (possessing a large c). Under this scenario, even the socially optimal solution will not call for large abatement levels. Therefore, the potential abatement gains will be small. Alternatively when γ is small, suggesting hazardous pollutants (for which b is large) that are cheap to control (for which c is small), countries will want to abate substantial quantities of emissions unilaterally. Therefore, negotiating the socially optimal level of abatement solution will not contribute large levels of additional abatement. Only when the potential damages are roughly equivalent to their control costs (γ is close to 1) will the gains from achieving the socially optimal level of abatement be substantial, but this is also the case where the free-riding problem is the greatest.

Table 6 Maximum Abatement Gain from Negotiating Q_2^c

Maximum Abatement Gain $(Q_2^c - Q_2^{nc})$	Maximizing γ	Relative differences between countries (δ)
74.52	7.14	0.01
43.35	3.32	0.05
28.60	2.46	0.1
17.38	1.90	0.2
10.59	1.57	0.4
8.49	1.46	0.6
7.75	1.42	0.8
7.58	1.41	1.0

assumes a=100, b=1

As the difference between countries increases (δ becomes smaller), two points become evident. First, as δ decreases in value, the larger is the γ which maximizes the gains from cooperation. To a certain extent, a larger γ enhances the gains from trade effect in the socially optimal solution, particularly when δ is very small. Second, the smaller the δ the larger the potential abatement gain from negotiating Q_2^c. The socially optimal solution effectively aggregates the countries into one decision unit. As a single decision unit, the effect is to increase the level of abatement as the unit no longer sees the pollutants as costly to control nor the damages from pollutants as harmless.

Therefore, the greater the differences between the countries, the greater the potential abatement gain from cooperating.

Figure 6 illustrates a diminished value of δ determines whether Q_2^c lies inside or outside the lens of Pareto preferred allocations. If Q_2^c lies outside the lens ($Q_2^c > Q_2^{max}$), JI is necessary to encourage the cooperation between two countries to ensure neither country is made worse off from the socially optimal level of abatement. Table 7 calculates Q_2^c, Q_2^{max} and the value of the difference between them across a range of δ values.

Table 7 Role for JI as δ changes

Ratio between developed and developing net benefits (δ)	Q_2^{max}	Q_2^c	Q_2^{max}-Q_2^c
0.01	21.29	59.31	-38.02
0.05	14.74	23.95	-9.21
0.10	11.51	14.74	-3.23
0.20	8.83	9.33	-0.49
0.25	8.14	8.20	-0.06
0.30	7.64	7.45	0.19
0.40	6.98	6.54	0.44
0.60	6.34	5.71	0.59
0.80	6.10	5.47	0.63
1.00	6.04	5.41	0.64

Assuming $\gamma = 35$, $b = 1$ and $a = 100$.

The scenarios where JI is necessary to allocate Q_2^c are depicted by the discrepancy between Q_2^{max} and Q_2^c being negative. In general, JI is more likely to be necessary the smaller the value for δ. This is an intuitive result. The calculation of Q_2^c takes into consideration the benefits of trading while the calculation of Q_2^{max} does not. Therefore, as the gains from trading increase (the smaller the δ), the more likely that a policy of JI which facilitates trading will be necessary to achieve the socially optimal level of abatement.

Examining the solutions for Q_2^c and Q_2^{max}, one finds that the value for both δ and γ will determine whether the use of JI is necessary. Table 8 calculates Q_2^c and Q_2^{max} corresponding to a range of γ, utilizing the same range of δ values in table 7. Table 8 shows that a policy of JI is most likely to be necessary the smaller the value of δ, independent of the value γ. However, with the discrete range of γ presented in table 8, JI is required only if $\delta \leq 0.25$. This implies that the difference between the developed and developing costs of abatement and the developed and developing benefits of abatement must be equal to or greater than a ratio of 4:1, before JI is necessary.

Table 8 **How Q_2^c-Q_2^{max} Varies with δ and γ**

Relative differences between countries δ	γ=1	γ=15	γ=35	γ=75	γ=250
0.01	-11.52	-43.38	-38.02	-27.56	-12.01
0.05	-5.88	-14.65	-9.21	-5.15	-1.75
0.10	-1.57	-5.63	-3.23	-1.71	-0.56
0.20	2.70	-0.81	-0.49	-0.26	-0.09
0.25	3.77	0.01	-0.06	-0.04	-0.02
0.30	4.48	0.50	0.19	0.08	0.02
0.40	5.27	0.98	0.44	0.21	0.06
0.60	5.83	1.30	0.59	0.28	0.09
0.80	5.96	1.37	0.63	0.30	0.09
1.00	5.98	1.38	0.64	0.31	0.09

5.6 Two Country Model Summary

This two country model of one developed and one developing country has presented a methodology for assessing the gains from negotiating the socially optimal level of abatement and the role JI play in achieving these gains. From the analysis, two general trends are evident.

First, the abatement gain to be expected from negotiating the socially optimal level of abatement will depend on the diversity between countries (δ) and the ratio between the slopes of each country's marginal costs function and the global marginal benefit function. In the model, this ratio is represented by γ. In general, if countries are uniform (δ=1), the abatement gains from the socially optimal level of abatement will be maximized when this ratio is close to 1. As the differences between countries increase, the value of γ which maximizes the abatement gain will increase. Table 4 showed that when the differences between countries are great (δ=0.01), the value of γ which maximizes the potential gains from cooperating is 7.14.

Second, when countries are very different (δ is small), JI is a necessary instrument to achieve the socially optimal level of abatement. If countries are similar, (δ is large), the socially optimal level of abatement may be allocated between the two countries without making either country worse off and without the use of JI. JI always provides a means to minimize the costs of achieving the aggregate net benefits but when δ is small, it is unlikely to be necessary to induce cooperation.

The next chapter examines how the potential abatement gains and role for JI changes as stages of partial cooperation are introduced and the number of countries increases to the number of FCCC signatories.

CHAPTER SIX

A MODEL OF GRADUAL INTERNATIONAL COOPERATION WITH MANY COUNTRIES

In Chapter 5, JI was shown to represent not only a cost minimizing policy, but sometimes a necessary one to achieve the gains from the socially optimal level of abatement. In this chapter, the analysis is applied to a model with several countries in which cooperation between developed and developing countries is assumed to take place gradually. The model is used to assess the role for JI in furthering international cooperation to reduce GHG emissions.[58]

6.1 The N Country Model

The same net benefit functions specified, for the case of two countries in Chapter 5, are utilized, with N>2. Let the following functions, NB_{Ai}, NB_{NAi} be representative of the net benefits of GHG abatement for one developed and one developing country respectively.[59]

Equation 8: $$NB_{Ai} = \frac{b\left[aQ - \frac{Q^2}{2}\right]}{N} - \frac{cq_{Ai}^2}{2}$$

Equation 9: $$NB_{NAi} = \frac{\delta b\left[aQ - \frac{Q^2}{2}\right]}{N} - \frac{\delta cq_{NAi}^2}{2}$$

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[58] It is assumed countries will choose to cooperate when there is a positive change in net benefits from cooperating over not cooperating. The model does not address the issue of free-riding - one country reneging its commitment assuming the other country will continue abating.

[59] The derivation of all equations associated with the two country model is provided in Appendix C

As in the case of two countries, the first term of each equation refers to the country's benefits of abatement, assumed to depend on the global abatement, Q. Both a and b are positive parameters. The second term of each equation represents a country's abatement costs which are assumed to depend only on its own abatement level where q_A is the developed country's abatement and the parameter c represents the slope of each country's marginal abatement cost curve. The ratio of developed abatement costs to developing abatement costs is represented by δ where $0<\delta<1$.

The variable α, where $0<\alpha<1$, represents the proportion of developed countries. Thus, αN equals the number of countries which are developed and $(1-\alpha)$N, the number of developing countries. The variable β, where $0<\beta<1$, represents the proportion of developing countries which are cooperating to abate GHG emissions. Thus $\beta(1-\alpha)$N represents the number of developing countries choosing to abate cooperatively and $(1-\beta)(1-\alpha)$N, the number of non-cooperating developing countries. Aggregate net benefits of abatement, where global abatement $Q = Q_A + Q_{NA1} + Q_{NA2}$, for developed countries, cooperating developing countries and non-cooperating developing countries are represented by the following equations:

Equation 10: $$NB_A = \alpha b(aQ - \frac{Q^2}{2}) - \sum_{i=1}^{\alpha N} \frac{cq_{Ai}^2}{2}$$

Equation 11: $$NB_{NA1} = (1-\alpha)\beta\delta b(aQ - \frac{Q^2}{2}) - \sum_{j=1}^{(1-\alpha)\beta N} \frac{\delta c q_{NA1j}^2}{2}$$

Equation 12: $$NB_{NA2} = (1-\beta)(1-\alpha)\delta b(aQ - \frac{Q^2}{2}) - \sum_{j=(1-\alpha)\beta N}^{(1-\alpha)(1-\beta)N} \frac{\delta c q_{NAj}^2}{2}$$

In Chapter 5, the analysis focused on the comparison between no cooperation and the socially optimal level of abatement. To date, only developed countries have been required to undertake commitments to reduce GHG abatement. It is assumed an international agreement requiring abatement commitments from all countries will occur gradually, in a series of stages.

Drawing as much from possible the cooperative process established with the FCCC, the N country model defines four stages through which developed and developing countries are assumed to progress through before achieving the socially optimal level of abatement. These four stages are important to consider as the decision to participate in the next stage of cooperation will be influenced by the expected incremental gains from participation as opposed to the long term gains to be expected from achieving total cooperation.

Table 9 Stages of International Cooperation

	Name of Stage	Description of Stage
I	**No Cooperation**	All countries are assumed to select the level of GHG abatement which maximizes each countries own net benefits. This scenario existed prior to the signing of the FCCC.
II	**Developed Countries Cooperate**	Currently, the FCCC requires abatement commitments only from developed countries. Stage 2 represents the potential of present FCCC agreement as it calculates the maximum abatement if only developed countries cooperatively reduce GHG emissions.
III	**Developed Countries and β developing countries cooperate**	This case may be considered to the next stage of the FCCC. It is assumed 100% of developed countries and β developing countries undertake commitments to abate GHG emissions. As developing commitments are not expected to be arrived at easily, Stage 3 allows for gradual participation from the developing countries with increasing rates of β.
IV	**All countries cooperate** (Socially optimal abatement)	Stage 4, assumes 100% of developed and developing countries undertake GHG abatement commitments to achieve the socially optimal level of abatement. Sidepayments are implicitly assumed if necessary.

6.2 Solving the Model

As in the case of two countries, the non-cooperative N country case uses the Cournot model. If no cooperation exists between the countries, each country will select q_A^{nc} or q_{NA}^{nc} to maximize its own net benefits, taking all other country's abatement as given. Solving for the Nash equilibrium non-cooperative solutions yields the following aggregate level of Stage 1 abatement:

$$\text{Equation 13:} \quad Q_{stage1}^{nc} = \frac{a}{1+\gamma}$$

The solutions for partial cooperation and total cooperation differ only with respect to the percentage of developing countries assumed to cooperate. In Stage 2, only the developed countries are assumed to cooperate and β=0. In Stage 3, gradual cooperation of the developing countries occurs and β is assumed to possess a range of values where $0 < \beta < 1$. In Stage 4, there is 100% participation of both developed and developing countries and $\beta = 1$.

The decision unit of cooperating countries and the individual non-cooperating countries each behave according to the Cournot conjecture, each considering the other's emission levels as given. The solution for the cooperating countries is the level of abatement which maximizes their collective net benefits, taking as given the level of abatement for the non-cooperating developing countries. The solution for the non-cooperating developing countries is found by each country taking as given the abatement level of the cooperating unit as well as the abatement of all other non-cooperating developing countries. Thus the model uses a Cournot approach with an embedded assumption of collective action among developed and cooperating developing countries.

The cooperating countries, comprised of the developed countries and β developing countries will act to maximize their collective net benefits represented by the following equation.

Equation 14: $$NB^{c} = \left(\alpha b + b\delta\beta - \alpha b\delta\beta\right)\left(aQ - \frac{Q^2}{2}\right) - \sum_{i=1}^{\alpha N}\frac{cq_{Ai}^2}{2} - \sum_{j=1}^{\beta N}\frac{\delta c q_{NA1j}^2}{2}$$

The non-cooperating, developing countries will maximize their individual net benefits represented by the following:

Equation 15: $$NB_{q_{NA2}}^{nc} = \frac{\delta b(aQ - \frac{Q^2}{2})}{N} - \frac{\delta c q_{NA2}^2}{2}$$

The cost minimizing level of developed GHG abatement which maximizes the net benefits of the cooperating countries is equal to:

Equation 16:

$$Q_A = \frac{\delta\alpha N a\gamma(\alpha + \delta\beta - \alpha\delta\beta)}{\{\gamma\delta + (\delta\alpha N + N\beta(1-\alpha))(\alpha + \delta\beta - \alpha\delta\beta)\}[\gamma + (1-\alpha)(1-\beta)] - N(1-\alpha)(1-\beta)(\alpha + \delta\beta - \alpha\delta\beta)(\alpha\delta + \beta(1-\alpha))}$$

The cost minimizing level of developing GHG abatement which maximizes the net benefit of the cooperating developing countries in the cooperating group is equal to:

Equation 17: $$Q_{NA1} = \frac{\beta(1-\alpha)Q_A}{\delta\alpha}$$

The sum of Q_A and Q_{NA1}, is the socially optimal level of GHG abatement for the cooperating group of countries and is equal to:

Equation 18: $$Q_A + Q_{NA1} = \frac{[\alpha\delta + \beta(1-\alpha)]}{\alpha\delta} Q_A$$

Each non-cooperating developing country will maximize its individual net benefits taking as given the abatement of all other countries. The Nash equilibrium abatement of all non-cooperating developing countries is equal to:

Equation 19: $$Q_{NA2} = \frac{(1-\beta)(1-\alpha)\left(a - \frac{[\alpha\delta+\beta(1-\alpha)]Q_A}{\alpha\delta}\right)}{\gamma+(1-\beta)(1-\alpha)}$$

Stages 2, 3 and 4 aggregate abatement, $Q = Q_A + Q_{NA1} + Q_{NA2}$ is equal to:

Equation 20:

$$Q = \left[\frac{\alpha\delta + \beta(1-\alpha)}{\alpha\delta}\right] Q_A + \frac{a(1-\alpha)(1-\beta)}{\gamma + (1-\alpha)(1-\beta)} - \left[\frac{(1-\alpha)(1-\beta)[\alpha\delta + \beta(1-\alpha]}{\alpha\delta/\gamma + (1-\alpha)(1-\beta)}\right] Q_A$$

To determine whether JI is necessary to induce the cooperation required to achieve partial cooperation (Stage 3) or the socially optimal level of abatement (Stage 4), the benchmark $Q^{\max}$ is used. The calculation of $Q^{\max}$ is the same as in the case of two countries.

The amount $q_{NA1}^{\max}$ for a cooperating developing country is determined by the following equation:

Equation 21: $$NB^{NA1}_{stage2} = \delta(1-\alpha)\beta b(aQ - \frac{Q^2}{2}) - \frac{(1-\alpha)N\beta\delta c q^{\max^2}_{NA1}}{2}$$

Abating $q^{\max}_{NA1}$, will leave each cooperating developing country at the same level of net benefits as stage 2, in which it does not cooperate. The amount $q^{\max}_{A}$ is determined similarly for the developed countries and is determined by the following equation:

Equation 22: $$NB^{A}_{stage2} = \alpha b(aQ - \frac{Q^2}{2}) - \frac{\alpha N c q^{\max^2}_{A}}{2}$$

Given that the non-cooperating developing abatement is fixed at Q^{c}_{NA2}, $Q^{\max}$ is represented by the following calculation:

Equation 23: $$Q^{\max} = \alpha N q^{\max}_{A} + (1-\alpha)\beta N q^{\max}_{NA1} + Q^{c}_{NA2}$$

If the socially optimal level of abatement calculated for Stage 3 or Stage 4 exceeds $Q^{\max}$, a policy of JI is considered necessary. Without JI, any allocation of Stage 3 or Stage 4 abatement would leave one country worse off than if it was not to cooperate. Only when no country is made worse, can cooperation be induced without JI.

6.3 Evaluating the Model

Specifying values for the model parameters permits analysis of the gains from cooperation and the role which JI play in attaining these gains for this N country model. For the parameters which are common between the two country case and the N country case, the values are assumed to be the same, where a=100, b=1, c=35, $\delta = 0.25$.

As of February 1996, there were 154 signatories to the FCCC. Of these signatories, 35 were Annex I countries with the remaining being developing. These figures are incorporated into the model with N=154 and $\alpha = 0.23$ (35/154=23%). To examine the scenarios of partial cooperation, the proportion of cooperating developing countries (β) is assumed to range from 5% - 75%. Table 10 summarizes the N country model parameter values.

Table 10 Parameter Values for N Country Model

Parameter	Interpretation	Assumed Value	Source of value
a	Intercept	100	Barrett [1994]
b	Slope of the global marginal benefit curve	1	Barrett [1992]
c	Slope of each country's marginal costs curve	35	Barrett [1992]
γ	The Ratio of c/b	35	Calculated as c/b
δ	Relative differences between developed and developing country's costs of abatement and between developed and developing country's benefits of abatement	0.25	Critical δ calculated in the two country case which necessitated JI to achieve the public good solution
N	Number of countries	154	FCCC
α	Proportion of developed countries	.23	FCCC
β	Proportion of developing countries cooperating	5%-75%	Range selected for modeling purposes

Utilizing the assumptions in table 10, table 11 summarizes the solutions to the N country model on an aggregate basis and by group of countries.[60] The results in table 11 suggest that if more than 50% of the developing countries cooperate, there is little abatement gain, additional to stage 3, from pursuing the socially optimal level of abatement (Stage 4). Stage 3, which involves only

60 It must be noted that interpretation of these results to a real world scenario must be done cautiously, recognizing the results are generated from a model with less than real world assumptions. First, all developed countries are assumed to be identical as is assumed with all developing. Second, when developed or developing countries cooperate, in stages 2 and 3, it is assumed each group maximizes their

partial cooperation from developing countries achieves over 71% of the socially optimal level of abatement with only 50% of the developing countries participating. With 75% of the developing countries participating, the model predicts that 81% of the socially optimal level of GHG abatement is achievable.

Further, table 11 shows that Q^{max} always exceeds the Stage 3 and Stage 4 abatement suggesting that in the case of 154 countries, JI is never required to allocate abatement. This result is due in part to the large number of countries assumed. The cooperative levels of abatement become distributed over a larger base of countries, relative to the two country case, leaving every country better off from some level of cooperation than with no cooperation. However, it must be noted that until 35% of the developing countries cooperate, the cooperating developing countries will be made worse off (observed by negative net benefits for cooperating developing countries). This implies that for gradual participation of developing countries, the cost minimizing allocation of Q^{c}_{stage3} must be reallocated in such a way so that no country is made worse off.

Table 11 also reveals that the greatest likelihood for JI being necessary to achieve cooperation, exists when the participation rate from the developing countries is very small (indicated by smaller discrepancies between the aggregate Q^{c}_{stage3} and corresponding value of Q^{max}). This is an intuitive result as when β is very small, the developing abatement is averaged across a small number of countries. Only in these cases is it to be expected that the burden among the countries is sufficiently great that it can not be reallocated among the 35 developed countries without making some worse off.

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collective net benefits. Lastly, all results generated are specific to the specified functional forms and the assumed values indicated in table 10.

Table 11 **Evaluating the Model of Incremental Cooperation** $[\delta = 0.25]$

	Stage 1	Stage 2	Stage 3							Stage 4
	No Cooperation	Annexed Countries Cooperate	Annexed and % of non-Annexed Cooperate							Socially Optimal
% Developed cooperating	0%	100%	100%							100%
% Developing cooperating	0%	0%	5%	10%	20%	25%	35%	50%	75%	100%
ABATEMENT										
Developed	0.64	18.55	17.01	15.67	13.47	12.56	11.04	9.30	7.30	5.98
Developing cooperating	0.00	0.00	11.39	20.98	36.08	42.06	51.75	62.24	73.32	80.04
Developing non-cooperating	2.14	1.75	1.47	1.23	0.87	0.74	0.52	0.31	0.11	0.00
AGGREGATE Q	**2.78**	**20.30**	**29.86**	**37.88**	**50.42**	**55.36**	**63.31**	**71.85**	**80.73**	**86.02**
% of public good solution	3%	24%	35%	44%	59%	64%	74%	84%	94%	100%
AGGREGATE Q^{max}			**30.55**	**39.70**	**58.27**	**64.26**	**79.37**	**101.00**	**135.46**	**168.89**
ABATEMENT COSTS										
Developed	0.20	170.01	142.93	121.30	89.66	77.99	60.23	42.69	26.33	17.65
Developing cooperating	0.00	0.00	95.70	162.44	240.13	261.10	282.28	285.85	264.48	236.38
Developing non-cooperating	0.17	0.11	0.08	0.06	0.04	0.03	0.02	0.01	0.00	0.00
AGGREGATE	**0.37**	**170.13**	**238.71**	**283.80**	**329.83**	**339.11**	**342.52**	**328.55**	**290.82**	**254.03**
ABATEMENT BENEFITS										
Developed	63.00	419.57	584.28	706.25	867.34	920.86	995.22	1058.84	1107.30	1127.53
Developing cooperating	0.00	0.00	24.45	59.11	145.19	192.68	291.53	443.10	695.07	943.69
Developing non-cooperating	52.73	351.16	464.57	531.99	580.74	578.04	541.42	443.10	231.69	0.00
AGGREGATE	**115.73**	**770.74**	**1073.30**	**1297.35**	**1593.27**	**1691.58**	**1828.17**	**1945.05**	**2034.06**	**2071.22**
ABATEMENT NET BENEFITS										
Developed	62.80	249.56	441.36	584.95	777.68	842.87	934.99	1016.15	1080.96	1109.87
Developing cooperating	0.00	0.00	-71.25	-103.33	-94.95	-68.42	9.26	157.25	430.59	707.31
Developing non-cooperating	52.56	351.05	464.49	531.93	580.71	578.01	541.40	443.10	231.69	0.00
AGGREGATE	**115.36**	**600.61**	**834.59**	**1013.55**	**1263.44**	**1352.46**	**1485.65**	**1616.50**	**1743.24**	**1817.18**

As in the case of two countries, the model results shown in table 11 are sensitive to the parameter values assumed and the variable δ is a critical determinant as to whether the use of JI is necessary. In Chapter 4 it was pointed out that the value of δ is not known with a certainty. To examine a scenario where JI is necessary to achieve gradual levels of participation, table 12 evaluates the model assuming δ=0.1. This is equivalent to assuming the developing country's costs of abatement are one tenth the size of the developed abatement costs and the developing benefits of abatement are one tenth the size of the developed benefits.[61]

Table 12 shows that, having assumed a greater difference between the group of developed and developing countries, JI becomes necessary to achieve up to 20% participation from the developing countries. This is evident from Q^{c}_{stage3} exceeding $Q^{\max}$ and is what would be expected given the analysis of the two country case presented in Chapter 4. As the participation by developing countries increases (β gets larger), JI is no longer necessary as the difference between $Q^{\max}$ and Q^{c}_{stage3} declines and becomes positive.

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[61] This assumption was based on the observed differences of GHG abatement costs between developed and developing countries. In developed countries, the cost of reducing one tonne of carbon from the atmosphere is most often considered to be \$20 U.S.. In developing countries, the costs for reducing one tonne of carbon range from \$1 U.S. to \$10 U.S.. Utilizing a value of 0.1, which assumes the developing countries costs of GHG abatement are one tenth the size of developed countries is within this range of reported costs. As the model has assumed that the ratio between developing and developed costs of abatement is equal to the ratio between developing and developed benefits of abatement, this assumption implies that the developing country's benefits of GHG abatement are one tenth the size of the developed country's benefits. While it is reasonable to suggest that developing countries possess a higher social discount rate than developed countries, further research is required to determine whether it is reasonable to assume that ratio between developed and developing countries benefits from abatement is as large as is assumed here.

Table 12 **Evaluating the Model of Incremental Cooperation** [$\delta = 0.1$]

	Stage 1	Stage 2	Stage 3							Stage 4
	No Cooperation	Annexed Countries Cooperate	Annexed and % of non-Annexed Cooperate							Socially Optimal
% Developed cooperating	0%	100%	100%							100%
% Developing cooperating	0%	0%	5%	10%	20%	25%	35%	50%	75%	100%
ABATEMENT										
Developed	0.64	18.55	14.31	11.65	8.48	7.46	6.02	4.66	3.38	2.65
Developing cooperating	0.00	0.00	23.95	38.99	56.78	62.46	70.51	78.00	84.94	88.81
Developing non-cooperating	2.14	1.75	1.26	0.96	0.60	0.49	0.33	0.19	0.06	0.00
AGGREGATE Q	**2.78**	**20.30**	**39.53**	**51.59**	**65.86**	**70.41**	**76.86**	**82.85**	**88.38**	**91.46**
% of public good solution			43%	56%	72%	77%	84%	90%	97%	
AGGREGATE Q^{max}			**36.62**	**46.92**	**63.25**	**70.61**	**84.65**	**104.93**	**137.91**	
ABATEMENT COSTS										
Developed	0.20	170.01	101.18	67.00	35.52	27.52	17.89	10.73	5.65	3.48
Developing cooperating	0.00	0.00	169.37	224.31	237.86	230.31	209.63	179.58	141.96	116.40
Developing non-cooperating	0.07	0.05	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00
AGGREGATE	**0.27**	**170.06**	**270.58**	**291.32**	**273.39**	**257.84**	**227.53**	**190.31**	**147.61**	**119.87**
ABATEMENT BENEFITS										
Developed	63.00	419.57	729.48	880.49	1015.93	1049.33	1088.41	1116.18	1134.48	1141.62
Developing cooperating	0.00	0.00	12.21	29.48	68.02	87.82	127.53	186.84	284.85	382.19
Developing non-cooperating	21.09	140.47	232.01	265.30	272.09	263.47	236.85	186.84	94.95	0.00
AGGREGATE	**84.09**	**560.04**	**973.70**	**1175.27**	**1356.05**	**1400.63**	**1452.80**	**1489.86**	**1514.29**	**1523.81**
ABATEMENT NET BENEFITS										
Developed	62.80	249.56	628.30	813.49	980.41	1021.81	1070.52	1105.45	1128.83	1138.14
Developing cooperating	0.00	0.00	-157.16	-194.83	-169.84	-142.49	-82.10	7.25	142.90	265.80
Developing non-cooperating	21.02	140.42	231.98	265.28	272.09	263.47	236.85	186.84	94.95	0.00
AGGREGATE	**83.82**	**389.98**	**703.12**	**883.94**	**1082.66**	**1142.79**	**1225.27**	**1299.54**	**1366.68**	**1403.94**

Another difference to be noted between table 11 and 12 is the share of the socially optimal level of abatement which can be achieved with partial cooperation. As the differences between countries increase (as δ decreases from 0.25 in table 11 to 0.1 in table 12), small percentages of developing country's participation will produce greater portions of the socially optimal level of abatement being attainable. If δ =0.25, 25% of developing countries cooperate contributing 64% of the socially optimal level of abatement. If δ =0.1, 25% of developing countries cooperating contribute 77% of the socially optimal level of abatement.

6.4 Sensitivity Analysis

As in the simplified case of two countries, the sensitivity of the N country model results to the assumed parameter values assists in understanding the abatement gains from cooperation and the role for JI in achieving these gains. As JI was found to be necessary in Table 12 with δ<0.1, the sensitivity analysis base case assumes δ=0.1 with the rest of the parameters equal to the values expressed in table 10.

Tables 11 and 12 showed that all countries received a positive change in net benefits from the movement from Stage 1 to Stage 2. This implies movement from Stage 1 to Stage 2 is achievable without JI and the sensitivity analysis will focus on the movement from Stage 2 to Stage 3 and Stage 2 to Stage 4.

The decision to participate in the next stage of international cooperation will depend on whether each country is made better off by participating to achieve the next cooperative stage of abatement. To determine whether JI is necessary, the difference between $Q^{\max}_{stage3}$ and Q^{c}_{stage3} is examined. If the value of Q^{c}_{stage3} < $Q^{\max}_{stage3}$, there exists an allocation of Q^{c}_{stage3} abatement that will leave no country worse off. It may be that the cost minimizing allocation will leave some countries worse off, but there will exist some other allocation of Q^{c}_{stage3} which will leave no country worse off. If $Q^{c}_{stage3} > Q^{max}_{stage3}$, there does not exist any allocation of Q^{c}_{stage3} that does not leave at least one country worse off. In this case, JI provides a mechanism to share the gains from achieving Q^{c}_{stage3}. The sidepayment policy improves the incentives for the country made worse off so that Q^{c}_{stage3} is achievable. This section examines how the discrepancy between Q^{max}_{stage3} and Q^{c}_{stage3} is affected by changes in the values for δ, γ, α and N across a range of participation rates for developing countries.

Table 13 calculates Q^{max}_{stage3} - Q^{c}_{stage3} for a range of values for δ and β. The table suggests that the ratio of the slope of the developed country's marginal cost to the developing marginal cost must exceed 7 ($\delta \leq 0.15$) before JI will be necessary to achieve the cooperative outcome.

Table 13 Necessity for JI as δ changes

STAGE 3	Q^{max}_{stage3} - Q^{c}_{stage3}						
δ	$\beta = 5\%$	$\beta = 10\%$	$\beta = 15\%$	$\beta = 20\%$	$\beta = 25\%$	$\beta = 50\%$	$\beta = 100\%$
0.01	-32.31	-33.65	-30.41	-25.72	-20.38	9.49	72.63
0.05	-9.36	-13.39	-13.39	-11.26	-7.90	16.64	46.22
0.10	-2.91	-4.67	-4.38	-2.61	0.19	22.08	79.02
0.15	-0.74	-1.03	-0.11	1.84	4.60	25.44	80.81
0.20	0.21	0.80	2.21	4.40	7.23	27.64	82.02
0.25	0.69	1.82	3.58	5.97	8.90	29.15	82.87
0.30	0.96	2.43	4.45	6.99	10.01	30.23	83.50
0.50	1.31	3.36	5.85	8.74	11.99	32.36	84.82
0.75	1.38	3.59	6.25	9.29	12.64	33.17	85.36
1.0	1.39	3.63	6.32	9.38	12.76	33.34	85.48

Assumes a=100, b=1, c=35, N=154, α = 23%

However, the precise value of γ is not known with certainty. In the two country case it was found the value of γ will also in part determine whether $Q^{\max}_{stage3}$ -<Q^{c}_{stage3}. To examine the case of 154 countries, Table 14 tests the sensitivity of this discrepancy to a range of values for β and γ.

Table 14 **Necessity for JI as γ changes** [δ=0.10]

Stage 3	$Q^{\max}_{stage3}$ - Q^{c}_{stage3}						
γ	β=5%	β=10%	β=15%	β=20%	β=25%	β=50%	β=100%
1.0	-2.13	0.49	4.24	8.44	12.85	36.10	83.95
5.0	-2.03	0.79	5.76	11.74	18.26	53.94	129.19
15.0	-3.02	-2.85	0.01	4.38	9.68	42.19	115.67
35.0	-2.91	-4.67	-4.38	-2.61	0.19	22.08	79.02
50.0	-2.56	-4.65	-5.15	-4.37	-2.64	14.00	61.98
175.0	-1.15	-2.64	-3.79	-4.53	-4.88	-2.08	16.45
350.0	-0.64	-1.55	-2.35	-3.00	-3.48	-3.52	4.68

Assumes a=100, b=1, N=154, α = 23%, δ = 0.25

Table 14 reflects a scenario where the steepness of the developed marginal cost curve is ten times the steepness of the developing marginal cost curve (δ=0.1). The table shows that the value of γ will have an impact on whether JI is necessary. In general, as the participation rates of developing countries increase, JI will be required only for relatively harmless pollutants which are costly to control. If $\beta = 50\%$, JI is required only if γ is equal to or greater than 175. When the participation rates of developing countries are very low, for example 5%, JI will be likely required even in cases where pollutants are more harmful and less expensive to control (e.g. γ=15).

The necessity of JI will also vary with the values for N and α. However, care must be taken when interpreting the sensitivity analysis of α and N because it is not necessarily true that the other parameters, such as γ, will remain constant as α and N change. For example, γ may be expected to decrease as N decreases.

Consider the parameter α which represents the proportion of the total number of countries which are developed. The value of α will change as countries industrialize and shift from being considered developing to developed countries. Further, it is possible to consider that some countries may not be defined most appropriately. Further, if countries were to enter negotiations in regional blocks of countries, changing the number of negotiating parties, the value of α as well as N would have to be reassessed. Table 15 shows how the discrepancy between Q^{max}_{stage3} and Q^{c}_{stage3} changes with values for α.

Table 15 **Necessity for Sidepayments as α changes [δ=0.10]**

Stage 3	Q^{max}_{stage3} - Q^{c}_{stage3}						
α	β=5%	β=10%	β=15%	β=20%	β=25%	β=50%	β=100%
5%	-2.30	-2.96	-1.92	0.52	4.08	32.90	114.05
10%	-3.50	-5.14	-4.51	-2.19	1.40	29.92	106.64
15%	-3.65	-5.58	-5.12	-2.94	0.45	27.07	96.98
23%	-2.91	-4.67	-4.38	-2.61	0.19	22.08	79.02
35%	-1.44	-2.57	-2.49	-1.46	0.28	14.52	52.59
50%	-0.33	-0.78	-0.82	-0.43	0.31	7.26	27.57
65%	0.05	-0.01	-0.02	0.09	0.32	2.99	12.13
90%	0.04	0.08	0.12	0.16	0.20	0.40	1.06

Table 15 shows there is a fairly complex interaction between the variables. However, it tends to be that at low levels of β (few developing countries cooperating), the abatement Q^{c}_{stage3} will require large abatement shares for each of the developing countries. If the cooperating developing countries are not to be made worse off, the developed countries would have to absorb the loss. Hence, you need a relatively high proportion of countries to be developed in order to absorb this loss without making them worse off. At large levels of β (many developing countries cooperating), there are sufficient developing countries to do the abating so that Q^{c}_{stage3} need not make either the developing or developed countries worse off. Hence, JI is less likely required as the value of β and α increase.

It is also necessary to consider variations in the number of countries, represented by N. In the case of GHG abatement, it is possible that future negotiations will involve the development of regional groups of countries, thereby reducing the number of negotiating parties. In the Convention on Biological Diversity, there if growing interest in regional cooperation.[62] With respect to Biological Diversity, Asian officials view regional cooperation as means to avoid a bidding war that would drive down prices of biological resources. The pursuit of regional representation is reasonable as biological species are not necessarily unique to any one country, but unique to the Southeast region. Regional cooperation would facilitate efficient processing of permits, upfront payments for samples and provide a one-stop shopping center that could provide extensive data on natural resources. These arguments are easily transferable to international negotiations to abate emissions of GHGs. If regional groups of developing countries were to offer a one-stop shopping Center for carbon offset projects or permits, the efficiency of the processing of permits, distribution of GHG credits and technology transfer among the countries may be improved while at the same time a bidding war on projects may be avoided. Table 5.8 evaluates the model under varying assumptions for the value of N.

62 Cohen [1996]

Table 16 **Necessity for Sidepayments as N changes [δ=0.10]**

Stage 3	Q^{max}_{stage3} - Q^{c}_{stage3}						
N	β=5%	β=10%	β=15%	β=20%	β=25%	β=50%	β=100%
10	-0.49	-1.17	-1.81	-2.36	-2.82	-3.75	-0.06
25	-1.06	-2.41	-3.53	-4.34	-4.85	-3.62	10.46
50	-1.76	-3.73	-5.01	-5.60	-5.57	0.87	28.89
75	-2.24	-4.42	-5.49	-5.55	-4.79	6.47	44.53
100	-2.56	-4.73	-5.41	-4.87	-3.40	11.92	57.54
154	-2.91	-4.67	-4.38	-2.61	0.19	22.08	79.02
250	-2.88	-3.56	-1.72	1.69	6.10	35.10	103.46
500	-1.82	-0.19	3.98	9.49	15.78	52.04	131.06

Table 16 shows that small numbers of countries or negotiating parties, increase the likelihood of the necessity of JI. A smaller number of countries decreases the ability to distribute the same aggregate abatement level without making at least one party worse off. If countries were to enter negotiations in regional groups, the more likely that a policy of JI would be necessary to achieve socially optimal levels of abatement.

6.5 Conclusion

The model of gradual cooperation with N countries provides an assessment of the potential for partial cooperation to contribute to international GHG abatement and the necessity for JI in developing this cooperation.

Tables 11 and 12 showed that a large share of the socially optimal level of abatement Q^{c}_{stage4} is achievable with only a small percentage of the developing countries cooperating with developed countries to reduce GHG emissions. In table 11 it was assumed that the developed costs of abatement were four times the developing costs of abatement and the developed benefits of abatement were four times the developing benefits of abatement (δ =0.25). Under this assumption, if only 25% of the developing countries were cooperate with the developed countries

(β =0.25), 64% of Q^c_{stage4} could be achieved. Table 12 assumed a greater difference between countries with δ =0.10. In this case, 25% developing participation would provide 77% of Q^c_{stage4}.

Tables 11 and 12 showed that with reasonable parameter values assumed, a policy of JI is never required to achieve the socially optimal level of abatement Q^c_{stage4}. The model suggests that when there is a large number of countries participating, there will most likely exist an allocation of Q^c_{stage4} which will leave no country worse off because each country's share of the abatement burden will be relatively small. However, if to achieve the socially optimal level of abatement, gradual participation by developing countries is anticipated, this will no longer be the case. As in the case of two countries presented in Chapter 4, small values of δ, (large differences between developed and developing countries) are sufficient to necessitate the use of JI. Table 11, which assumed that δ =0.25, showed JI was not necessary to provide incentives, even for very small levels developing participation. Instead, socially optimal levels of partial cooperation could be achieved through the reallocation of the abatement burden. However, if δ =0.10, table 12 showed that low levels of developing participation (β = 5% to 20%), a policy of JI among the cooperating countries is necessary to achieve Q^c_{stage3}.

Whether JI is necessary to achieve the gains from partial cooperation (Stage 3) was shown to depend on the values of δ, γ, α and N. Tables 13 through 16 tested the sensitivity of the difference between $Q^{\max}_{stage3}$ and Q^c_{stage3} to a range of parameter values to assess whether JI is necessary to provide an incentive for the gradual participation of developing countries.

Table 13 showed that the greater the difference between countries (the smaller the δ) and the smaller the developing participation rate (the smaller the β), the more likely JI will be necessary to induce gradual international cooperation. The precise value of δ is not known but it is most likely that in the case of GHG abatement δ will be small.

Table 14 showed that the use of JI is most likely to be necessary the larger the value of γ (where $\gamma = c / b$). As the participation rates of developing countries increase (β increases), larger levels of γ may still necessitate a policy of JI. A large γ implies a scenario of pollutants which are costly control and whose abatement benefits are either small, uncertain or highly discounted. It is most likely that for the case of international GHG abatement, the value of γ is large. This will necessitate a policy of JI.

Table 15 allowed the proportion of developed countries (α) to vary. If there is a high proportion of developed countries (α is large), JI will not be necessary to achieve Q^{c}_{stage3}, regardless of the participation rates of developing countries. This is because there will be a great enough number of developed countries to absorb the losses of the developing countries, enabling reallocation of Q^{c}_{stage3}. However, as the proportion of developed countries declines (α gets smaller), JI may be necessary, especially if the participation rate of developing countries is small (β is small). As developed countries must absorb the losses of developing countries, the fewer the developed countries, the less likely they will be able to fully absorb the developing losses without also being made worse off.

Table 16 examined how the model results change as the number of countries or negotiating parties declines. The number of countries may be reduced if developing countries were to consider forming regional groups for the development of GHG abatement projects. The smaller the number of negotiating parties, the more likely JI will be necessary to achieve Q^{c}_{stage3} as there will be fewer countries across which the abatement burden can be distributed.

The analysis in this chapter has shown that a policy of JI is most likely necessary to induce further abatement commitments from FCCC signatories. The conditions which are characteristic of international GHG abatement and contribute to this conclusion include the likely emergence of gradual participation by developing countries, the existence of large differences between developed and developing abatement net benefits and incremental marginal costs of abatement increasing steeply relative to uncertain marginal benefits.

CHAPTER SEVEN

CONCLUSION

The purpose of this research was to refocus the current debate over JI by providing insight as to whether a policy of JI will be necessary to induce the next steps in international cooperation for the abatement of GHG emissions. The results of a model of international cooperation suggest that without a JI policy, it is possible that the gradual participation of developing countries in undertaking GHG commitments will be threatened, eliminating the opportunity for effective mitigation of global climate change.

This conclusion is based on the results of a Cournot model of oligopoly which assumes the gradual participation of developing countries, a few at a time. In the case of GHG abatement, cooperation among developed countries alone will provide only a small share of the socially optimal level of abatement. To achieve greater emission reductions, it will be necessary for both developed and developing countries to undertake GHG commitments. However, it will not be easy to negotiate commitment from developing countries given the five year history of the FCCC.

The main issue in the debate over GHG abatement is one of responsibility. Developing countries are concerned that if they were to undertake additional GHG abatement, their process of industrialization may be jeopardized. Further, there is a sentiment that developed countries are responsible for the current GHG build-up, a direct result of creating their affluent economies through the 19^{th} and 20^{th} centuries. As developing countries have not yet had their chance to develop, they feel they should not be unduly punished. Therefore, the developed countries should be responsible for the abating. Given the position of developing countries, it is reasonable to expect that GHG commitments from developing countries will only be achieved gradually, a few countries at a time.

To analyze the role that JI plays in developing gradual cooperation, a model of international cooperation was presented where developed countries were joined by small increments of developing countries in undertaking additional GHG abatement. The model showed that, in some cases, JI was a necessary policy to act as a participation incentive for the first few developing countries. In these cases, a policy of JI was necessary to achieve the socially optimal level of abatement among the group of cooperating countries. Without JI, there would be no way to distribute the socially optimal level of abatement without making some countries worse off.

Whether JI was necessary for the gradual participation of developing countries was found to depend on the magnitude of a number of factors, the most important of which were the magnitude of the ratio between developed and developing countries net benefits (δ) and the size of the ratio between the slopes of each country's marginal cost and the global marginal benefit (γ).

The greater the ratio between developed and developing abatement net benefits (the smaller the δ), the more likely JI was necessary as a means to redistribute the gains from cooperative abatement to ensure no country was made worse off. In the case of international GHG abatement, it is most likely that the ratio between developed and developing net benefits is large. The fact that countries are engaging in JI pilot projects, which are not allowed to count for credit towards their nations' commitments, is evidence there is a significant cost difference between developed and developing countries.

Further, the larger the value of γ , the more likely JI was found to be necessary to achieve socially optimal levels of gradual cooperation. If γ was large, this suggested a scenario in which pollutants which are costly to control and benefits are either small, uncertain or highly discounted. It is most likely that for the case of international GHG abatement the value of γ is large.

This research has provided a compelling argument for the necessity of JI and the value in supporting and promoting the development of a JI framework, so that the future participation of developing countries is not jeopardized. Private companies should be encouraged to engage in pilot JI projects both within the country and in foreign countries. This will enable the marketplace to gain valuable experience with GHG reduction projects and provide critical working knowledge to policy makers to ensure JI investments are both efficient and measurable.

The work presented in this thesis would benefit from further research regarding the precise values of δ and γ which have been shown to be critical factors in determining the necessity of JI policy. Clarity regarding these values is a first step to affirming the preliminary conclusions presented and to ascertaining the role for JI in the next stage of FCCC negotiations. Furthermore, the analysis has imposed a number of restrictive assumptions and additional research is needed to learn how the conclusion of this paper would be altered by changes in these assumptions. The most important assumptions are: (i) all developing countries are identical (ii) all developed countries are identical (iii) abatement cost functions are independent (iv) the ratio between developed and developing countries costs of abatement is equal to the ratio between developed and developing countries benefits of abatement.

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APPENDIX A

DERIVATION OF NET BENEFIT FUNCTIONS

The following section describes how the net benefit functions presented in Chapter 5 were derived from Barrett [1992, 1994]

The Abatement Benefit function

Aside from the fact that the abatement benefits for any country will depend on global abatement, not much is known about the actual schedule of marginal abatement benefits. However, Barrett [1992] proposed it to be reasonable to assume: first, the marginal damage will increase with increasing levels of emissions; second, the abatement benefits will be in part determined by how sensitive the economy is to climate change as well as the size of the country's economy and; third, that the marginal abatement benefits will be reduced to zero at some level of abatement. From these assumptions, Barrett proposed country i's marginal abatement function could be written as:

$$MB_i(Q) = b_i G_i (a_i - \frac{Q}{E})$$

where G_i represents the Gross Domestic Product of country i and E is the global emissions in the absence of any abatement. As with equations specified earlier, a and b are positive parameters and Q is global abatement. The intercept of the function is determined by $b_i G_i a_i$ with b_i reflecting both the sensitivity of an economy to climate change and the weight with which is attached to deferred benefits.

In 1994, Barrett's analysis of self enforcing environmental agreements assumed countries to be uniform. For this analysis, Barrett removed the variables G_i and E from the abatement benefit function. With each country assumed to be identical, distinguishing between each country's Gross Domestic Product no longer provided an important distinction. With regards to the removal of E, it is reasonable to assume the abatement benefit will be related just as much to the absolute level of abatement (Q) as it will be to the percentage of emissions abated (Q/E). The last alteration Barrett made was to specify a global benefit function, making the individual benefit function to vary with N. These revisions yielded the following total abatement benefit function:

$$B_i(Q) = \frac{b\left\{aQ - \dfrac{Q^2}{2}\right\}}{N}$$

The only difference between this expression of abatement benefits and presented in Chapter 5 is the inclusion of the variable δ which acts similarly to the variable G_i in Barrett's earlier work. Barrett [1992], used the parameter G_i to differentiate between countries on the basis of their Gross Domestic Product. Here, δ also differentiates between countries, representing the relative differences between the Annexed country and non-Annexed benefits of GHG abatement and Annexed and non-Annexed costs of GHG abatement. As it is assumed the developed country's benefits from abatement will always equal or exceed the abatement benefits of the developing country, δ is restricted to being $0 \leq \delta \leq 1$.

The Abatement Cost Function

On the cost side of the equation, there is much more empirical evidence to assist with the formation of an abatement cost function. Barrett [1992] states that marginal abatement costs can be expected to vary among countries for several reasons. First, it is reasonable to expect that different countries will have different substitution possibilities. Second, countries will have different base year emission levels. Further, depending on how abatement is defined, marginal abatement costs may also vary because of the differences in the rate of economic growth. From these assumptions, Barrett proposed country i's marginal cost function could be written as:

$$MC_i(q_i) = \frac{c_i q_i}{e_i}$$

where c_i is a technical parameter which reflects the ease with which country i can abate its emissions, q_i is i's level of abatement and e_i is the base-year emissions (q_i/e_i is equivalent to country i's percentage abatement). Integrating this marginal cost function yields the following total cost function:

$$TC_i(q_i) = \frac{c_i q_i^2}{2e_i}$$

Barrett [1994] assumed countries to be uniform in his analysis of self enforcing environmental agreements. Under a scenario of identical countries, there was no need to differentiate between countries costs of abatement or country's percentage abatement. Thus, Barrett [1994] defined the following total cost function for the case of uniform countries.

$$TC_i(q_i) = \frac{c q_i^2}{2}$$

Notice the only difference between this abatement cost function and the one presented in the two country model in Chapter 5 is the inclusion of the variable δ which acts similarly to Barrett's [1992] variable c_i. Barrett used c_i to reflect the differences in the ease with which countries can abate its emissions. Here, δ represents the ratio between developed and developing net benefits of abatement. As it is assumed the developing country's costs of abatement will always be less than or equal to the abatement costs faced by the developed country, δ is restricted such that $0 \leq \delta \leq 1$.

APPENDIX B

EQUATIONS FOR TWO COUNTRY MODEL PRESENTED IN CHAPTER 5

Net Benefit Functions

For each of the equations below, the first term represents the Benefits of GHG abatement, the second term, the associated costs of GHG abatement. The difference between the two determines the net benefits of GHG abatement faced by one developed and one developing country.

1. $$NB_A = \frac{b(aQ - \frac{Q^2}{2})}{N} - \frac{cq_A^2}{2}$$

2. $$NB_{NA} = \frac{\delta b(aQ - \frac{Q^2}{2})}{N} - \frac{\delta cq_{NA}^2}{2}$$

Solving for the non-cooperative solution:

Each country will select the level of abatement that maximizes its own net benefits taking as given the abatement decision of the other country.

3. $$\frac{\partial NB_A}{\partial q_A} = \frac{b(a - q_A - q_{NA})}{2} - cq_A$$

4. $$\frac{\partial NB_{NA}}{\partial q_{NA}} = \frac{\delta b(a - q_A - q_{NA})}{2} - \delta cq_{NA}$$

Setting each derivative equal to zero and substituting $q_A = q_{NA}$ we find from 3:

5. $$b(a - q_A - q_{NA}) = 2cq_A$$

Dividing through by b and setting $\gamma = \frac{c}{b}$, yields:

6. $$q_A^{nc} = \frac{a}{2(\gamma + 1)}$$ and by symmetry,

7. $$q_{NA}^{nc} = \frac{a}{2(\gamma+1)}$$

Thus the non-cooperative aggregate abatement $Q_2^{nc} = q_A^{nc} + q_{NA}^{nc}$ is equal to:

8. $$Q_2^{nc} = \frac{a}{(\gamma+1)}$$ **Non-cooperative solution**

Solving for the Socially Optimal Solution:

In the socially optimal case, each country will select the level of abatement that maximizes the total net benefits

9. $$TNB = \frac{(1+\delta)b\left[aQ - \frac{Q^2}{2}\right]}{2} - \frac{cq_A^2}{2} - \frac{cq_{NA}^2}{2}$$

Maximizing this collective net benefits subject to q_A, q_{NA} yields

10. $$\frac{\partial TNB}{\partial q_A} = \frac{(1+\delta)b}{2}(a - q_A - q_{NA}) - cq_A = 0$$

11. $$\frac{\partial TNB}{\partial q_{NA}} = \frac{(1+\delta)b}{2}(a - q_A - q_{NA}) - \delta cq_A = 0$$

Substituting $q_A = \delta q_{NA}$ into 10 and $q_{NA} = \frac{q_A}{\delta}$ into 11 yields

12. $$q_A^c = \frac{a\delta(1+\delta)}{2\gamma\delta + (1+\delta^2)}$$ and

13. $$q_A^c = \frac{a(1+\delta)}{2\gamma\delta + (1+\delta^2)}$$

Thus the socially optimal aggregate abatement $Q_2^c = q_A + q_{NA}$ is equal to:

14. $$Q_2^c = \frac{a(1+\delta)^2}{2\delta\gamma + (1+\delta)^2}$$ **Socially Optimal Solution**

Solving for the Maximum Allocation of the Socially Optimal

The maximum allocation of the socially optimal level of abatement that either country is willing to undertake is one that leaves it no worse off than at the non-cooperative outcome. For the developed country, this can be found by solving for the level of abatement, $q_A^{\max}$ which solves:

15. $$B_A^c - NB_A^{nc} = \frac{c(q_A^{\max})^2}{2}$$

Equation 15 implies the maximum allocation $q_A^{\max}$ is the one whose costs of achieving are equivalent to the difference between the benefit the developed country receives from the socially optimal level of abatement (B_A^c and how well off the country was without cooperating at the non-cooperative outcome (NB_A^{nc}). The same is true for the developing country.

16. $$B_{NA}^c - NB_{NA}^{nc} = \frac{\delta c(q_{NA}^{\max})^2}{2}$$

Substituting the non-cooperative level of abatement, Q_2^{nc} into the developed and developing net benefit functio yields 17 and 18 respectively:

17. $$NB_A^{nc} = \frac{2a^2b(1+2\gamma) - a^2c}{8(\gamma+1)^2}$$

18. $$NB_A^{nc} = \frac{\delta\left(2a^2b(1+2\gamma) - a^2c\right)}{8(\gamma+1)^2}$$

Substituting the cooperative level of abatement, Q_2^c, into the developed and developing benefit functions yields 19 and 20 respectively:

$$19. \quad B_A^c = \frac{b}{2}\left\langle \frac{a^2\delta^4 + 4a^2\delta^3\gamma + 4a^2\delta^3 + 8a^2\delta^2\gamma + 6a^2\delta^2 + 4a^2\delta\gamma + 4a^2\delta + a^2}{2\left(2\gamma\delta + (1+\delta)^2\right)^2} \right\rangle$$

$$20. \quad B_{NA}^c = \frac{\delta b}{2}\left\langle \frac{a^2\delta^4 + 4a^2\delta^3\gamma + 4a^2\delta^3 + 8a^2\delta^2\gamma + 6a^2\delta^2 + 4a^2\delta\gamma + 4a^2\delta + a^2}{2\left(2\gamma\delta + (1+\delta)^2\right)^2} \right\rangle$$

Substituting 17 and 19 into 15, and 18 and 20 into 16, enables one to solve for $q_A^{\max}$ and $q_{NA}^{\max}$ as the followir

$$21. \quad q_A^{\max^2} = \frac{b}{2}\left\langle \frac{a^2\delta^4 + 4a^2\delta^3\gamma + 4a^2\delta^3 + 8a^2\delta^2\gamma + 6a^2\delta^2 + 4a^2\delta\gamma + 4a^2\delta + a^2}{2\left(2\gamma\delta + (1+\delta)^2\right)^2} \right\rangle - \left\langle \frac{2a^2b(1+2\gamma) - a^2c}{8(\gamma+1)^2} \right.$$

$$22. \quad q_{NA}^{\max^2} = \frac{b}{2}\left\langle \frac{a^2\delta^4 + 4a^2\delta^3\gamma + 4a^2\delta^3 + 8a^2\delta^2\gamma + 6a^2\delta^2 + 4a^2\delta\gamma + 4a^2\delta + a^2}{2\left(2\gamma\delta + (1+\delta)^2\right)^2} \right\rangle - \left\langle \frac{2a^2b(1+2\gamma) - a^2c}{8(\gamma+1)^2} \right.$$

The maximum aggregate allocation of the socially optimal allocation, $Q_2^{\max}$, is equal to the sum of $q_A^{\max}$ and $q_{NA}^{\max}$ and is as follows:

$$23. \quad Q_{NA}^{\max} = 2\sqrt{\frac{b}{2}\left\langle \frac{a^2\delta^4 + 4a^2\delta^3\gamma + 4a^2\delta^3 + 8a^2\delta^2\gamma + 6a^2\delta^2 + 4a^2\delta\gamma + 4a^2\delta + a^2}{2\left(2\gamma\delta + (1+\delta)^2\right)^2} \right\rangle - \left\langle \frac{2a^2b(1+2\gamma) - a^2c}{8(\gamma+1)^2} \right\rangle}$$

APPENDIX C

EQUATIONS FOR N COUNTRY MODEL PRESENTED IN CHAPTER SIX

Net Benefit Functions

For each of the equations below, the first term represents the benefits of GHG abatement, the second term, the associated costs of GHG abatement. The difference between the two determines the net benefits of GHG abatement faced by one developed and one developing country. Let equations 1 and 2 represent the net benefits of GHG abatement for one developed country and one developing country respectively.

1. $$NB_{Ai} = \frac{b(aQ - \frac{Q^2}{2})}{N} - \frac{cq_{Ai}^2}{2}$$

2. $$NB_{NAi} = \frac{\delta b(aQ - \frac{Q^2}{2})}{N} - \frac{\delta cq_{NAi}^2}{2}$$

where a and b are positive parameters, c is the marginal cost of abatement, q_A is the developed country's abatement, Q is global abatement ($Q = q_A + q_{NA}$) and N is the number of countries. The parameter δ reflects the relative differences between the developed and developing country's costs of abatement and the developed and developing benefits of abatement. The developing costs and benefits of abatement are assumed to never exceed the respective costs and benefits of abatement for the developed country thus δ is restricted to being $0 \leq \delta \leq 1$. The parameter α represents the proportion of countries which are developed. Hence, αN is the number of developed countries and $(1-\alpha)N$ is the number of developing countries.

Stages of Cooperation:

A Cournot model of incremental cooperation is developed from the assumption of four hypothetical stages of cooperation. Consider these stages outlined below. The stages are discussed in greater detail in Chapter 6.

	Cooperative Stages			
	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Description	No Cooperation	Developed Countries Cooperate	Developed Countries and a % developing countries Cooperate	Total Cooperation

In Stage 3, the proportion of developing countries which cooperate are represented by the parameter β where $0<\beta<1$. The Cournot solutions for Stages 1 through 4 are worked through and provided below.

Stage 1: **No Cooperation**

Each developed and developing country will select the level of abatement that maximizes its own net benefits taking as given the abatement decision of all other countries. Each developed country will maximize the following:

3. $$\frac{\partial NB_{Ai}}{\partial q_{Ai}} = \frac{b}{N}(a - Q_A - Q_{NA}) - cq_{Ai} = 0$$

Dividing through by b, setting $\gamma = \frac{c}{b}$, and multiplying the single country solution by the number of developed countries (αN) yields the developed countries reaction function:

4. $$Q_A^\gamma = \frac{\alpha(a - Q_{NA})}{\gamma + \alpha}$$

Each developing country will maximize the following:

5. $$\frac{\partial NB_{NAi}}{\partial q_{NAi}} = \frac{\delta b}{N}(a - Q_A - Q_{NA}) - \delta c q_{Ai} = 0$$

Dividing through by b, setting $\gamma = \frac{c}{b}$, and multiplying the single country solution by the number of developing countries yields the developing countries reaction function:

6. $$Q_{NA}^{rf} = \frac{(1-\alpha)(a-Q_{NA})}{(\gamma+1-\alpha)}$$

Substituting 6 into 4 yields Q_A^{nc} below:

7. $$Q_A^{nc} = \frac{\alpha a}{\gamma+1}$$

Substituting 4 into 6 yields Q_{NA}^{nc} below:

8. $$Q_A^{nc} = \frac{a(1-\alpha)}{\gamma+1}$$

Thus the non-cooperative aggregate abatement $Q^{nc} = Q_A + Q_{NA}$ is equal to:

9. Stage 1: Non-cooperative abatement: $$Q^{nc} = \frac{a}{1+\gamma}$$

Stage 2: Developed countries Cooperate

In this stage, only the developed countries are assumed to make commitment to reduce emissions of GHGs. This is equivalent to having all developed countries and β developing countries cooperating where β=0. Consider this group of cooperating countries. Their net benefits of GHG abatement will be represented by equation 10. Let q_{NA1} be the GHG abatement from one cooperating developing country.

10. $$NB^c = (\alpha b + b\delta\beta - \alpha b\delta\beta)(aQ - \frac{Q^2}{2}) - \sum_{i=1}^{\alpha N} \frac{cq_{Ai}^2}{2} - \sum_{j=1}^{BN} \frac{cq_{NA1j}^2}{2}$$

Each developed country will maximize the following:

11. $$\frac{\partial NB^c}{\partial q_{Ai}} = b(\alpha + \delta\beta - \alpha\delta\beta)(a - Q_A - Q_{NA1} - Q_{NA2}) = cq_{Ai}$$

where Q_{NA1} and Q_{NA2} represent the collective GHG abatement from cooperating developing countries and non cooperating developing countries respectively.

Each cooperating developing country will maximize

12. $$\frac{\partial NB^c_{stage2}}{\partial q_{NAj}} = b(\alpha + \delta\beta - \alpha\delta\beta)(a - Q_A - Q_{NA1} - Q_{NA2}) = \delta cq_{NAj}$$

Multiplying 11 by the number of developed countries, αN and 12 by the number of cooperating developing countries, $\beta(1-\alpha)N$ and dividing both 7 and 8 by b as well as setting $\frac{c}{b} = \gamma$ yields 11a and 12a.

11a. $$Q_A = \frac{\alpha N(\alpha + \delta B - \alpha\delta B)(a - Q_A - Q_{NA1} - Q_{NA2})}{\gamma + \alpha N(\alpha + \delta\beta - \alpha\delta\beta)}$$

12a. $$Q_{NA1} = \frac{\beta(1-\alpha)N(\alpha + \delta B - \alpha\delta B)(a - Q_A - Q_{NA1} - Q_{NA2})}{\delta\gamma + \beta(1-\alpha)N(\alpha + \delta\beta - \alpha\delta\beta)}$$

Consider the group of non-cooperating developing countries. A single non-cooperating developing countries is assumed to possess the following net benefits from GHG abatement.

13. $$NB^{nc}_{q_{NA2}} = \frac{\delta b(aQ - \frac{Q^2}{2})}{N} - \frac{\delta cq^2_{NA2}}{2}$$

Each country will maximize the following:

$$14.\qquad \frac{\partial NB^{nc}_{q_{NA2}}}{\partial q_{NA2}} = \frac{b(a - Q_A - Q_{NA1} - Q_{NA2})}{N} = cq_{NA2}$$

Multiplying 14 by the proportion of developing countries which do not cooperate, $(1-\beta)(1-\alpha)$ and dividing b as well as setting $\frac{c}{b} = \gamma$ yields 14a

$$14a.\qquad \beta(1-\alpha)N\left(\alpha + \delta\beta - \alpha\delta\beta\right)(a - Q_A - Q_{NA1} - Q_{NA2}) = \delta\gamma c q_{NAj}$$

Rearranging,

$$14b\qquad Q_{NA2} = \frac{(1-\beta)(1-\alpha)(a - Q_A - Q_{NA1})}{\gamma + (1-\beta)(1-\alpha)}$$

From 11a and 12a

$$15.\qquad Q_{NA1} = \frac{\beta(1-\alpha)Q_A}{\delta\alpha}$$

Therefore,

$$16.\qquad Q_A + Q_{NA1} = \frac{\alpha\delta Q_A}{\alpha\delta Q_A} + \frac{\beta(1-\alpha)Q_A}{\alpha\delta} = \frac{[\alpha\delta + \beta(1-\alpha)]Q_A}{\alpha\delta}$$

Subbing $Q_A + Q_{NA1}$ into 14b yields 14c

$$14c.\qquad Q_{NA2} = \frac{(1-\beta)(1-\alpha)(a - \frac{[\alpha\delta + \beta(1-\alpha)]Q_A}{\alpha\delta})}{\gamma + (1-\beta)(1-\alpha)}$$

Substituting 14c and 15 into 11a yields 11b:

$$\text{11b.} \quad \underset{\sim}{Q}_A = \frac{\alpha N(\alpha + \delta B - \alpha\delta B)\left(a - \frac{\beta(1-\alpha)\underset{\sim}{Q}_A}{\alpha\delta} - \frac{(1-\beta)(1-\alpha)\left(a - \frac{[\alpha\delta+\beta(1-\alpha)]\underset{\sim}{Q}_A}{\alpha\delta}\right)}{\gamma+(1-\beta)(1-\alpha)}\right)}{\gamma + \alpha N(\alpha + \delta\beta - \alpha\delta\beta)}$$

and isolating $\underset{\sim}{Q}_A$ produces:

$$\text{11c.} \quad \underset{\sim}{Q}_A = \frac{\delta\alpha N a\gamma(\alpha+\delta\beta-\alpha\delta\beta)}{\{\gamma\delta+(\delta\alpha N+N\beta(1-\alpha))(\alpha+\delta\beta-\alpha\delta\beta)\}[\gamma+(1-\alpha)(1-\beta)]-N(1-\alpha)(1-\beta)(\alpha+\delta\beta-\alpha\delta\beta)(\alpha\delta+\beta(1-\alpha))}$$

Solving for the aggregate abatement $\underset{\sim}{Q}$ is found from $\underset{\sim}{Q} = \underset{\sim}{Q}_A + \underset{\sim}{Q}_1 + \underset{\sim}{Q}_2$

$$\text{17.} \quad \underset{\sim}{Q} = \left\langle \frac{\alpha\delta+\beta(1-\alpha)}{\alpha\delta} \right\rangle \underset{\sim}{Q}_A + \frac{a(1-\alpha)(1-\beta)}{\gamma+(1-\alpha)(1-\beta)} - \left\langle \frac{(1-\alpha)(1-\beta)[\alpha\delta+\beta(1-\alpha]}{\alpha\delta \big/ \gamma+(1-\alpha)(1-\beta)} \right\rangle \underset{\sim}{Q}_A$$

Substituting in the solution for $\underset{\sim}{Q}_A$ found above solves $\underset{\sim}{Q}$. The numerical evaluations of $\underset{\sim}{Q}$ provided in Chapte 5 are calculated with the use of a computer.

Stage 3: Developed Countries and β Developing Countries Cooperate

The solutions to Stage 3 are the same as those found for Stage 2. In Stage 2 where only developed countries cooperate, this was equivalent to having β developing countries also cooperating where β=0. Hence the numerical evaluations provided in Chapter 5 are the solutions to Stage 2 with the values for β ranging from 5% to 95% with increments of 5%.

Stage 4 Total Cooperation

In Stage 4 it is assumed all developed and developing countries cooperate to deliver the socially optimal level o GHG abatement. Stage 4 is also equivalent to the solutions for Stage 2 and having β=100%. However, it is also possible to arrive at equivalent results from the following.

Consider equations 1 and 2. In the socially optimal case, each country will select the level of abatement that maximizes the collective net benefits. The following represents the collective net benefits of the developed and developing countries.

18. $$\sum NB = b(\alpha + \delta - \alpha\delta)(aQ - \frac{Q^2}{2}) - \sum_{i=1}^{\alpha N} \frac{cq_{Ai}^2}{2} - \sum_{j=1}^{(1-\alpha)N} \frac{\delta c q_{Aj}^2}{2}$$

Each developed countries will abate according to:

19. $$\frac{\partial \sum NB}{\partial q_{Ai}} = b(\alpha + \delta - \alpha\delta)(a - Q_A - Q_{NA}) - cq_A = 0$$

Each developing country will abate according to:

20. $$\frac{\partial \sum NB}{\partial q_{NAi}} = b(\alpha + \delta - \alpha\delta)(a - Q_A - Q_{NA}) - \delta c q_{NAi} = 0$$

Taking statement 19, dividing through by b, setting $\gamma = \frac{c}{b}$, and multiplying both sides by the number of developed countries yields the developed countries reaction function:

21. $$Q_A = \frac{\alpha N(\alpha + \delta - \alpha\delta)(a - Q_{NA})}{\gamma + \alpha N(\alpha + \delta - \alpha\delta)}$$

Doing the same for statement 20 yields the developing countries reaction function:

22. $$Q_{NA} = \frac{(1-\alpha)N(\alpha+\delta-\alpha\delta)(a-Q_A)}{\gamma\delta+N(1-\alpha)(\alpha+\delta-\alpha\delta)}$$

As $\alpha Nq_A = Q_A$ and from 19 and 20, $q_A = \delta q_{NA}$, then it is possible to write

23. $$\alpha N\delta q_{NA} = Q_A$$ 24. $$(1-\alpha)N\frac{q_{Ai}}{\delta} = Q_{NA}$$

Substituting 24 into 21 yields the socially optimal level of abatement for the developed countries, Q_A^c:

25. $$Q_A^c = \frac{\alpha Na\delta(\alpha+\delta-\alpha\delta)}{\gamma\delta+(\alpha N\delta+N-\alpha N)(\alpha+\delta-\alpha\delta)}$$

Substituting 25 into 22 yields the socially optimal level of abatement for the developing countries, Q_{NA}^c:

26. $$Q_{NA}^c = \frac{aN(1-\alpha)(\alpha+\delta-\alpha\delta)}{\gamma\delta+(\alpha N\delta+N-\alpha N)(\alpha+\delta-\alpha\delta)}$$

Thus the socially optimal aggregate abatement $Q^c = Q_A^c + Q_{NA}^c$ becomes:

27. $$Q^c = \frac{(\alpha+\delta-\alpha\delta)(aN\alpha\delta+aN(1-\alpha))}{\gamma\delta+(\alpha+\delta-\alpha\delta)(\alpha\delta N+N-\alpha N)}$$

Solving for Qmax

The maximum allocation (q_{NA1}^{max})of the Q_{stage3}^c a cooperating developing country is willing to undertake is determined by the following equation:

$$NB_{stage2}^{NA1} = \delta(1-\alpha)\beta b(aQ-\frac{Q^2}{2}) - \frac{(1-\alpha)N\beta\delta c q_{NA1}^{max^2}}{2}$$

The maximum allocation $q_{NA1}^{\max}$, will leave the cooperating developing country at the same level of net benefits a stage 2, where they would be were they not to cooperate. Substituting in the necessary values will determine tl solution $q_{NA1}^{\max}$. Solving for the maximum allocation for a developed country is done in the same manner. The maximum allocation ($q_A^{\max}$) of the cooperative outcome (Q_{stage3}^c) a cooperating developed country is willing to undertake is determined by the following equation:

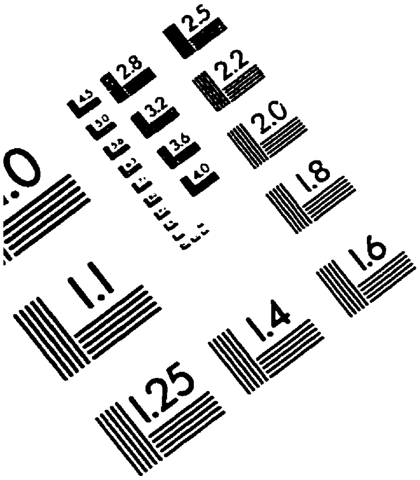
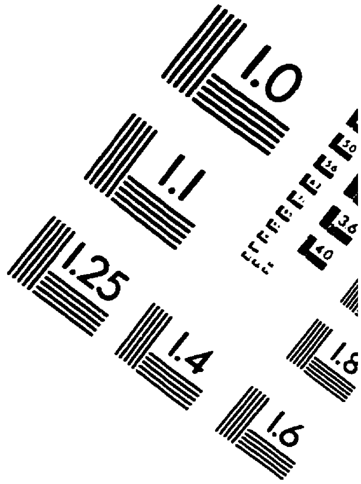
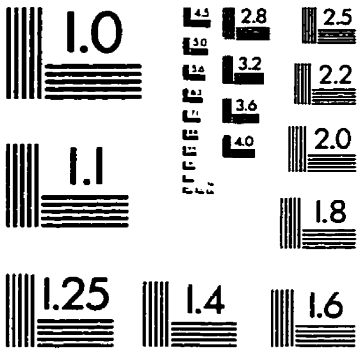
$$NB_{stage2}^A = \alpha b(aQ - \frac{Q^2}{2}) - \frac{\alpha N c {q_A^{\max}}^2}{2}$$

Substituting into the equation the assumed parameter values and necessary calculated variable yields $q_A^{\max}$. Given that the cooperating countries assume the non-cooperating countries' abatement levels as given, there is no possible reallocation of the abatement attributable to the non-cooperating developing countries. Thus the maximum abatement the three group of countries are willing to undertake is represented by the following calculation.

$$Q_{stage3}^{\max} = \alpha N q_A^{\max} + (1-\alpha)\beta N q_{NA1}^{\max} + Q_{stage3NA2}^c$$

Since $Q_{stage3}^{\max}$ exceeds Q_{stage3}^c, JI are not necessary to negotiate Q_{stage3}^c as there exists an allocation of Q_{stage3}^c which leaves no country worse off than were they not to cooperate. However, there must be reallocation of the cooperative solution such as to require the developed countries to undertake greater levels of abatement.

TEST TARGET (QA-3)

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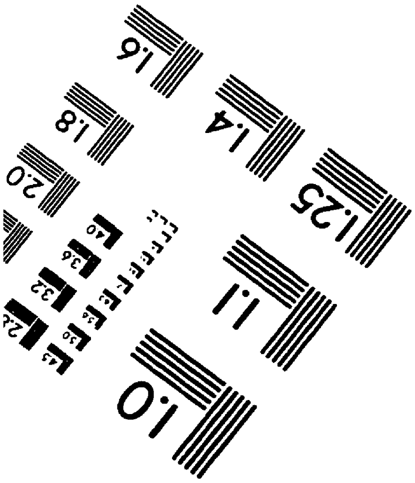
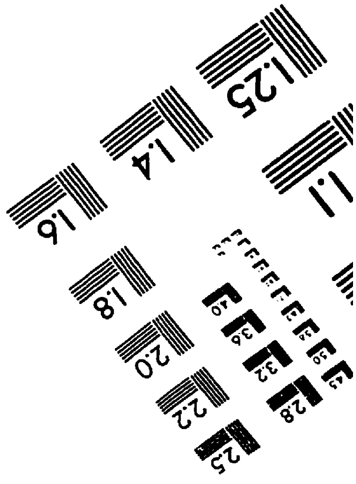

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