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Is the Kyoto Protocol Good for the Environment?

A General Equilibrium Consideration of Global Carbon Leakage

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled " Is the Kyoto Protocol Good for the Environment? A General Equilibrium Consideration of Global Carbon Leakage " submitted by Rochelle Pancoast in partial fulfilment of the requirements of the degree of Masters of Arts.

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Abstract

This paper explores the possibility of global carbon leakage under the Kyoto Protocol on climate change despite international political efforts to curb emissions. The paper formulates a two-country (developed North and developing South), two-input (emissions and labour), two-sector (clean and dirty) general equilibrium model to investigate: (1) the impact of tightening a Northern emissions constraint in the presence of an unconstrained South; and (2) the effect of allowing the South to introduce emission credits. The paper demonstrates that: (1) When less than 100% of the world faces an emissions constraint, carbon leakage contributes to a net increase in global emissions; and (2) Allowing the unconstrained South to generate and sell credits for use by the constrained North has an incrementally ambiguous carbon leakage effect. These results suggest that the Kyoto Protocol may generate a perverse environmental result, which is contrary to the intent of its drafters.

Acknowledgements

Several individuals have contributed, both directly and indirectly, to the successful completion of this thesis. While words cannot appropriately express the gratitude I feel and the praise that is deserved for these individuals, I hope that the longevity of this document will serve as a partial testament.

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Thank you, each and every one of you!

Dedication

To my loving parents,

To my loving husband,

for inspiring me to soar above the clouds.

Table of Contents

List of Tables

List of Figures

List of Symbols

α	Scale parameter; $\alpha > 1$
$a_{\ell 2}^{k}$	Amount of labour per unit of output for good 2 (clean good) in country k (if applicable)
AC_i^k	Average cost per unit of output for good i in country k (if applicable)
b	Slope parameter within the $f(\cdot)$ function
BEC_i^k	Break-even condition/curve for firms producing good i in country k (if applicable)
C_i^k	Cost function for producing good i, in country k
Δ	Determinant for the applicable matrix
D	Determinant for the applicable matrix
$D(p_i)$	World demand for good i, as a function of price for good i
ε_1^d	Elasticity of demand for the dirty good with respect to the price of the dirty good
e^k	Emissions associated with production of the dirty good, for country k (if applicable)
$\bar{e}^s$	Business as usual (or baseline) emissions level for the South, prior to the introduction of credits
E^k	Level of national emissions actually released by all firms in country k, if applicable; $k = W$ represents world, or combined North and South, actual emissions
$\overline{E}$	Government-imposed national emissions constraint; one-country scenario

$\overline{E}^N$	Government-imposed national emissions constraint for firms in the North
EE	Emissions Equilibrium
$f(\cdot)$	Function within the production function
γ	Scale parameter within a modified Cobb-Douglas production function
GME	Goods Market Equilibrium
$h(\cdot)$	Input price function
i	Generic subscript attached to a variable or parameter to represent the applicable good; $i = 1, 2$
k	Generic superscript attached to a variable or parameter to represent the applicable country; $k = \text{N, S}$
ℓ_i^k	Labour associated with the production of good i, in country k (if applicable)
λ	Parameter to allow for full or partial introduction of credits; $0 \geq \lambda \geq 1$, $\lambda = 0$ represents no credits, $\lambda = 1$ represents full credits, $0 > \lambda > 1$ represents partial introduction of credits
η_1^N	Elasticity of Northern emissions with respect to the price of Northern emissions
n_i^k	Number of firms producing good i, in country k (if applicable)
N	North Country (may or may not be used in superscript form on a variable or parameter)
ϕ^k	Quasi-fixed cost parameter that allows for initial increasing returns to scale in the production function before imposing decreasing returns to scale, in country k (if applicable)
p_i	World price for good i

$\hat{p}_1$	World price for good 1 as determined by the Southern dirty good sector in the permit-only 2-country model
π_i^k	Firm-level profits for firms producing good i in country k (if applicable)
σ_1^N	Northern share of the dirty good market
S	South Country (may or may not be used in superscript form on a variable or parameter)
τ^k	Price of emissions in country k (if applicable)
$\hat{\tau}^N$	Price of Northern emissions as jointly determined by the North and South dirty good sectors in the permit-only, 2-country model
v^k	Variable cost parameter within the production function, in country k (if applicable)
w^k	Price of labour in country k (if applicable)
W	Superscript to denote world (or N + S)
y_1^k	Dirty good produced in country k (if applicable)
$\tilde{y}_1^k$	Dirty good minimum efficient scale of output at the firm level in country k (if applicable)
y_2^k	Clean good produced in country k (if applicable)

Chapter 1: Introduction

In an effort to address the global concern of anthropogenically enhanced global warming, heads of state have negotiated and agreed upon the Kyoto Protocol, an international agreement that prescribes emissions constraints and related climate change responsibilities across nations of the world. The international agreement, however, remains especially controversial, for scientific, political, economic and social reasons. While the fundamental objective of the agreement is reducing the atmospheric concentration of greenhouse gases, the debate is often centered on economic and political considerations. Few observers have questioned the agreement's overall merits of being a first step towards improving the environment. This paper attempts to provide economic rationale for why such perceived merits should be questioned, or in the very least, approached very cautiously.

Chapter 2 introduces the science behind the issue, including key related phenomena such as the greenhouse effect, global warming and climate change. It establishes the issue as whether or not human activity is altering the natural climate cycles of earth. Since historic scientific evidence is difficult to interpret, the issue is not easily resolved. Accordingly, the chapter proceeds by discussing the findings and conclusions of the Intergovernmental Panel on Climate Change, the United Nations – declared scientific authority on the issue of climate change and global warming. The chapter concludes by suggesting that sufficient evidence of anthropogenically induced climate change exists to warrant action by all nations.

Chapter 3 establishes the political context behind the contentious Kyoto Protocol, which at the time of writing this thesis has not yet entered into force. It explores the history of international political negotiations and agreements, with a particular focus on the United Nations Framework Convention on Climate Change and the Kyoto Protocol. Each of these agreements were drafted and designed with a core objective of reducing atmospheric greenhouse gases while also recognizing the socio-economic disadvantage of the lesser-developed nations. Key flexible mechanisms built into the Kyoto Protocol play a significant role in how the costs and benefits of mitigating climate change are to be disbursed across all the nations. In particular the developed nations are charged with a greater responsibility for action while the lesser-developed nations are offered sustainable development opportunities with the assistance of developed nations. Finally, the chapter considers case studies of national approaches to the climate change issue, in an effort to highlight the varied positions and responses to this very unsettled subject. Additional context behind national conditions with respect to national climate, industrial influences, vulnerability to climate change, adaptability, and other climate change factors is provided in Appendix 1 following the main thesis.

Chapter 4 follows the political context provided in chapter 3 by introducing general economic issues as they relate to climate change. It surveys some of the important economic literature and assesses the basic themes that have emerged to date. In particular, the chapter discusses climate change as a tragedy of the commons that requires coordinated action by national governments. This, however, introduces further issues including enforceability, international trade implications, etc. The chapter explores in greater detail related transboundary pollution literature and market-based solutions such as permit trading. Importantly, however, the chapter concludes by noting that while much empirical and computational-model based literature has surfaced over recent months, less work has been done on theoretical models relating to climate change, apart from leading studies by Copeland and Taylor.

Accordingly, the remainder of the thesis focuses on economic theory behind climate change, and the environmental objectives of the Kyoto Protocol. Chapter 5 introduces the intuitive foundation behind the mathematical modeling that is outlined in Chapter 6 and supplemented with Appendix 2. Both of chapters 5 and 6 introduce a general equilibrium framework in which a simplified version of the Kyoto Protocol is considered on the basis of its environmental merits. Firstly, a one-country-world model is introduced as a useful comparator against the two-country models, which are intended to reflect important facets of the Kyoto Protocol. In the one-country-world, a dirty industry and a clean industry exist, and the government succeeds in reducing its emissions when it places an emissions constraint on the dirty good industry. In the two-country world, however, in which only the North is emissions-constrained and the South is not (comparable to the Kyoto Protocol), when the North adopts an emissions constraint, the result is a net increase in global emissions. It is unambiguous that overall carbon leakage results under this model; the two-country world fails to reduce global emissions and instead increases global emissions! A final model is considered, in which Southern generated credits are introduced to the earlier two-country model. Credits in this final model are available for use by the constrained North to offset any Northern emissions that exceed the Northern cap. This model suggests that it is ambiguous whether or not further carbon leakage occurs with the introduction of credits. The relative magnitudes of various drivers, however, offer conditions under which it is more or less likely that carbon leakage will be present. Nevertheless, the ambiguity of the model suggests that the Kyoto Protocol and its related flexible mechanisms, such as the Clean Development Mechanism, may or may not be of assistance in achieving its environmental objective of reducing atmospheric greenhouse gases. Observers of the Kyoto Protocol have not considered this possibility – the usual concern is whether or not the Kyoto Protocol does enough, *not* whether or not it will reduce emissions!

The final chapter, Chapter 7, closes by providing a summary of the key topics in the paper. Further, the chapter includes concluding remarks pertinent to further work in this topic, political considerations moving forward, and factors that must be considered when attempting to interpret this model against "real-world" settings.

Chapter 2: Climate Change -- The Global Scientific Debate

2.1 Introduction

Prominent international scientists continue to debate the reality of anthropogenic induced climate change; this important debate has climaxed over recent years, forcing nations of the world to acknowledge the issue. Nevertheless, the diversified political, social and economic positions of each of the world's nations have engendered equally diversified political positions on the climate change issue. The United States led by President George W. Bush, for instance, has continued to question the balance of facts and has opted not to introduce aggressive action to mitigate climate change. On the other hand, while most remaining nations differ on details of scientific research regarding climate change, they have agreed that sufficient evidence has culminated to suggest that future generations are threatened by amplified climate change and, accordingly, prompt action by all nations is warranted.

To understand the scientific basis behind this increasingly political debate, this chapter will introduce key scientific concepts such as the greenhouse effect, global warming, and climate change; in doing so, the chapter will infer how scientific evidence has spurred such an internationally important debate. Subsequently, the chapter proceeds by highlighting the findings and conclusions expressed by the Intergovernmental Panel on Climate Change. These latter conclusions are especially important since this body is the de facto authoritative voice for international scientists in this debate, and accordingly, holds tremendous influence over the many nations of the world. North American case studies of national climate change history, projections and vulnerabilities may be found in Appendix I.

2.2 The Greenhouse Effect and Global Warming

Global warming is possible through the existence of the greenhouse effect. Without this phenomenon, the earth would be too cold for human existence. However, the current issue, more accurately described as climate change, is the extent to which human actions may be reinforcing this natural process to create an enhanced greenhouse effect such that the earth experiences unprecedented accelerated warming.

As illustrated in Figure 2.1, the greenhouse effect is a naturally occurring process whereby solar radiation enters the earth's atmosphere and is partially trapped by heat absorbing gases to provide an important insulating layer over the earth.[1] Without the presence of such an insulating layer, average surface temperatures would be minus eighteen degrees Celsius compared to the comfortable average of fifteen degrees Celsius that sustains life, as we know it.[2]

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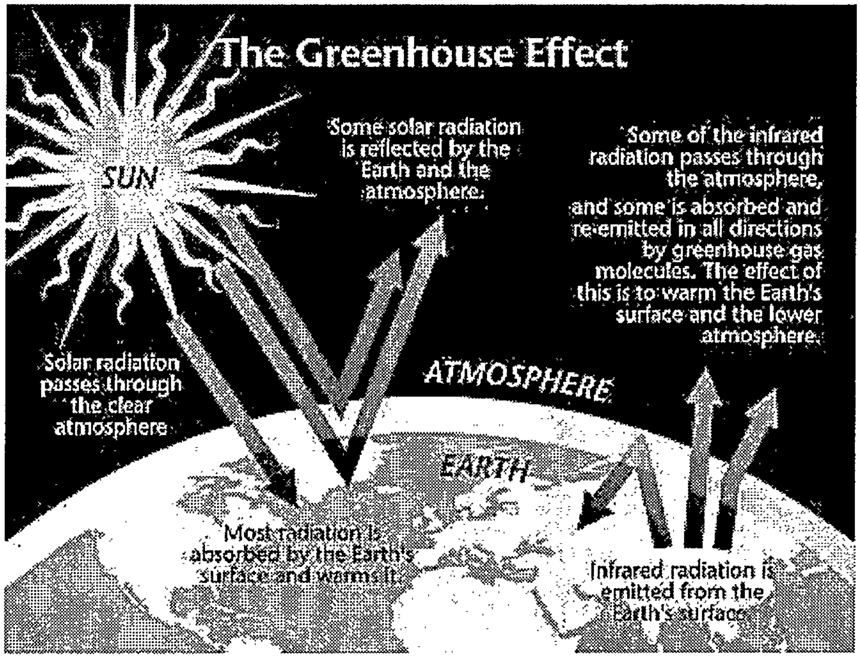
[1] Blaine, Thomas W. "Global Climate Change" 1996. Ohio State University Extension Fact Sheet (CDFS-186-96) http://ohioline.osu.edu/cd-fact/0186.html p. 1

[2] Union of Concerned Scientists "Frequently Asked Questions about Global Warming", 2001 http://www.ucsusa.org/warming

Figure 2.1: The Greenhouse Effect[3]



The gases that enable this warming are referred to as greenhouse gases (GHGs); naturally occurring GHGs include water vapour, carbon dioxide, methane, nitrous oxide, and ozone. In addition to these gases, chlorofluorocarbons and their substitutes are man-made GHGs that also contribute to the greenhouse effect.[4] Because each of these gases vary by atmospheric lifetime as well as their direct warming potential, they have been ascribed a global warming potential (GWP) value measured over a 100 year period to allow for meaningful comparison between the gases.[5] In particular, carbon dioxide has a base unit of one, against which the other GHGs are measured. The GHGs and their

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[3] Graphic from the Union of Concerned Scientists http://www.ucsusa.org/warming
[4] Union of Concerned Scientists "The Science of Global Warming", 2001 http://www.ucsusa.org/warming
[5] Nordhaus, William D. "Economic Approaches to Greenhouse Warming," *Global Warming: Economic Policy Approaches* edited by RD Dornbush and JM Poterba, 33-68. Cambridge, MA: MIT Press 1991.

relative GWPs are listed in Table 2.1[6]; the higher the relative GWP, the greater the gas's contribution to the warming in the greenhouse effect.

[6] Some Global Warming Potential (GWP) values are under scientific discussion and may be reassessed by the Intergovernmental Panel on Climate Change. For instance, some scientific bodies have recommended to increase the GWP for methane to 23 rather than the GWP of 21 that it was originally assigned.

Table 2.1: Global Warming Potential of Greenhouse Gases [7]

Gas	Lifetime (years)	Global Warming Potential (GWP) time horizon in years		
		20 yrs	100 yrs	500 yrs
Carbon dioxide CO_2		1	1	1
Methane CH_4	12.0	62	23	7
Nitrous oxide N_2O	114	275	296	156
Hydrofluorocarbons				
HFC-23 CHF_3	260	9400	12000	10000
HFC-32 CH_2	5.0	1800	550	170
HFC-41 CH_3F	2.6	330	97	30
HFC-125 CHF_2CF_3	29	5900	3400	1100
HFC-134 CHF_2CHF_2	9.6	3200	1100	330
HFC-134a CH_2FCF_3	13.8	3300	1300	400
HFC-143 CHF_2CH_2F	3.4	1100	330	100
HFC-143a CF_3CH_3	52	5500	4300	1600
HFC-152 CH_2FCH_2	0.5	140	43	13
HFC-152a CH_3CHF_2	1.4	410	120	37
HFC-161 CH_3CH_2	0.3	40	12	4
HFC-227ea CF_3CHFCF_3	33	5600	3500	1100
HFC-236cb $CH_2FCF_2CF_3$	13.2	3300	1300	390
HFC-236ea CHF_2CHFCF_3	10	3600	1200	390
HFC-236fa $CF_3CH_2CF_3$	220	7500	9400	7100
HFC-245ca $CH_2FCF_2CHF_2$	5.9	2100	640	200
HFC-245fa $CHF_2CH_2CF_3$	7.2	3000	950	300
HFC-365mfc $CF_3CH_2CF_2CH_3$	9.9	2600	890	280
HFC-43-10mee $CF_3CHFCHFCF_2CF_3$	15	3700	1500	470
Fully fluorinated species				
Sulphur Hexafluoride SF_6	3200	15100	22200	32400
Perfluoromethane CF_4	50000	3900	5700	8900
Perfluoroethane C_2F_6	10000	8000	11900	18000
Perfluoropropane C_3F_8	2600	5900	8600	12400
Perfluorobutane C_4F_{10}	2600	5900	8600	12400
Perfluorocylcobutane c-$C4F_8$	3200	6800	10000	14500
Perfluoropentane C_5F_{12}	4100	6000	8900	13200
Perfluorohexane C_6F_{14}	3200	6100	9000	13200
Ethers and Halogenated Ethers				
CH_3OCH_3	0.015	1	1	<<1
HFE-125 CF_3OCHF_2	150	12900	14900	9200
HFE-134 CHF_2OCHF_2	26.2	10500	6100	2000
HFE-143a CH_3OCF_3	4.4	2500	750	230
HCFE-235da2 $CF_3CHClOCHF_2$	2.6	1100	340	110
HFE-245fa2 $CF_3CH_2OCHF_2$	4.4	1900	570	180
HFE-254cb2 $CHF_2CF_2OCH_3$	0.22	99	30	9
HFE-7100 $C_4F_9OCH_3$	5.0	1300	390	120
HFE-7200 $C_4F_9OC_2H_5$	0.77	190	55	17
H-Galden 1040x $CHF_2OCF_2OC_2F_4OCHF_2$	6.3	5900	1800	560
HG-10 $CHF_2OCF_2OCHF_2$	12.1	7500	2700	850
HG-01 $CHF_2OCF_2CF_2OCHF_2$	6.2	4700	1500	450

[7] "Technical Summary – A Report Accepted by Working Group I of the International Panel on Climate Change but not approved in detail" from *Climate Change 2001 – The Scientific Basis,* Contribution of Working Group I to the *Third Assessment Report of the International* Panel *on Climate Change* edited by JT Houghton, Y Ding, DJ Griggs, M Noguer, PJ van der Lindon, and D Xiaosu. Cambridge University, UK 2001

French scientist Jean Baptiste Fourier first described the greenhouse effect in 1824. In 1896, Swedish scientist Svante Arrhenius introduced the possibility of an *enhanced* greenhouse effect arising from the increased concentration of atmospheric GHGs due to increased burning of coal.[8] Fossil fuel combustion (such as the burning of coal or gas), as well as changing practices in agricultural management, are examples of human activities believed to have directly contributed to the increased atmospheric GHG concentrations evident today. Pre-industrial concentrations of carbon dioxide, for instance, were 280 parts per million volume (ppmv) in 1860 compared to 354 ppmv as measured in 1990;[9] this increase in atmospheric concentration may be of great consequence since, while not proving causation, historical data confirm a correlation between atmospheric GHG concentration and temperature fluctuations.[10] Further, it is important to recognize that the long lives of the GHGs compound the potential problem of increasing GHG concentrations because, for our purposes, these gases exemplify stock pollutants and only major reductions in emission levels will prevent further increases in atmospheric accumulation.[11]

Scientists have little ground to dispute the clear warming trend that has continued over the last two hundred (and even one thousand) years; rather, the true debate, which has been the focus of climate change scientists and the international community over the last few decades, is the extent to which this enhanced greenhouse effect may interrupt the

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[8] Harris, Jonathan and Codur, Anne-Marie "The Economics of Climate Change" *Environmental and Natural Resource Economics: A Contemporary Approach*, Houghton-Mifflin, forthcoming. p.2

[9] Sohngen, Brent, "Climate Change: Science, Policy, and Economics" 1998. Ohio State University Extension Fact Sheet (AE-3-98) http://ohioline.osu.edu/ae-fact/0003.html p.1

[10] Hahn, Robert W., *The Economics of Climate Change*, Washington D.C., AEI Press, 1998, p. 4

[11] Harris and Codur, forthcoming p. 1

natural climate change cycle, and more specifically, what the scale and timing of any resulting effects may be.

2.3 Climate Change

The United Nations Framework Convention on Climate Change, for its purposes in referring to this current global issue, has defined climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."[12] This definition clearly identifies the debate as the marginal impact of human activities on climate change beyond the variation that exists in the natural cycle. It is useful to note that while the current warming trend may be described as global warming, climate change is a broader descriptor that more appropriately includes the variety of effects that the world is expected to experience: warming in some areas, cooling in others, and likely increased variability in our climate.

It may be surprising for those less familiar with this climate change issue to learn that the earth has been exposed to natural climate change cycles for millions of years – climate change is in fact nothing new. For instance, two extreme cases of peaks and troughs in the cycle include the dinosaur era 100 million years ago when the earth was about ten degrees Celsius warmer, and the most recent ice-age which ended about 10,000

[12] United Nations Framework Convention on Climate Change, Article 1; http://unfccc.int/resource/conv/conv_003.html

years ago when the earth was about six degrees Celsius cooler.[13] The regular climate cycle exhibits distinct ice-age and interglacial intervals with a typical temperature variation of a mere twelve degrees Celsius. Considering the main cooling period occurs over 80,000 years, we would not expect the warming trend experienced over the last century to cause such alarm[14]. Most evidence suggests that we may simply be at the crest of one of these main interglacial periods; however, projections of increased atmospheric GHG concentrations, partially attributable to anthropogenic activity, suggests that further warming will occur at an accelerated rate that is unprecedented in such a short time period. It is this distinctive revelation that has caused alarm for some groups in the international community.

Nevertheless, given all these complexities plus the uncertainty present when trying to project future climate patterns, it is understandable that unanimous scientific agreement is currently untenable. The Intergovernmental Panel on Climate Change, however, has offered a consensus of leading climate change scientists that is difficult to dispute.

2.4 Intergovernmental Panel on Climate Change (IPCC)

The United Nations Environment Programme and the World Meteorological Organization established the IPCC in 1988 to unite leading scientists to survey the latest scientific and technical climate change literature. Three working groups compose the

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[13] Blaine, Thomas W. 1996 p. 2

[14] Muller, Benito "The Global Climate Change Regime: Taking Stock and Looking Ahead", forthcoming in the *Yearbook of International Co-Operation on Environment and Development*, London: Earthscan, forthcoming August 2002 p. 2 http://www.wolfson.ox.ac.uk/~mueller

IPCC: Working Group I – Science of Climate Change; Working Group II – Impacts and Vulnerability & Adaptation; and Working Group III – Mitigation. Since its creation, the IPCC has released three reports, with the first in 1990 (FAR), the second in 1995 (SAR) and the most recent in 2001 (TAR).[15] The *Third Assessment Report of the IPCC - Climate Change 2001* encompasses three volumes, each representing the individual reports from each of the Working Groups.[16] Given the technical nature of this report, information will be drawn from the scientific summary prepared for policymakers, herein referred to as SPM.[17]

The 1990, 1995, and 2001 assessment reports have gained global attention given the vast number of prestigious scientists involved in the creation of the reports. For instance, on the most recent report, 122 coordinating lead authors and lead authors, 515 contributing authors, 21 review editors and 337 expert reviewers all worked to ensure the accurateness of the report (SPM p. 2). Each of the report's conclusions have inspired and driven further political efforts at the global level. The global community took notice, for instance, when the SAR concluded, "the balance of evidence suggests a discernible human influence on global climate."[18] The most recent report galvanized the attention of the international community by stating that "there is new and stronger evidence that most

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[15] UNFCCC website http://unfccc.int/resource/process/components/institution/ipcc.html

[16] IPCC, *Third Assessment Report of the International Panel on Climate Change – Climate Change 2001*, including the contribution from Working Group I *Climate Change 2001 – The Scientific Basis*, the contribution from Working Group II *Climate Change 2001 - Impacts, Adaptation & Vulnerability*, and the contribution from Working Group III *Climate Change 2001 – Mitigation*, Cambridge University Press, UK 2001.

[17] "Summary for Policy Makers – A Report of Working Group I of the International Panel on Climate Change" from *Climate Change 2001 – The Scientific Basis*, Contribution of Working Group I to the *Third Assessment Report of the International Panel on Climate Change* edited by JT Houghton, Y Ding, DJ Griggs, M Noguer, PJ van der Lindon, and D Xiaosu. Cambridge University, UK 2001

[18] UNFCCC website http://unfccc.int/resource/process/components/institution/ipcc.html

of the warming observed over the last 50 years is attributable to human activities" and that this warming equated to approximately 0.6 degrees Celsius (SPM p. 10). The TAR continued their aggressive statements by concluding "globally averaged surface temperature is projected to increase by 1.4 – 5.8 degrees Celsius over the period 1990-2100" (SPM p. 13). Considering the normal twelve-degree fluctuation range occurs over an entire cycle, these relatively short-term projections are truly significant.

In particular, the TAR comprehensively documented both the historic evidence and future projections of climate change. Noticeable effects of warming experienced to date, for instance, include the rise of the global sea level by 0.1-0.2 meters over this past century, and the increase of the ocean heat content since the late 1950s. In addition, satellite data has revealed that there has been a "very likely"[19] 10% decrease in the extent of snow cover globally since the 1960s, along with widespread retreat of mountain glaciers located in the non-polar regions (SPM p. 4).

The authors were also careful to note, however, that evidence of warming has not been found in the southern hemispheric oceans and parts of Antarctica. Also, scientists have not found a systematic change in the frequency of tornadoes, thunder days or hail events, tropical nor extra-tropical storms (SPM p. 5).

Quantifiable indicators also revealed apparent trends in our past climate and underlying atmospheric composition of greenhouse gases. Since 1750, for example, the atmospheric concentration of carbon dioxide has increased by 31%. Indeed, the present

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[19] The TAR has used specific language to denote judgmental confidence levels: *virtually certain*: 99%+ chance that the result is true, *very likely*: 90<99%, *likely*: 66<90%, *medium likelihood*: 33<66%, *unlikely* 10<33%, *very unlikely*: 1<10%, *exceptionally unlikely*: <1%.

concentration has been unsurpassed during the last 420,000 years, and this is *likely* true for the past twenty million years. Furthermore, the current rate of increase in atmospheric concentration has been unparalleled in at least the past 20,000 years (SPM p. 7). These statistics in themselves are somewhat startling, but the IPCC has added that "in light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last fifty years is *likely* to have been due to the increase in GHG concentrations" (SPM p. 10) in which carbon dioxide emissions from burning fossil fuel are *virtually certain* to have been the principal factor (SPM p. 12). These conclusions are bold scientific interpretations that dare to be challenged.

Furthermore, future projections are equally pessimistic. For instance, carbon cycle models have estimated year 2100 atmospheric concentration of carbon dioxide concentrations to be 90-250% above those in 1750 (SPM p. 12). Moreover, the TAR suggests that warming attributable strictly to anthropogenic contributions is *likely* to be between 0.1 and 0.2 degrees Celsius per decade over the next few decades (SPM p. 13). These projections imply that the global sea level will rise between 0.09 and 0.88 meters from 1990 to 2100, and both glaciers and ice-caps will continue their extensive retreat (SPM p. 16). What is worse, however, is that the surface temperature and sea level increases are projected to continue for hundreds of years after stabilization of atmospheric GHG concentration is achieved (SPM p. 17).

Unsurprisingly, and as the IPCC noted, the impacts of climate change are expected to affect different regions in unique ways. In Africa, for instance, grain yield is expected to decrease, infectious diseases are likely to be more extensive, desertification will be aggravated, and there will likely be an increase in droughts, floods and other extreme events, just to name a few (SPM p. 14). On the other hand, Europe anticipates dissipation of half of the alpine glaciers and large permafrost areas by 2100, summer run off, water availability and soil moisture are likely to decrease, and there is high probability that loss of habitat will endanger some species (SPM p. 15). The vulnerability of the two regions vary significantly, both given the level and type of impact they each face as well as their individual ability to adapt and respond to the particular impacts they face. The impacts of climate change are sure to disproportionately affect the poor given their limited resources to adapt as may be required.

The differing regional vulnerabilities have played a large role in the political debate regarding climate change; this is a debate that is far from resolution. On the other hand, the IPCC has authoritatively cleared confusion on the underlying scientific debate; industrialized nations have played a large role in increasing atmospheric carbon dioxide concentrations and all nations will be exposed to the future climate change implications.

2.5 Summary

The scientific debate surrounding climate change has focused on whether or not anthropogenic induced climate change exists beyond the natural climate change cycle.

To be certain, greenhouse gases in the atmosphere trap heat to warm the earth to levels tolerable for human existence. We also know that atmospheric GHG concentrations are correlated with temperature fluctuations. Since the Industrial

Revolution, humans have been responsible for significant increases in atmospheric GHG concentrations, primarily from the combustion of fossil fuels and altered farming practices. The current concentration levels are unprecedented in history, as we know it; unfortunately, this trend is anticipated to continue given our current and anticipated emission levels, as well as the long lives of the subject GHGs.

Most troubling, historic evidence has led leading scientists to project further temperature increases, rising sea levels, receding and thinning ice-caps and glaciers, more severe precipitation/drought events, etc. Clearly, the most recent findings and conclusions of the IPCC are difficult to ignore given their serious implications for all land, water and species.

Additionally, given regional and national disparities in terms of their historic contributions to GHG levels, their resources to mitigate further increases, and their ability to adapt, the scientific issue has quickly turned to a political issue. This will be the focus of the next chapter.

Chapter 3: Climate Change -- The Political Response

3.1 Introduction

The Intergovernmental Panel on Climate Change's (IPCC's) increasingly clear messages of confirmed anthropogenic induced climate change, and warnings of the resulting implications, have galvanized the attention of the international community. Nevertheless, even before the IPCC was formed in 1988, the international community had recognized the potential issue and had begun a series of international meetings that resulted in a number of international agreements. The combined success and future impact of these prominent meetings and related agreements, however, remain uncertain.

Notably, the United Nations Framework Convention on Climate Change (UNFCCC or Convention), the Kyoto Protocol and the subsequent Marrakech Accords have been remarkable international achievements that now guide future international climate change action. Each of these agreements iteratively strengthened the call for action to mitigate enhanced climate change.

Nevertheless, not all nations of the world have supported these agreements, either in whole or in part. For instance, while the UNFCCC has been ratified and is in force today, its defined target of stabilizing greenhouse gas (GHG) emissions at 1990 levels among the signatory parties has yet to be achieved. Furthermore, the Kyoto Protocol and the supporting Marrakech Accords, which collectively speak to stronger GHG emission reduction targets against a carefully defined timeline, are currently in danger of not coming into force. Ironically, competing national and regional interests acted to strengthen the support required to reach consensual agreement on the Marrakech Accords, but the continued existence of such factions threatens to unravel the fabric of all international agreements on climate change to date.

3.2 Preliminary International Conferences on Climate Change

Prior to formation of the UNFCCC, there were a series of international meetings relating to the global climate change issue. In 1979, for instance, the First World Climate Conference was a scientific gathering that called upon the world "to foresee and prevent potential man-made changes in climate that might be adverse to the well-being of humanity."[20] This was followed by a number of intergovernmental climate change conferences throughout the 1980s and the early 1990s. Interestingly, however, the United Nations General Assembly did not begin discussions on climate change until 1988.[21] Nevertheless, these conferences and meetings succeeded in advancing international awareness of both scientific and policy issues relating to climate change, with an increasingly tenacious call to action.

After being established two years earlier, in 1990 the IPCC issued its First Assessment Report, which confirmed the scientific evidence of climate change and called for the launch of negotiations on a global climate change agreement.[22] This affirmation

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[20] United Nations Framework Convention on Climate change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact17.html

[21] United Nations Framework Convention on Climate change resources found at the website, http://unfccc.int/resource/process/components/response/landmarks.html

[22] International Panel on Climate Change, *First Assessment Report. 1990* composed of three volumes including (i) "Scientific Assessment of Climate Change – Report of Working Group I, JT Houghton, GJ Jenkins and JJ Ephraums (Eds), Cambridge University Press, UK; (ii) "Impacts Assessment of Climate Change – Report of Working Group II" W.J. Mc G Tegart, G.W. Sheldon, D.C. Griffiths (Eds), Australian Government Publishing Service, Australia; and (iii) The IPCC Response Strategies – Report of Working Group III" Island Press, USA.

of climate change by such a prestigious Panel of international scientists was especially important in setting the stage for subsequent international climate change discussions. The call for action was also reinforced that same year, when the Second World Climate Conference also called for a framework treaty on climate change. Interestingly, included in the Conference's final declaration, were principles that would later be included in Climate Change Convention.[23] By December 1990, the United Nations General Assembly opened negotiations on a framework convention on climate change (the UNFCCC).

3.3 The United Nations Framework Convention on Climate Change – UNFCCC

After only fifteen months from initiating the negotiations, the Intergovernmental Negotiating Committee adopted the Convention in New York on May 9th, 1992, just in time for consideration by heads of state at the Earth Summit in Rio de Janeiro the following month. After waiting the necessary ninety days from receiving the fiftieth instrument of ratification, the Convention came into force on March 21st, 1994.[24]

As stated in Article 2 of the UNFCCC, its core objective is to achieve,

> ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.[25]

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[23] United Nations Framework Convention on Climate Change website "fact sheets" found at, http://unfccc.int/resource/iuckit/fact17.html

[24] United Nations Framework Convention on Climate Change website, http://unfccc.int/resource/process/components/response/respconv.html

[25] *United Nations Framework Convention on Climate Change*, Article 2

To support the stated objective, the Parties to the Convention agreed to key principles including:

- Protection of the environment for the benefit of all present and future generations
- *Equitable* participation, recognizing *differentiated responsibilities* and differentiated capabilities among the various nations; developed countries are charged with taking the lead in mitigating climate change
- It is recognized that *developing countries bear a disproportionate burden* given their particular vulnerability to adverse effects brought about by climate change; full consideration of this is encouraged
- Even in the absence of full scientific certainty, *precautionary measures* should be taken to combat climate change
- Mitigation efforts should be *cost-effective* with socio-economic considerations
- *Sustainable development* is desired including sustainable economic growth[26]

Appropriately, these principles are reflected tonally throughout the Convention.

To reinforce the vision as contemplated by both the objective and principles, the Parties agreed to explicit commitments under Article 4 of the Convention. All Parties, for instance, are individually responsible for publishing and periodically updating their national greenhouse gas inventories, as well as the mitigation and adaptation measures they've implemented. Parties also agreed to promote technology transfer as well as

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[26] *United Nations Framework Convention on Climate Change*, Article 3

sustainable development. Further, Parties are expected to cooperate in scientific and other climate change related research and educational initiatives.[27]

In the spirit of the principle recognizing differentiated responsibilities, the UNFCCC categorizes Parties of the Convention into Annex I and Annex II countries (See Table 3.1). Largely as a result of industrialization, Annex I Parties have historically contributed most to the rising levels of atmospheric GHG concentrations. In addition to the responsibilities outlined in the Convention for all Parties, Annex I Parties are charged with taking the lead on climate change efforts, especially as it pertains to the adoption of national programs and policies. More concretely, either mutually or individually, these nations have the aim of returning their carbon dioxide and other GHG emissions to their 1990 levels by the year 2000[28]. Nevertheless, Parties with Economies In Transition (EIT), are allowed a degree of flexibility in implementing their Annex I commitments[29].

On the other hand, Annex II Parties, largely representing Organization for Economic Cooperation and Development (OECD) nations, have additional responsibilities since they are considered to be the wealthiest of the developed nations. These countries, for instance must contribute new and additional financial resources (over and above their official development assistance funding) to help cover the full costs incurred by developing Parties in their efforts to comply with the Convention. They also

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[27] *United Nations Framework Convention on Climate Change*, Article 4
[28] Most nations were unable to reach this commitment; however, as shown by **Figure 3.1,** nations in the EU were collectively able to achieve this target.
[29] *United Nations Framework Convention on Climate Change*, Article 4

Table 3.1: Annex I and Annex II Countries [30]

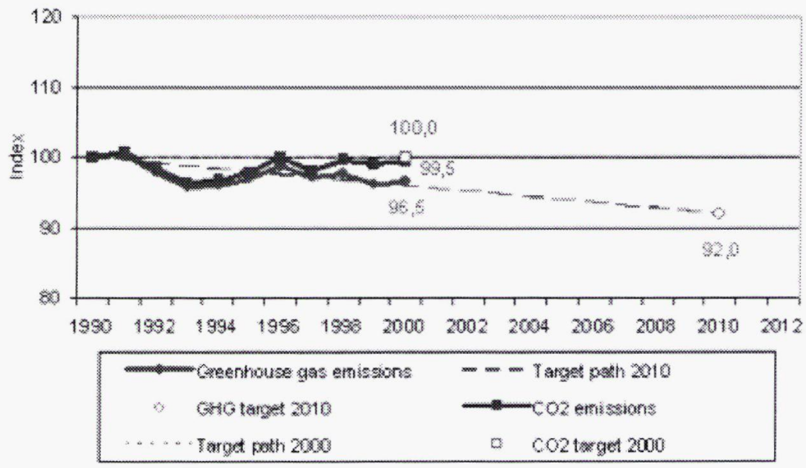
Annex I Countries		
Also *Annex II* nations	**Economies in Transition a/**	**Other**
Australia	Belarus	Croatia*
Austria	Bulgaria	Liechtenstein*
Belgium	Czech Republic*	Monaco*
Canada	Estonia	
Denmark	Hungary	
European Union	Latvia	
Finland	Lithuania	
France	Poland	
Germany	Romania	
Greece	Russian Federation	
Iceland	Slovakia*	
Ireland	Slovenia*	
Italy	Ukraine	
Japan		
Luxembourg		
Netherlands		
New Zealand		
Norway		
Portugal		
Spain		
Sweden		
Switzerland		
Turkey		
United Kingdom of Great Britain and Northern Ireland		
United States of America		

a/ Countries that are undergoing the process of transition to a market economy.

* Countries added to Annex I by an amendment that entered into force on 13 August 1998.

[30] *United Nations Framework Convention on Climate Change*, Annex I and Annex II

Figure 3.1: Total EU greenhouse gas emissions in relation to the Kyoto target[31]



have other responsibilities including the facilitation of climate friendly technology transfer.[32]

The final subset of Parties to the UNFCCC is referred to as the Non-Annex I Parties, and this subset includes all remaining Parties not previously categorized as Annex I or Annex II. Essentially, this group represents the developing nations, and as such, these Parties have fewer accountabilities than the more developed nations; the Non-Annex I countries are expected to provide a fairly general report on their mitigation and adaptation actions, and they are offered flexibility on the timeline in which these reports must be provided.[33]

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[31] European Environmental Agency, "EU reaches CO_2 stabilisation target despite upturn in greenhouse gas emissions", News Release April 29, 2002 (Copenhagen) available at http://org.eea.eu.int/documents/newsreleases/greenhouse_gas_emission

[32] Ibid

[33] United Nations Framework Convention on Climate Change website, http://unfccc.int/resource/process/components/response/respconv.html

Appropriately, the division of the Parties to the Convention in this manner reflects the principles embodied within Annex 2, particularly those aspiring to fairness and equity, as differentiated by historical atmospheric GHG concentration contribution, resource availability and vulnerability to climate change.

3.3.1 Berlin Mandate

The UNFCCC established the Conference of the Parties (COP) as its supreme body, responsible for ensuring the effective implementation of the Convention and its related legal instruments. The COP is composed of the Parties which have ratified the Convention (over 180 nations) and holds annual sessions to review the existing commitments, assess new scientific evidence, evaluate national climate change programs, etc. Also, the COP has the ability to adopt new commitments, amendments and other legal instruments to ensure the effective implementation of the UNFCCC.[34]

The first COP meeting (COP 1) was held in Berlin in 1995, and resulted in the Berlin Mandate, calling for additional commitments beyond the year 2000 in order to achieve the Convention's objective. A subsidiary body, the Ad Hoc Group on the Berlin Mandate, was created to provide a draft protocol or other legal instrument outlining these additional commitments, in time for COP 3 held in Kyoto, Japan in 1997.[35] The second COP (COP 2) was held in Geneva in 1996. Importantly, the Geneva Declaration sanctioned the IPPC's Second Assessment report as the "most comprehensive and

[34] United Nations Framework Convention on Climate change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact18.html

[35] United Nations Framework Convention on Climate change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact17.html

authoritative assessment of climate change, its impacts and response options" lending further support for the recognition of climate change as a serious issue warranting action by all nations.[36]

Just over one year later, the highly anticipated COP 3 was held in Kyoto, Japan in December of 1997. On target, this meeting concluded the Berlin Mandate process with the adoption of the Kyoto Protocol.[37]

3.3.2 The Kyoto Protocol to the UNFCCC

The Kyoto Protocol (KP or Protocol) subsequently opened for signature by Parties on March 16th, 1998 at the United Nations headquarters in New York. The KP will not enter into force until ninety days after it has been ratified, accepted or approved by at least fifty-five Parties to the UNFCCC, including Parties in Annex I representing at least fifty-five percent of the 1990 emissions accountable to Annex I Parties.[38] The full conditions for entry into force have yet to be satisfied.

Not surprisingly, the KP embodies many of the same principles as contemplated by the Convention. The key significance of the Protocol, therefore, is its introduction of new and tighter targets for the period beyond 2000. In particular, the KP establishes a collective commitment for the Annex I Parties to reduce or remove[39] their GHG[40] emissions to at least five percent below the levels that existed in 1990, by the 2008-2012

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[36] United Nations Framework Convention on Climate change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact19.html

[37] United Nations Framework Convention on Climate change resources found at the website, http://unfccc.int/resource/process/components/response/landmarks.html

[38] *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Article 25

[39] The Protocol also allows the use of "sinks", or activities that remove carbon dioxide from the atmosphere, including land use, land use change and forestry activities (soil sequestration from improved farming practices, afforestation, reforestation, etc.)

[40] Recall that GHGs include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

commitment period.[41] The Protocol specifies individual national targets that recognize the differences in current national circumstances relative to the 1990 baseline (see Table 3.2). Each country may retain their individual target, or they may opt to work with others to jointly reach a "bubble" or collective commitment. The European Union, for example, has opted to incorporate the bubble concept and has, accordingly, redistributed its collective target among its fifteen member states within a Burden Sharing Agreement.[42]

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[41] United Nations Framework Convention on Climate change resources found at the website, http://unfccc.int/resource/process/components/response/respkp.html
[42] Ibid

***Table 3.2: Annex B of the Kyoto Protocol -- National Reduction Commitments*[43]**

Party	Quantified emission limitation (percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain & Nothern Ireland	92
United States of America	93

* Countries with economies in transition to a market economy.

[43] *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Annex B

It is important to understand that the commitments, which range from eight percent below to ten percent above the 1990 GHG emission levels, are in most cases, far from trivial. In reality, for most countries, this commitment represents a twenty to thirty percent decrease in emissions relative to a "business as usual" scenario; increases in GHG emissions have historically accompanied economic growth, so the true obligation is not evident by the commitment as stated. On the other hand, for many of the nations with Economies in Transition, these countries have experienced weakened economies, and thus lower GHG emissions, relative to their 1990 baseline. In some cases, this means that their true emissions during the 2008-2012 commitment period are also anticipated to be lower than their 1990 emissions. Since these nations have committed to emission levels above their 1990 emissions, however, they may meet and exceed their commitment without having to make any real emission reductions. Many observers have termed this situation as "hot air"; this likely reality has troubled environmental advocates.

Furthermore, the Protocol requires Parties to negotiate additional GHG emission reduction targets for subsequent five-year commitment periods. For instance, no later than 2005, the same year by which Parties must show demonstrable progress towards their commitments, Parties must consider targets for the next commitment period, 2013-2017.[44] While targets for future commitment periods have yet to be negotiated, it is expected that any remaining hot air from Economies in Transition will disappear under tighter targets. Eventually, it is also expected that Non-Annex I countries will assume

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[44] *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Article 3

absolute or relative targets in future commitment periods[45]. However, involving developing countries in such a direct manner has proven to be a very contentious issue, and may indeed, be the very issue that could make or break the Protocol's entry into force.[46]

To facilitate fulfillment of these already challenging Annex I commitments, the Protocol introduced flexible mechanisms for voluntary use by the Parties. These mechanisms include Emissions Trading (ET), Joint Implementation (JI), and the Clean Development Mechanism (CDM). These mechanisms are intended to help reduce the cost of achieving compliance with each country's target by expanding the reduction opportunities beyond each country's border.

The Emissions Trading mechanism, as described in Article 17 of the KP, functions much like a cap and trade program, and involves only the Annex I Parties. In this case, the "cap" is each country's commitment under the KP, and Assigned Amount Units (AAUs) representing units akin to quotas or allowances are traded between the Annex I Parties. AAUs are defined for the years within the commitment period.[47]

Joint Implementation, as described in Article 6 of the KP, is a program that allows an Annex I Party to receive "credit" or Emission Reduction Units (ERUs) when they invest in an emission reduction project located in another Annex I Party. ERUs can only

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[45] Experts are now attempting to find a politically acceptable metric to bring developing countries under a carbon commitment. For instance, rather than an absolute target, there has been suggestion of a per capita target or another such target under which required reductions will be relatively lower in magnitude than those required by developed nations.

[46] The United States, for instance, has cited the lack of meaningful developing country participation as a core reason for its rejection of the Kyoto Protocol (see section 3.4.1)

[47] *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Article 17

be created during the 2008-2012 commitment period, though the emission reduction projects themselves can be implemented any time after the year 2000.[48]

The Clean Development mechanism, as described in Article 12 of the KP, is similar to the JI program, except it allows an Annex I Party to receive Certified Emission Reductions (CERs) when they invest in an emission reduction project located in a non-Annex I country. In practice with the principles of the Convention and the Protocol, projects eligible for CERs must also exhibit elements of sustainable development acceptable to the host country. As with the JI mechanism, projects can be implemented beginning in the year 2000, but in contrast to the JI mechanism, eligible CERs can accrue for use in the first commitment period with the onset of the project (beginning in the year 2000);[49] this obvious advantage of "bankability" was designed specifically to foster socio-economic improvements within developing countries, in accordance with the principles of sustainable development, differentiated responsibilities of the Parties and in recognition of the disproportionate burden shouldered by the non-Annex I nations.

Of course, there are numerous methods, modalities, and other conditions that must be satisfied prior to official transfer and receipt of any AAUs, ERUs or CERs. Nevertheless, should an Annex I Party qualify for receipt of these instruments, they can adjust their national emissions accounting accordingly. For instance, inclusion of additional AAUs allows for a higher "cap", and inclusion of foreign ERUs and CERs offset actual emissions:

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[48] *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Article 6
[49] *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Article 12

<u>Example</u>
Annex I Party Y commitment = 95% * Party Y GHG emissions (net of removals) in 1990 * 5 (5 years in the commitment period) = C
Party Y's "allowable emissions" or adjusted target = C + acquired AAUs – AAUs sold[50] = T
Party Y's actual emissions (net of removals) in 2008-2012 = A
Party Y's effective emissions in 2008 –2012 = A – foreign CERs earned – foreign ERUs earned = E
Compliance with KP Annex B commitment when T > E
Non-compliance with KP Annex B commitment when T < E

As is typical with agreements such as the KP, strict rules and exceptions apply to the accounting of a country's emissions and removals within its emissions inventory, as well as to the treatment of both the creation and transfer of the above instruments. Nevertheless, for the more general purposes of this thesis, these complications are disregarded.

In addition to agreement on stronger quantifiable emissions targets under the Kyoto Protocol, the Parties also agreed to a means of addressing instances of non-compliance by the Parties. They also accepted stronger reporting obligations.[51]

Nevertheless, although the KP accomplished much in terms of defining the flexible mechanisms and proposing the compliance system, the operational details of these components were incomplete. Also, greater clarity was still required on issues such as the treatment of sinks, reporting and review guidelines, and means for assisting the most vulnerable nations.[52] This "unfinished business" would prove to be the focus of

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[50] AAUs must also be "retired" or converted into ERUs for Joint Implementation projects occurring within the nation's borders. Here, this is considered a component within AAUs that are sold.
[51] United Nations Framework Convention on Climate change resources found at the website, http://unfccc.int/resource/process/components/response/respkp.html
[52] Ibid

subsequent COP sessions, and the negotiations surrounding such matters would prove to alter the political climate change debate.

3.3.3 Buenos Aires Plan of Action

To address the unfinished business of the Kyoto Protocol, the Parties adopted the Buenos Aires Plan of Action at COP 4, in Buenos Aires in 1998; this plan also addressed outstanding implementation issues relating to the Convention. Similar to the timeframe adopted for the Berlin Mandate, COP 6 was set as the negotiating deadline for resolution of the concerns identified in the Buenos Aires Plan of Action.[53] In the interim, COP 5 was held in Bonn from October 25 to November 5th of 1999; this session was relatively uneventful. In contrast, however, COP 6 was unforgettable for those individuals intimately engaged in this issue!

COP 6 was held in The Hague in November of 2000, and after difficult negotiations, the Parties were unable to reach consensus on a balanced package of decisions that would conclude the efforts of the Buenos Aires Plan of Action. This was almost entirely due to the large gap on several issues that the United States (and its allies including Canada, Japan, Australia, New Zealand and others) and the European Union were unable to bridge. For instance, the European Union wanted to place a "supplementarity" cap on the use of the flexible mechanisms, such that actions through the mechanisms could only be supplemental to (in this case, they argued < 50%) the more dominant implementation of domestic emission reduction actions. There was also

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[53] United Nations Framework Convention on Climate change resources found at the website, http://unfccc.int/resource/process/components/response/baaction.html

considerable disagreement around the treatment of sinks, with the European Union wishing to limit their use for compliance purposes, and the United States wanting extensive recognition for sink activities. Somewhat surprisingly, but also recognizing the desperate position they were in, the Parties agreed to an unscheduled COP, which they affectionately termed COP 6 *bis* (others have termed it COP 6 Part 2, and COP 6.5).

To further exacerbate the tenuous position the climate change negotiations were in after the failed COP 6 talks, recently elected President Bush announced his country's rejection of the Kyoto Protocol in March 2001.[54] President Bush could not accept that developing countries did not have an emissions cap, and he refused to subject the United States' economy to a program that he believed was contrary to its best interests. The United States' rejection of the Kyoto Protocol severely constrained the KP's ability to enter into force; since the United States emissions constitute over one third of all those for Annex I Parties, the fifty-five percent emissions representation requirement quickly appeared unachievable even though it remained mathematically possible (refer to Table 3.3).

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[54] Office of the Press Secretary (White House) "Text of a Letter from the President to Senators Hagel, Helms, Craig, and Roberts", March 13, 2001

Table 3.3: Annex I Country 1990 Emissions[55]

Party	1990 Carbon Dioxide Equivalent GHG emissions (Rounded to nearest Gg)	Percentage of Total Annex I Party GHG emissions
United States of America	**4,957,022**	**36.1%**
Russian Federation*	**2,388,720**	**17.4%**
Japan	**1,173,360**	**8.5%**
Canada	**457,441**	**3.3%**
Poland*	**414,930**	**3.0%**
Australia	**288,965**	**2.1%**
European Community	**3,326,423**	**24.2%**
Austria	59,200	0.4%
Belgium	113,405	0.8%
Denmark	52,100	0.4%
Finland	53,900	0.4%
France	366,536	2.7%
Germany	1,012,443	7.4%
Greece	82,100	0.6%
Ireland	30,719	0.2%
Italy	428,941	3.1%
Luxembourg	11,343	0.1%
Netherlands	167,600	1.2%
Portugal	42,148	0.3%
Spain	260,654	1.9%
Sweden	61,256	0.4%
United Kingdom of Great Britain and Northern Ireland	584,078	4.3%
Others	**721,445**	**5.4%**
Bulgaria*	82,990	0.6%
Czech Republic*	169,514	1.2%
Estonia*	37,797	0.3%
Hungary*	71,673	0.5%
Iceland	2,172	0.0%
Latvia*	22,976	0.2%
Liechtenstein	208	0.0%
Monaco	71	0.0%
New Zealand	25,530	0.2%
Norway	35,533	0.3%
Romania*	171,103	1.2%
Slovakia*	58,278	0.4%
Switzerland	43,600	0.3%
Total	**13,728,306**	**100%**

* Countries with economies in transition to a market economy.

[55] Adapted from http://unfccc.int/resource/kpco2.pdf "Kyoto Protocol: Total carbon dioxide emissions of Annex I Parties in 1990, for the purposes of Article 25 of the Kyoto Protocol"

Nevertheless, and to the great surprise of all participating Parties and observers, in July of 2001, COP 6 *bis* salvaged the wayward negotiations when political consensus was reached on the Bonn Agreements, named for the session's location. Many interested observers have suggested, that in an extremely ironic fashion, the greatest supporters of the Protocol (including the European Union) backed off their original demands in a new resolve to recover the beleaguered Protocol. As a result, the remaining United States' allies were able to claim victory on many of the previous issues that contributed to the failure of COP 6.

The Bonn Agreements addressed key issues identified in the Buenos Aires Plan of Action; importantly, however, some key decisions remained outstanding. In particular, detailed decisions on the flexibility mechanisms, the treatment of sinks, and on Kyoto Protocol compliance were deferred until COP 7 in Marrakech (2001).[56]

3.3.4 The Marrakech Accords

COP 7 was held in Marrakech, Morocco, in October/November of 2001. After intense negotiations, the Marrakech Accords were documented in 245 pages of draft text.[57] The complex decisions that comprise the Accords provide legal text to the broader principles that were embedded in the Bonn Agreements. With agreement in the form of the Marrakech Accords, the Buenos Aires Plan of Action was fulfilled and countries were able to seriously consider their individual ratification of the Kyoto Protocol.

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[56] United Nations Framework Convention on Climate change resources found at the website, http://unfccc.int/resource/process/components/response/baaction.html

[57] *The Marrakech Accords and the Marrakech Declaration*, advance unedited version November 2001.

Again leaving aside the onerous and complicated details of the agreement, COP 7 introduced some important changes and/or clarifications that are worth mentioning. For instance, removal units (RMUs) were introduced as a unit to describe emission removals generated through sink activities in an Annex I country. This distinction was created to address continued European Union concerns around the permanence of the atmospheric removal caused by sink activities[58]; with this new distinction, RMUs can be treated differently than the other instruments as deemed appropriate. Also, banking restrictions (the ability to carry over unused compliance instruments such as AAUs, ERUs, CERs and RMUs into the next compliance period) were placed on CERs, ERUs and RMUs; AAUs, on the other hand, are not subject to any banking limitations. Nevertheless, it was agreed that all the instruments would be fully fungible, or exchangeable, with each other. Accordingly, the banking restrictions may only have a limited effect in practice. In addition, a Commitment Period Reserve was established in an attempt to limit the likelihood of overselling by any one Party; the Reserve limits a Party's ability to sell to a mere ten percent of its allowable emissions. Other important decisions were also made, including a much-needed expansion of the operational details for the three flexibility mechanisms, and a softening of the supplementarity requirement (it was agreed that domestic actions are to constitute a "significant" element of a nation's efforts). Perhaps most importantly, however, was a decision to defer the question regarding the legal

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[58] The sequestration of carbon/carbon-dioxide via land use, land use change and forestry activities can result in RMUs. However, the reduction or removal of atmospheric GHGs in this manner can later be reversed, or undone, through intentional anthropogenic actions or through natural causes. For instance, planting trees encourages storage of increased levels of carbon, however, these tress can later fall victim to fire, or pests at which point, the carbon will be released to the atmosphere as carbon dioxide, resulting in a "0 net improvement" to the state of GHGs.

nature of the compliance regime until the first meeting after the KP's entry into force.[59] Up until that clarification, some Parties understood the Protocol to be a legally binding agreement immediately upon its entry into force.

Some outstanding issues remained after COP 7, however, they were largely considered technical in nature, and were not expected to attract the political attention that the overriding principles have demanded. Accordingly, KP advocates had hoped that Parties would feel comfortable ratifying quickly such that the KP could enter into force by the World Summit on Sustainable Development in Johannesburg in September 2002. When this did not happen, some KP advocates remained optimistic that COP 8 in New Delhi in October/November of 2002 would reinforce the growing pressure for countries to respond.

To the contrary, COP 8 and its resulting "Delhi Declaration" were viewed as a dismal event by many who attended; the Delhi Declaration did not raise any new issues or decisions, rather, COP 8 merely continued the effort of progressing rules and procedures that had not yet been finalized. Still, given national policy signals by the various government leaders, participants to the event and other observers continue to remain optimistic about a full Protocol ratification prior to the subsequent COP 9 in Italy in December of 2003.[60]

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[59] Global Change Strategies International, "Background Document for National Workshop on CDM and JI: COP 7 Results" Spring 2002

[60] Should ratification occur before COP 9, the Italy meeting will also become the first Meeting of the Parties to the Kyoto Protocol (MOP1).

Regardless of the apparent (but weak) success of the climate change negotiations themselves, the true test is the extent to which countries are able to accept, approve or ratify the resulting agreements such that the Kyoto Protocol enters into force. It is worth noting that without the United States' voluntary participation, the importance of other players (particularly Russia) has increased significantly; we have already witnessed instances of Russia leveraging this fact and many observers suspect that such leveraging/political demands will only increase into the future as Russia's ratification becomes increasingly important for a timely KP ratification.

3.4 Responses at the National Level

As already referenced, the United States has chosen not to formally participate in any resulting Kyoto Protocol because President Bush believes the agreement is "fatally flawed." On the other end of the spectrum, member states of the European Union are actively embracing the Protocol and taking whatever actions are necessary to achieve full compliance with their respective targets. Most nations, however, have been much less decisive in their approach to the ratification decision or their respective implementation strategy.

3.4.1 United States of America -- USA

Since President Bush's clear rejection of the Kyoto Protocol, it was hoped that the USA would introduce a global alternative for consideration by the international community. However, after lengthy delays and great speculation, President Bush gave an address outlining his Global Climate Change Initiative on February 14th, 2002. The

President's address described a high-level proposal for a *domestic* response to climate change:

> … I reaffirm America's commitment to the United Nations Framework Convention and it's central goal, to stabilize atmospheric greenhouse gas concentrations… My administration is committed to cutting our nation's greenhouse gas intensity -- how much we emit per unit of economic activity -- by 18 percent over the next 10 years. This will set America on a path to slow the growth of our greenhouse gas emissions and, as science justifies, to stop and then reverse the growth of emissions… If, however, by 2012, our progress is not sufficient and sound science justifies further action, the United States will respond with additional measures that may include broad-based market programs as well as additional incentives and voluntary measures designed to accelerate technology development and deployment…[61]

A new voluntary challenge program intended to embody the President's climate change initiative has had increasing stimulus as the Bush administration is actively promoting action by industry. Interestingly, competing climate change bills and their related amendments continue to be discussed in congress. There is growing momentum in the USA on the climate change front and many believe that a mandatory domestic program is inevitable; to the contrary, however, Kyoto Protocol ratification by the USA or meaningful involvement in any international climate change agreement is unrealistic under this Presidency.

3.4.2 European Union -- EU

Unlike the USA, the EU and its member states have aggressively committed to doing their part to ensure ratification of, and compliance with, the Kyoto Protocol. In

[61] President Bush "Clear Skies & Global Climate Change Initiatives" -- speech text, National Oceanic and Atmospheric Administration Silver Spring, Maryland http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html

October 2001, for instance, the European Commission released a proposal for a Directive that would establish a European Community wide cap and allowance trading system for carbon dioxide emissions.[62] Participants would not face legally binding targets in the first phase, 2005-2007, but beginning in 2008, the targets would become legally binding.[63] Interestingly, the proposal is designed to align with the targets and mechanics of the Kyoto Protocol, but it is also sufficiently independent such that the Directive would survive in the event of KP failure. Over one year later, on December 10th, 2002 the European Council reached a common position on the Commission's proposed Directive. The Council proposed several changes including opt-in and opt-out provisions, greater inclusion of greenhouse gases (previously only carbon dioxide was considered), etc. Still, the Directive must undergo further political analysis and agreement before it can come into effect.

In the interim, on March 4th, 2002, the EU Council of Environment Ministers accepted the previously agreed to Burden Sharing Agreement (EU and member state emission reduction targets) into legally binding form (see Table 3.4 for targets). On that date, the EU and member states also accepted the Commission's proposal to simultaneously submit their instruments of ratification to the United Nations prior to June 1st, 2002, (which they subsequently did on May 31st, 2002.) This date was deliberately chosen with the hope that simultaneous ratification by other Annex I Parties would allow

[62] The proposed Directive discusses the consideration of project-based emission reductions but has not provided details to date.
[63] Commission of the European Communities, "Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC", Brussels, October 23rd, 2001.

the Kyoto Protocol's entry into force in time for the World Summit to be held at Johannesburg.[64] Conscious of the difficulty in achieving such a result, however, the EU Commissioner encouraged the USA to act beyond its proposed Global Climate Change Initiative:

> These proposals will not lead to a reduction of GHG emissions from the United States but allow a significant increase. The EU has legally bound itself today to actually reduce its emissions. We continue to urge the United States to return to the Kyoto process.[65]

Table 3.4: Legally Binding EU Burden Sharing Agreement [66]

Country	GHG emission reduction target relative to 1990 emission levels
Austria	-13%
Belgium	-7½%
Denmark	-21%
Finland	0%
France	0%
Germany	-21%
Greece	+25%
Ireland	+13%
Italy	-6½%
Luxembourg	-28%
Netherlands	-6%
Portugal	+27%
Spain	+15%
Sweden	+4%
United Kingdom	-12½%
European Community	**-8%**

[64] European Commission press release "The Kyoto Protocol and Climate Change" Brussels, March 4, 2002
[65] European commission press release "EU Honours Commitment to Early EU Ratification of the Kyoto Protocol" Brussels, March 4, 2002
[66] European Commission press release "The Kyoto Protocol and Climate Change" Brussels, March 4, 2002

3.4.3 Other States

Without the United States' stated desire to ratify the Kyoto Protocol, the positions of the remaining Annex I countries quickly became paramount in determining the continued life of the Protocol. Once the European Community ratified in May 2002 and Japan ratified less than one week later, all eyes focused on Russia, and to a limited extent on Canada, since their mutual acceptance of the Kyoto Protocol would allow its entry into force.

Canada, therefore, found itself in a precarious position that placed the country between its largest trading partner and the rest of the world. At least three options appeared worthy, but all of them seemed rather dismal:

- Do nothing -- receive tremendous backlash from the international environmental community and Parties supportive of the Kyoto Protocol;
- Ratify the Kyoto Protocol knowing that the targets are all but impossible to meet given economic growth over the past decade – Canadian industries feared this option would place them in a competitive disadvantage relative to those of its largest trading partner; or
- Negotiate a regional GHG trading agreement with the United States (and perhaps others to resemble the North American Free Trade Agreement) – secure a level playing field with its largest trading partner but receive backlash from Kyoto supporters

Ultimately, Prime Minister Chrétien opted to ratify the Kyoto Protocol, and on December 17th, 2002, Canada became the 100th Party to submit its instrument of ratification[67].

On November 21st, 2002, shortly before Canada's ratification, the Government of Canada released its "Climate Change Plan for Canada".[68] While some observers would argue that the document provided few, if any, operational details, it did outline general principles and themes under which a domestic emission reduction program is likely to be implemented and subsequently function. One tool that is referenced in the Plan, for instance, is a (voluntary) cap and trade program. Sectoral covenants and private-public partnerships are additional mechanisms that will play a large role as Canada strives to reach compliance with its Kyoto Protocol target.

Nevertheless, it remains to be seen whether or not the Kyoto Protocol will enter into force. Ratification by the Russian Federation is the only remaining Party action required to breath life into the Kyoto Protocol, and while the government has signaled its intention to ratify, progress has been very slow.

Refer to Appendix 1 for additional North American case study information regarding national contribution to, and vulnerability to, climate change.

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[67] United Nations, United Nations Framework Convention on Climate Change, Secretariat press release "Kyoto Protocol receives 100th ratification", December 18th, 2003.
[68] This Plan can also be found at http://climatechange.gc.ca/plan_for_canada/plan/pdf/full_version.pdf

3.5 Summary

After decades of mounting scientific certainty and growing political resolve to combat anthropogenically induced climate change, the global community awaits with bated breath as to whether or not years of negotiations will succeed or fail.

After several preliminary international climate change meetings, the UNFCCC established a framework for international action based on a core objective of stabilizing GHG emissions to those levels that occurred in 1990. UNFCCC principles including those based on equity, sustainable development, and differentiated responsibilities paved the way for further discussions and actions on climate change. Recognizing that the challenge of climate change was more acute than the UNFCCC was able to address, the international community responded with agreement on the Kyoto Protocol.

The Kyoto Protocol introduced quantitative emission limits for the 2008-2012 period for each Annex I nation. The Protocol also introduced three important flexible mechanisms that were devised to ease the cost of achieving compliance with the agreed-upon targets.

The Marrakech Accords have since been drafted to provide detailed legal language to the principles embodied within the Kyoto Protocol. This document provides the operational details that will allow the program envisioned by the Protocol to proceed.

Now that the international agreements are in place, it is up to each Party to determine its willingness to accept, approve or ratify the Kyoto Protocol and be subject to its provisions. The United States has made it painfully clear to supporters of the Kyoto Protocol that, under President Bush, it will not consider any form of participation in the

Protocol. On the other hand, the European Community aggressively pursued ratification and is now deep into the political process to introduce a Community wide cap and trade program. Japan (and to a lesser extent, Canada) has also been on the forefront, and has shown its support for the Protocol with its ratification and similar efforts on domestic policy. Still, many other nations such as Australia, are caught in difficult positions and are seen to be ambiguous in their resolve to cooperate with international efforts. Nevertheless, Russia is currently the only Party that will "make or break" the Kyoto Protocol's entry into force. All interested climate change observers will monitor the Russian Federation with close scrutiny and bated breath. The fate of all climate change political action to date rests on the Federation's ratification decision.

The political context provided in this chapter, as well as the scientific context provided in the previous chapter, should provide a useful framework for exploring related economic issues in the next chapter, as well as the subsequent model that is the primary focus of this thesis.

Chapter 4: International Trade & the Environment -- Literature Review Addressing Global Climate Change

4.1 Introduction

Public goods such as natural resources often fall victim to over exploitation due to the absence of properly assigned user-costs, or in many cases, the absence of prices altogether. Indeed, such exploitation is synonymous with market failure, or as some may prefer to characterize, the lack of a market altogether. Without individuals or firms being able to internalize the true costs of using a particular common good, negative externalities accumulate and contribute to the "tragedy of the commons".

The earth's atmosphere is perhaps the grandest example of a public good that is deteriorating due to misuse. Anthropogenically induced climate change currently commands the attention of heads of state across virtually all borders. How citizens of the earth address this important issue, however, is currently the source of great debate among government representatives, environmentalists and, of course, scholars.

Economists typically advocate for the imposition of market mechanisms such as pollution permits or effluent charges as means of correcting apparent market imperfections. In this approach, a nation's government sets the framework for the market and strictly enforces the accompanying rules. Nevertheless, as we do not have a comparable supreme body at the global level, we must rely upon the collective heads of state abiding by an international agreement that is similarly enforceable. Naturally, politics and various other distractions inevitably complicate this already impossible undertaking.

Not surprisingly, there is a growing body of literature that explores a whole host of issues relating to the design and enforceability of such an agreement, the related international trade implications, the resulting market organization, the effects on greenhouse gas levels, among others.

The empirical body within the environment and international trade literature typically (using computable general equilibrium models) explores the following questions:

1. How does economic growth affect the environment?
2. How do environmental regulations affect trade flows?
3. How has pollution intensity of production changed over time?[69]

On the other hand, theoretical work in this area has been less extensive. Nevertheless, recent articles have built upon the foundations present within public economics, environmental economics, and international trade literature.[70] Integrating learnings and analysis from each of these areas into more comprehensive analysis has been a recent trend that is proving to be valuable in both understanding and addressing the economic issue of climate change. Such literature is explored within the following pages.

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[69] Antweiler, W., Brian R. Copeland and M. Scott Taylor, "Is Free Trade Good for the Environment", forthcoming pp. 3-4

[70] Copeland, Brian R. and M. Scott Taylor, "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol", draft January 2001, pp. 4-6

4.2 Origins of Tradable Emission Permits

Prior to exploring the more rigorous literature on the integration of trade and the environment, it is important to outline the basis for emissions permits. Most authors in today's literture credit Dales for formally introducing the concept of emission permits in "Land, Water and Ownership" (1968).

While Dales described typical pollution externalities in the context of water, the scenarios are directly analogous to air pollution. In particular, Dales illustrated a common American concern in which pollution is released into a river at one location, only to negatively affect the water used by a downstream neighbour. This situation is akin to regional air pollution; for instance, sulphur dioxide releases contribute to the formation of acid rain in downwind regions, without necessarily affecting the original polluter. On the other hand, Dales suggested a more common Canadian *lake* scenario, in which pollutant releases in the water by one individual negatively affects the use for all users of the lake, including the polluter.[71] This situation is analogous to the implications of global air pollutants such as greenhouse gases. An increase in the release of greenhouse gases in one location will lead to an increase in atmospheric greenhouse gas concentrations globally. Thus, economic analysis for either the regional or global scenarios requires the application of social decision making in the context of social welfare functions.

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[71] Dales, J.H. "Land, Water, and Ownership", *Canadian Journal of Economics*, November 1968, reprinted with permission in Dorfman, Robert and Nancy S. Dorfman, *Economics of the Environment: Selected Readings"* 3rd Edition W.W. Norton & Company (New York, London) 1993 p. 227

In attempting to address the public good concern, Dales recognized that public goods such as water, and in this case air, do not naturally have a price or cost associated with their use:

> What is not owned cannot be priced since prices are payments for property rights or rights to use the asset. In the course of allocating property rights to assets among different owners, the price system in fact transforms most potential technological externalities into pecuniary externalities, a synonym for prices.[72]

Of course, the allocation of property rights is relatively easy for something such as land because it is both immobile and divisible;[73] this is obviously not the case for water or air. Nevertheless, Dales purported that it is possible to assign rights to anything that is valuable, and user rights imply ownership. Accordingly, an ownership-rental system could be devised for items that otherwise appear to be impossible to divide.[74] Dales succinctly captures the essence of the article on page 226:

> Economists tend to assume implicitly that it is impossible to own water and therefore seek to devise artificial price systems that are identical to what prices "would be" if ownership were possible. The alternative strategy is to devise an ownership system and then let a price system develop. The purpose of this article is to suggest that there are very considerable advantages to attacking our water problems by means of a system of explicit ownership rather than by a system of shadow prices.

Dales succeeded very well in his purpose, as scholars, and more recently, politicians have recognized such advantages and have both advocated for, and implemented, systems of ownership as a means of imposing a user cost to intangibles such as air.

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72 Ibid, p. 226
73 Ibid, p. 229
74 Ibid, p. 232

4.3 From Concept to Formal Theory

The economic literature has evolved significantly since Dales' 1968 article. Since that time, environment and international trade linkages have been explored extensively, and tradable emission permits have played an increasing role within this literature.

Copeland and Taylor have been important contributors to this theoretical area. Their work has evolved from the analysis of regional air pollution and international trade interactions to the analysis of global air pollution permit trade, and international trade in underlying goods. This team has also explored the environment and international trade area empirically.

As a first step in clarifying theoretical issues, Copeland and Taylor explored the level and incidence of *local* or regional pollution, income levels and trade in their 1994 "North-South Investment Flows and Optimal Environmental Policies" article. They developed a simple static two-country general equilibrium model. Each country produced a continuum of goods with differing levels of pollution intensity, and the countries only differed by their endowment of human capital (a highly developed North and a less developed South).[75] Copeland and Taylor allowed for environmental policy to be set endogenously by the government, with the higher-income country naturally choosing tighter regulations. By isolating the scale, composition and technique effects,[76] they determined that the altered income levels, brought about by such a change in

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[75] Copeland, Brian R. and M. Scott Taylor, "North – South Trade and the Environment", *The Quarterly Journal of Economics* V 109(3), August 1994, p. 759-760

[76] Copeland and Taylor define the scale effect as an "increase in pollution created by an increase in the level of economic activity", the technique effect as "the change in aggregate pollution arising from a switch to less pollution intensive production techniques" and the composition effect as "the change in pollution due to a change in the range of goods produced by a country". (Ibid, pp. 769-770.)

environmental policy, encouraged specialization in the cleaner good and induced trade.[77] This shifted pollution intensive production to the human-capital scarce country and increased the overall pollution levels. Nevertheless, this result always increased welfare because trade made each country better off and each government regulated their local pollution optimally.

Their theoretical work was validated in 2001, when Antweiler, Copeland and Taylor investigated how openness in the international goods market affected pollution levels. Using data on sulphur dioxide concentrations from the Global Environment Monitoring Project, they found that "if trade liberalization raises GDP by one percent, then pollution concentrations fall by about one percent."[78] This was consistent with the conclusions of the 1994 Copeland and Taylor article.

In addition, using a two country, two good trade model, Benarroch and Thille explore trade and welfare effects from transboundary pollution in which:

1. Cross-border pollution only flows in one direction;
2. One country uses a technology that does not produce pollution[79]

The authors find that with respect to their first objective, "trade leads to a loss in welfare for the "down-wind" country when demand for the dirty good is low, whereas trade is always welfare enhancing for the other country".[80] With respect to their second objective, the authors find that "the country with the clean technology specializes in the clean good. Production of the dirty good is concentrated in the country in which it does

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[77] Ibid, p. 756
[78] Antweiler, W., Brian R. Copeland and M. Scott Taylor, "Is Free Trade Good for the Environment", forthcoming, p. 2
[79] Benarroch, Michael and Henry Thille, "International Trade with Cross-Border Pollution Externalities" December 4th, 1997, p.3.
[80] Ibid, p.3

the most harm."[81] Thus, they find that under certain circumstances trade can exacerbate environmental problems, and indeed, may or may not provide mutual increases in welfare across the trading countries.

While these articles presented interesting results, perhaps more importantly, they provided an important basis for future work on transboundary and global pollutants.

4.4 Transboundary & Global Pollution

One year after their 1994 article, Copeland and Taylor's "Trade and Transboundary Pollution" article built upon the model from their previous work and extended it to explore the implications of transboundary pollution. They also adjusted the model to include trade in international pollution permits, international income transfers and international pollution control agreements.[82] Furthermore, Copeland and Taylor explored the differing effects of a large number of countries instituting environmental controls, versus a small number of countries instituting environmental controls. In this manner, they were able to isolate the terms of trade effects due to the change in environmental policy. In addition, they explored how inequalities in international distribution of income altered the effect of trade on the environment.[83]

As discussed earlier, by introducing transboundary pollution rather than limiting the analysis to local pollution, the welfare implications differed significantly from their earlier model. Due to the characteristics of transboundary pollution, welfare gains from

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[81] Ibid, p.3
[82] Copeland, Brian R. and M. Scott Taylor, "Trade & Transboundary Pollution", *The American Economic Review* V85(4), September 1995, p. 716
[83] Ibid, p. 717

trade may be eroded, and even negated, if world pollution levels increase. In particular, Copeland and Taylor concluded that:

1. Free trade raises world pollution if incomes differ substantially across counties;
2. If trade equalizes factor prices, human capital-abundant countries lose from trade, while human-capital-scare countries gain;
3. International trade in pollution permits can lower world pollution even when governments' [endogenous] supply of permits is unrestricted;
4. International income transfers may not affect world pollution or welfare; and
5. Attempts to manipulate the terms of trade with pollution policy leave the world unaffected.[84]

Copeland and Taylor also found that when factor price equalization is not achieved, the "dirty" or marginal good is produced in the more pollution intensive South, leading to higher global pollution[85]. While both their approach and their objective differs significantly from that which is explored in this paper (their particular model was designed to highlight income effects on the environment, and income is ignored in the model presented in this paper), the resulting observation is similar to the permit-only model discussed in chapters 5 and 6.

In a 2001 article, Unteroberdoerster showed a similar reversal of results when he introduced transboundary pollution to a local pollution model.[86] In particular, he introduced transboundary pollution to a local pollution trade and spatial separation model previously formulated by Copeland and Taylor.[87] In the original Copeland and Taylor

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[84] Ibid, p. 716
[85] Ibid, p. 727
[86] Unteroberdoerster, Olaf, "Trade and Transboundary Pollution: Spatial Separation Reconsidered", *Journal of Environmental Economics and Management* 41, pp 269-285, 2001
[87] Copeland, Brian and Scott Taylor, "Trade, spatial separation and the environment", *Journal of International Economics* V. 47, 1999. pp. 137-168

two good, two-country model, production of the clean good is adversely affected by production of the dirty good. Trade has the ability to improve welfare in both countries through productivity gains as the local pollution is concentrated in only one of the countries. Of course, this last result does not necessarily apply to transboundary pollution because the level of pollution may negatively impact both countries. In particular, the conditions required for welfare to decrease in both countries include the following:

- The dirty industry must have a higher emissions intensity in one country than the other country, and
- The ratio of transboundary pollution to local pollution must be great enough to allow the country with the relatively clean industry to be impacted more by the transboundary pollution than by the local pollution.[88]

Unteroberdoerster's above emissions intensity condition is an assumption within the permit-only model discussed in chapters 5 and 6. While the assumption proves to be important to the modeling results of this paper, it is easily argued that such an assumption is reasonable.

Unteroberdoerster's above results and the above Copeland and Taylor results are important transboundary conclusions that will assist in both the political climate change debate and in further theoretical efforts.

In 1995, Copeland and Taylor extended their work further by applying their theory in a framework of the Kyoto Protocol to the United Nation's Framework Convention on Climate Change. Their recent article "Free Trade and Global Warming: A

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[88] Unteroberdoerster, Olaf, "Trade and Transboundary Pollution: Spatial Separation Reconsidered", *Journal of Environmental Economics and Management* 41, pp 269-285, 2001 p. 269

Trade Theory View of the Kyoto Protocol" challenges conventional results obtained in environmental economics. By introducing an open economy with international trade in goods, typical results no longer hold.

The perfectly competitive general equilibrium model they used is static, allows for pollution, treats emissions as a global bad, and uses factors of production that are in inelastic supply. Similar to their previous model, Copeland and Taylor allow for both the trading of goods as well as emission permits; they also allow for interaction between income and environmental policy.[89] Furthermore, through regional differentiation of capital endowment levels, the authors capture the basic trading elements of the Kyoto Protocol. In particular, they categorized the countries into Northern and Southern regions, and assigned emission constraints to the Northern region. They then split the Northern group into East and West, and allowed the West to hold the greatest ratio of capital resources (while the Southern countries hold the smallest ratio of capital resources.)

In their typical fashion, Copeland and Taylor decompose a representative country's best response to a change in the rest of world's emissions to include free-riding, carbon leakage (substitution) and bootstrapping (income) effects.[90] Free-riding is a pure strategic effect while carbon leakage is an output response to the increase in dirty good price, and bootstrapping is an increased desire for environmental improvement as national income grows. As with their previous "Trade and Transboundary Pollution"

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[89] Copeland, Brian R. and M. Scott Taylor, "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol", draft January 2001, p. 1
[90] Ibid, p. 2

model, Copeland and Taylor demonstrated that welfare is determined by both the direct gains from permit trade as well as the environmental policy-induced change in goods trade. Also, since the South remains unconstrained, any increase in Southern pollution negatively affects world welfare since the pollution is assumed to be a global bad.[91] In particular, in an open trading world Copeland and Taylor conclude:

1. Unilateral emission reductions by the rich North can create self-interested emission reductions by the unconstrained poor South;
2. Simple rules for allocating emission reductions across countries (such as uniform reductions) may well be efficient even if international trade in emission permits is not allowed; and
3. When international emission permit trade does occur it may make both participants in the trade worse off and increase global emissions.[92]

The first point differs from the result that is shown later in this paper, primarily because Copeland and Taylor allow the South to have a self-imposed emissions cap due to income-related demand for environmental improvement. However, as will be discussed later in this thesis, such an assumption may or may not be appropriate in the context of the Kyoto Protocol.

The second result, which was not directly explored by this paper, arises from factor price equalization. Since the models explored in chapters 5 and 6 impose differing technologies across the two countries, however, factor price equalization will not occur and this result would not apply.

Recall that international permit trade, as referenced in the third result from Copeland and Taylor's paper, represents permit trade between the East and the West with

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[91] Ibid, p. 3
[92] Ibid, p. 1

both areas belonging to the constrained North. This third result arises because activities in the North cause an increase in the price of the dirty good, which then attracts expansion of the unconstrained South's dirty good sector. Depending on the magnitude of the elasticity of marginal damage in the South with respect to real income, such entry results in carbon leakage and world pollution levels are increased. While the result appears similar to the permit-only model discussed in chapters 5 and 6, again the approach is in reality significantly different. In this thesis, the long run price for the dirty good remains unchanged, Southern demand for environmental improvement is disregarded and it is unambiguous that carbon leakage results.

Given the level of interest in pursuing the Kyoto Protocol and its related trade in emission permits, however, such results – either those presented in this thesis; or those discussed by Copeland and Taylor – may be startling to staunch Kyoto Protocol advocates. This potential reality begs the question of what solution may exist to address global warming in a social welfare-improving manner.

4.5 Additional Research on Transboundary Pollution Issues

4.5.1 Win- Lose rather than Lose-Lose Scenarios

With respect to assessing the welfare implications of climate change, Caplan, Ellis and Silva have, interestingly, explored global warming as an asymmetric transboundary externality in which some regions actually benefit while others are harmed.[93] While such climate change benefits have not been confirmed to consistently exist over the long run, some scientists have predicted that some regions will benefit, or in the very least, be affected much less negatively than others. For instance, some scientists have suggested that northern regions will benefit from longer and warmer growing seasons while many coastal areas will lose agricultural lands due to rising sea levels. Even tourism destinations may shift as northern regions warm and other regions experience drier conditions. The possibility of "winning" countries is especially important to consider in establishing appropriate theoretical models. If some countries expect to gain from increased atmospheric greenhouse gas concentrations, they will strategically choose environmental policy very differently than those that expect to lose. Ultimately, a simple global agreement to restrict greenhouse gas emissions in each nation may not be optimal or even practical.

To explore the effects of climate change, Caplan et al use a simple two-country model to investigate expected changes in resource allocations, the stock of atmospheric greenhouse gases, and national and global welfare. Perhaps surprisingly, the authors do not allow for trade or capital mobility, and labour is restricted to its country of origin. Of course, the transboundary externality serves as an important link between the two countries.[94] Though their analysis, they find that "the winner country's greenhouse gas emissions are positively related to the loser's, but that the loser's are negatively related to

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[93] Caplan, Arthur J., Christopher J. Ellis, Emilson C.D. Silva, "Winners and Losers in a World with Global Warming: Non-cooperation, Altruism and Social Welfare", Journal of Environmental Economics and Management 37, (1999), p. 1
[94] Ibid p. 2

the winner's."[95] The authors also concluded that emission swaps could be a welfare improving mechanism, enabling movement towards the socially optimal level of atmospheric greenhouse gas concentrations; this is the case even if the socially optimal level is unidentifiable.[96] Of course, this implies that some form of global climate change agreement may prove to be beneficial regardless of whether some countries stand to gain from the effects of climate change.

4.5.2 Tied-Environmental Aid and Uncertainty

Chambers and Jenson use a two-stage game to determine the effectiveness of untied aid in reducing transboundary emissions. They assume informational asymmetries whereby the North is unable to identify *a priori* the South's willingness to enforce tough environmental regulations[97]. Accordingly, in stage 1 of the non-cooperative model, the richer North country must attempt to identify the Southern nations that are naturally weak in enforcing environmental policies, and therefore, which could benefit most from receiving the environmental aid. To increase their chances of receiving the Northern aid, however, both types of Southern countries have the perverse incentive of increasing their current emissions. The naturally weak policy nation wishes to prove its reputation type, and the country with a higher willingness to enforce tough policy will try to disguise itself in a similar effort to attract the Northern aid. Accordingly, in the short-run, emissions are more excessive than if the aid had not been available. Logically, the

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[95] Ibid p. 2
[96] Ibid p. 3
[97] Chambers, Paul E. and Richard A. Jensen, "Transboundary Air Pollution, Environmental Aid, and Political Uncertainty", *Journal of Environmental Economics and Management* V. 43, 2002, p. 1

existence of this uncertainty leads to less environmental aid from the Northern country than if the Northern country could correctly identify the weak policy country with certainty; the naturally weak Southern country will lose from the informational asymmetry while the naturally tough Southern country stands to gain. Nevertheless, because the Southern country must reveal its true type in stage 2, the uncertainty issue disappears. Still, the possibility of random shocks, including changes in political will, implies that some level of uncertainty will always remain.[98]

This particular article, while not directly addressing the issue of international trade and its effect on the environment as it relates to climate change, may have some interesting insights, and perhaps some parallels, to the Clean Development Mechanism currently contemplated within the Kyoto Protocol and related agreements. For instance, carbon constrained Northern countries have the ability to provide funding to unconstrained Southern nations in advance of the Kyoto Protocol's entry into force. As currently outlined in the Protocol, constrained countries may receive credit for greenhouse gas emission reduction actions taken in unconstrained nations beginning in the year 2000. To receive official credit, however, such Northern actions must receive the blessing of the host country, and must be additional to what would have otherwise occurred. These two factors are the source of large uncertainty and are currently hindering the development of the Clean Development Mechanism.

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[98] Ibid, p. 3

4.5.3 Local versus Central Enforcement of Transboundary Pollution

List and Mason consider transboundary pollution in the context of whether transboundary pollution regulations should be enforced locally or centrally in a second-best world. They explore this question by considering the heterogeneity of payoffs and the size of the initial pollution stock; the authors employ a dynamic model with asymmetric players to find that "combined payoffs are larger with decentralized control if payoffs are sufficiently heterogeneous and initial stocks are sufficiently small." [99] A key assumption in this article is that the central authority applies uniform standards whereas the local authorities apply varied shadow prices / standards.

4.5.4 Computational Models

Still further, many authors have pursued answers to transboundary pollution questions by applying large computational models. For instance, Stevens and Rose (2001) attempt to model issues that are at the heart of the current Kyoto Protocol debate. They present a mathematical programming model, followed by simulation analysis to demonstrate the effects of permit banking and borrowing, supplementarity, and the number of countries included. They concluded that the greatest gains in achieving cost-effectiveness came from allowing a larger number of countries to trade with each other. As expected, banking and borrowing also contributed to lowering the cost of achieving

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[99] List, John A. and Charles F. Mason, "Optimal Institutional Arrangements for Transboundary Pollutants in a Second- Best World: Evidence from a Differential Game with Asymmetric Players", *Journal of Environmental Economics and Management* 42, p. 277

lower emission levels, while supplementarity restrictions reduce the potential costs savings accessible through trading.[100]

It is interesting to note that there are considerably more articles drawing upon computational models in this area than there are articles expressing simpler theoretical models.[101]

4.5.5 Growth & the Environment

It is worth mentioning, however, that much of the literature in this area focuses on growth (often through trade) and the environment, which I have not discussed above.[102] The growth and environment literature appears to be inconclusive; the theory has developed to continually suggest a pollution haven result that is not consistently supported by the empirical evidence. Nevertheless, this particular set of research may have an interesting application to the Kyoto Protocol, as it may assist in determining how effective the Clean Development Mechanism is expected to be since there are high hopes for true sustainable development among these developing nations. Overall, however, the growth and environment literature does not appear to have a direct link to the larger issues regarding the economics of climate change as discussed in this thesis.

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[100] Stevens, Brandt and Adam Rose, "A Dynamic Analysis of the Marketable Permits Approach to Global Warming Policy: A Comparison of Spatial and Temporal Flexibility", *Journal of Environmental Economics and Management*, 2001 p. 1

[101] For additional transboundary topics with a computational approach, also see: Nordhaus , William D. and Zili Yang "A Regional Dynamic General Equilibrium Model of Alternative Climate Change Strategies", *American Economic Review*, Vol 86 Issue 4 (Sept 96), 741-765, and for price forecast models, see Varilek, Matt and Nina Marenzi, "Greenhouse Gas Price Scenarios for 2000-2012: Impact of Different Policy Regimes", IWOe Discussion Paper No. 96, November 2001, Institute for Economy and the Environment, University of Gallen

[102] Some examples include: Grossman, Gene M. and Alan B. Krueger, "Economic Growth and the Environment", *The Quarterly Journal of Economics* Volume 110 Issue 2 (May 95) 353-337; Moomaw, William R. and Gregory Unruh, "Are Environmental Kuznets Curves Misleading Us?", Tufts University, Medford, Massachusetts; Lopez, Ramon, "The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization", *Journal of Environmental Economics and Management*, 27, 163-184 (1994)

4.6 Summary

There is a wide variety of international trade and environment literature. Both the transboundary literature and the emissions permit literature, on the other hand, have direct ties to the question of addressing the economics of climate change. As discussed above, the very nature of transboundary pollutants affects the manner in which decisions are made. Governments must recognize that decisions they make within their national boundaries to control global pollutants such as greenhouse gases may affect production and other economic decisions in foreign countries. These foreign effects may then have further feedback effects that are global in nature. To ensure that all the effects of environmental constraints, such as those contemplated by the Kyoto Protocol, are captured, it is useful to consider them in a general equilibrium context; the results are typically surprising, and against conventional thinking.

It is quite clear that many areas within the international trade and environment field remain unexplored. For instance, Copeland and Taylor have collectively presented some interesting and challenging conclusions that dare to be questioned. On the other hand, some recent political developments have inspired additional questions regarding new issues, which appear not to have been addressed by the literature to date. One such issue, for instance, is the impact of introducing credits into a permit only system. This and other economic issues will be explored within the next two chapters.

Chapter 5: Intuitive Foundation for Carbon Leakage

5.1 Introduction

With both increasing scientific evidence of enhanced global warming, and the perceived correlation between human activity and the rising levels of atmospheric greenhouse gas (GHG) concentrations, nations of the world have voiced a call for action. Recognizing that transboundary, and in this case "global," pollution is a tragedy of the commons, heads of state agreed that a global framework was required to coordinate their action.

With idealist intentions and after years of negotiations, nations of the world – rich and poor, large and small, powerful and weak, significant GHG emitters and insignificant emitters – agreed to a framework intended to curb the growth of the world's GHG emissions. Importantly, it is understood that the key design component of the Convention and the subsequent Kyoto Protocol is the imposition of a cap on allowable emissions.

Under the agreement, the developed countries (*Annex I* nations, also referred to here as the *North*) must adhere to an absolute emissions cap (during the first commitment period, 2008-2012, as identified in Annex B of the Protocol) while developing countries (*non-Annex I* nations, also referred to here as the *South*) remain unconstrained in their ability to generate GHG emissions. By intentionally allowing both uncapped and capped groups of countries to co-exist, however, the designers may achieve a very unintentional result.

5.1.1 The Basic Question

"Carbon leakage" can occur if activities not directly controlled by the Kyoto Protocol (or any other international emissions agreement for that matter) act in concert to increase global GHG emissions; in particular, altered market signals may create perverse incentives necessary to foster activities that lead to such carbon leakage. Importantly, should the Kyoto Protocol indirectly encourage carbon leakage, the objective of reducing global GHG emissions could be partially or entirely negated; indeed, if the magnitude of any carbon leakage is strong enough, it is possible that a net increase in global GHG emissions could result.

As referenced below, many observers of the Kyoto Protocol have recognized the possibility of "project-level" carbon leakage and have, accordingly, both advocated and succeeded in ensuring sufficient rules to minimize such a result. Of greater concern, perhaps, is whether carbon leakage exists at the national or global level. It is this latter concern that will be explored, using a general equilibrium economic theory approach. In particular, this chapter will establish the intuitive foundation behind the formal model, which is detailed in the subsequent chapter.

5.1.2 The Basic Approach

General equilibrium theory suggests that in the long-run individual sectors in perfect competition (and other open-entry market structures) perform at their "break-even" level, where the price for the product is equal to the long-run average cost of producing that product. Further, the economy's overall equilibrium point will occur where the break-even condition for each sector is satisfied.

In particular, using a general equilibrium approach, this chapter first presents a single country scenario and then tests for global carbon leakage in the subsequent two scenarios: (1) two-country permit-only; and (2) two-country permit "plus credits". By exploring these three scenarios, it may be possible to gain some important insights into the Kyoto Protocol and its relationship to changes in global GHG emissions. To provide initial context for the three scenarios, however, it is first necessary to discuss the relevant features within the Kyoto Protocol and how such features translate to the models presented.

5.2 Flexible Mechanisms – "Caps" with International Emissions Trading

The Kyoto Protocol includes unique flexible mechanisms that were introduced to ease the costs incurred by Annex I nations in meeting their emissions commitments, while also allowing for a redistribution of technology and wealth from Annex I nations to lesser-developed, non-Annex I nations. One particular mechanism, Emissions Trading, allows the trading of emissions units (comprising the allocated cap and referred to here as *permits*)[103] between the Annex I nations as a means of facilitating cost minimization when complying with each national emissions cap. More generally, this type of mechanism is referred to as a "cap and trade" system.

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[103] Permits can also be referred to as quota or allowances. These permits are formally referred to as Assigned Amount Units (AAUs) under the Kyoto Protocol.

In practice, the sum of the aggregate Annex I permits cannot exceed the sum of the emissions caps placed on such nations. Fixed volumes of permits are allocated across the compliance period in accordance with the targets outlined in Annex B of the Protocol. In a permit-only scenario, each party has the choice of meeting their individual emissions targets by purchasing surplus permits from another party or by pursuing emission-reducing actions in their own jurisdiction. Accordingly, if the Protocol did not include other flexible mechanisms/instruments, (and was thus, a permit-only "cap and trade" system), Annex I nations would be constrained to a fixed level of emissions equal to the number of permits they held, thereby ensuring that the Annex I nations meet their collective emission reduction target.

For simplicity, and since the model(s) used below combine the northern nations into one representative nation (the North) it is sufficient to represent the above "Cap and Trade", or Emissions Trading flexible mechanism, by only considering the imposition of a cap on the North (rather than complicating the analysis further by including intra-country permit trading.)

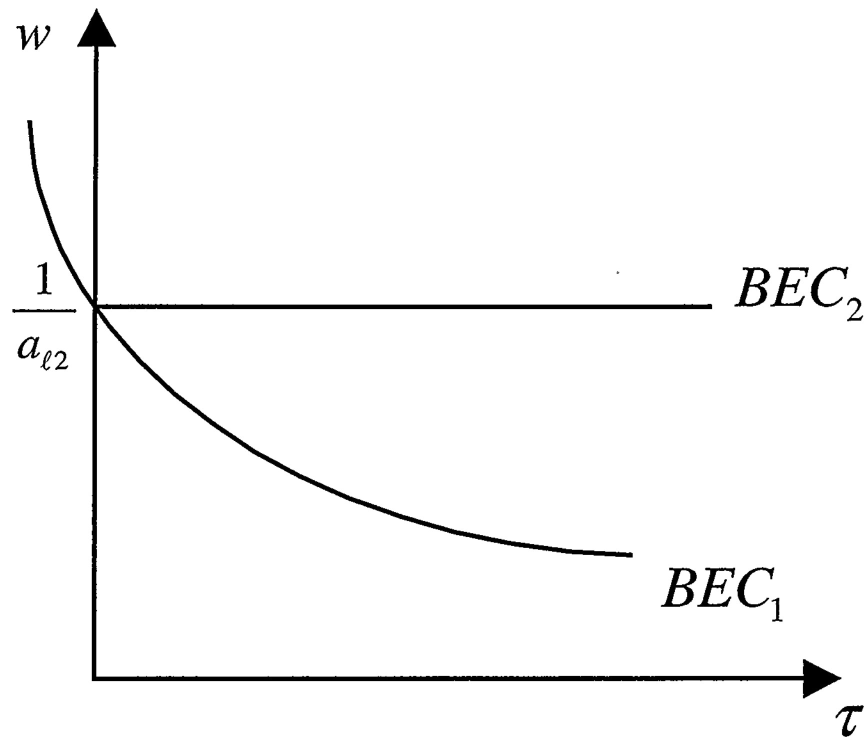
The effects of emission caps will first be explored in a one-country-world scenario, followed by a two-country world. Later, after introducing a further flexible mechanism, a two-country world with the ability to use "credits" will also be explored.

5.2.1 One-Country-World Model

Consider, for instance, a single nation representing the entire "world". Using a 2-good (an emissions-intensive "dirty" good, good one, and a zero emissions "clean" good,

good two), 2-input (emissions and labour), perfect competition model, the price equals unit cost conditions (alternatively, the break even curves) for the two sectors can be described as follows. The break-even curve for the clean good sector (BEC_2) is independent of emissions, since labour (ℓ) is the only factor required to produce the clean good. Accordingly, BEC_2 will not shift in response to any exogenous change in allowable aggregate emissions. On the other hand, the break-even curve for the dirty good sector (BEC_1) is downward sloping as illustrated in emission price and wage (τ, w) space below. In particular, as the price of emitting increases, the firm or industry requires a lower wage in order to produce at the zero-profit break-even level. Further, the dirty-good sector's break-even curve is not directly responsive to changes in allowable aggregate emission levels.

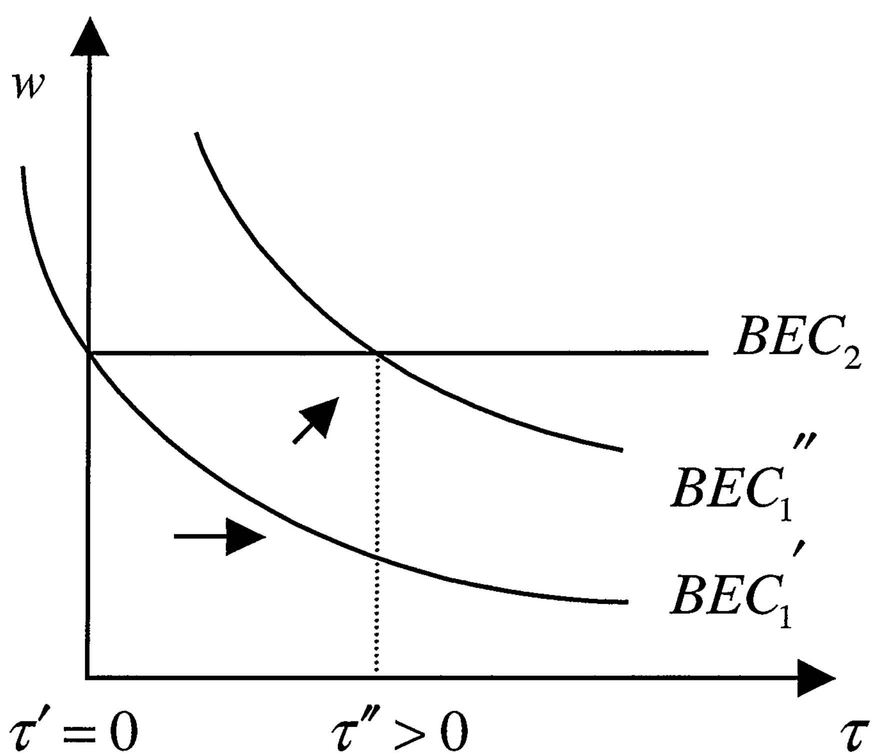
Figure 5.1: Slopes of Break-even Curves in Each of the Clean & Dirty Sectors



With this framework in mind, assume that the government tightens an exogenously set emissions constraint (cap). While emission levels do not directly affect the break-even points of a given sector, a change in their levels can create induced effects. In particular, as the nation's emissions constraint tightens, it triggers a series of events in the short-run, which results in a changed long-run equilibrium position for the nation.

When the allowable emissions level decreases, the short-run emissions price (τ) to any particular firm in the dirty sector increases and profits are eroded. Since firms were already at a break-even position before the change in emissions constraint, however, they now experience negative profits forcing exit from the dirty sector. This exit of firms correctly has negative feedback on the long-run level of emissions; while each remaining firm again produces at the original "minimum efficient scale" of output that minimizes long-run average cost, there are fewer firms and, therefore, long-run aggregate output has declined. Decreased industry output commands an increased price for the dirty good, which offsets the higher fees for emissions and, diagrammatically, necessarily moves the break-even curve away from the origin in emission price and wage (τ, w) space, as shown in Figure 5.2. This new break-even position results in a higher long-run price of emissions.

Figure 5.2: Introduction of an Emissions Cap in a One-Country-World



Since the long-run price of emissions has increased and output of the dirty good has conversely decreased to allow compliance with the lowered emissions constraint, the government of the one-country-world has achieved its goal of lowered total emissions (without the presence of carbon leakage). It is perhaps this rationale that inspired the designers of the Protocol. Since the Kyoto Protocol separates the world into two distinct categories of participants, however, it is more relevant to explore the implications of a national government introducing a cap beyond the one-country-world model.

5.2.2 Two-Country Permit-Only Model

To reflect the basic Annex I and non-Annex I taxonomy of the Protocol, consider an open-market model in which the world is divided into 2 countries (North and South). Once again using a 2-good (clean and dirty), 2-input (emissions and labour), perfectly competitive general equilibrium model, assume that only the North is subject to an emissions constraint (cap). Also assume that the Northern firms have more efficient technology and can produce more output (of good 1, the dirty good) with fewer emissions relative to firms in the South. This latter assumption corresponds with the condition Unteroberdoerster discusses in his 2001 results. This “condition”, however, is a very reasonable assumption as discussed further below.

Comparable to the one-country world scenario, as the allowable emissions level decreases in the North, the price of emitting rises in the short-run. Costs to a Northern firm in the dirty sector increase and profits are eroded. Again, since the Northern firms were already at a break-even position before the change in the emissions constraint, they now experience negative profits forcing exit from the dirty sector in the North. This exit of Northern firms from the dirty sector has the correct negative feedback on the level of Northern emissions. Such exit of Northern firms from the dirty sector also translates to lowered aggregate output of the dirty good in the North, which then puts short-run upward pressure on the world price for the dirty good.

Unlike the one-country-world, however, the increased world price for the dirty good then allows firms in the South to capture short-run positive rents in the dirty sector. Such positive rents encourage entry of firms to the dirty sector in the South until rents no longer exist. With perfect competition, each firm continues to produce at the minimum efficient scale of output, but since there are now more firms in the South, output in the South increases and now places downward pressure on the price of good one.

Since Southern firms do not face an emissions constraint like their counterparts in the North, they do not see any change in their production costs. Thus, any change in Southern profits is a direct result of a change in the world price for the dirty good. Since entry of Southern firms extracts any positive profits, firms in the South will continue to enter the dirty sector until profits are zero and, by a direct result, the world price and the world output of the dirty good equilibrate to their original levels. Thus, neither the price nor the quantities of the dirty good change in the long-run after a unilateral tightening of the emissions cap in the North, provided that both countries continue to produce the dirty good.

Since long-run input and output prices do not change, and since production levels do not change, the long-run break-even curves for each of the clean and dirty good sectors in each of the North and the South do not change, as illustrated in their respective national emission price and national wage (τ^k, w^k) space in Figures 5.3 and 5.4.

Figure 5.3: No Change in South after Introduction of Emissions Cap in the North

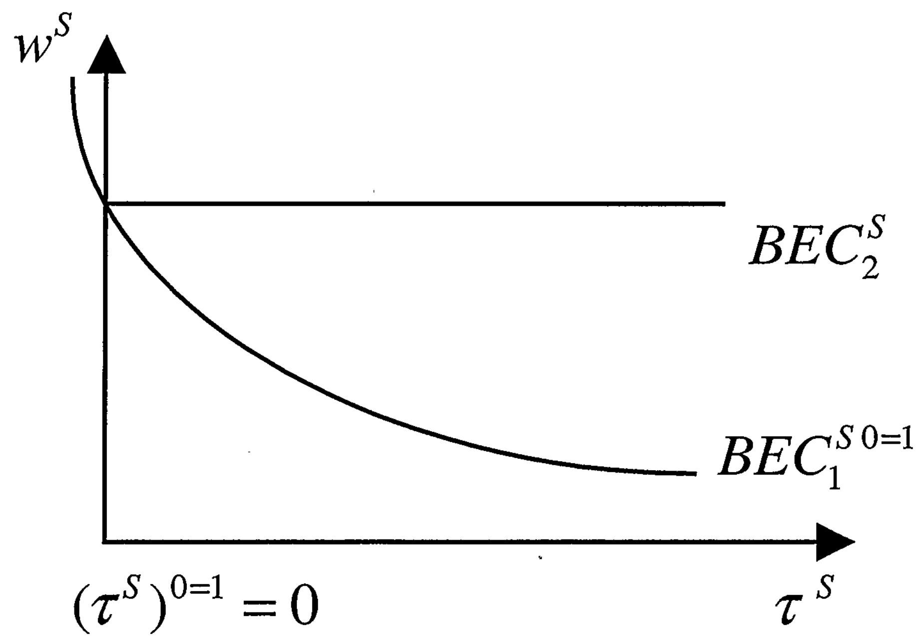
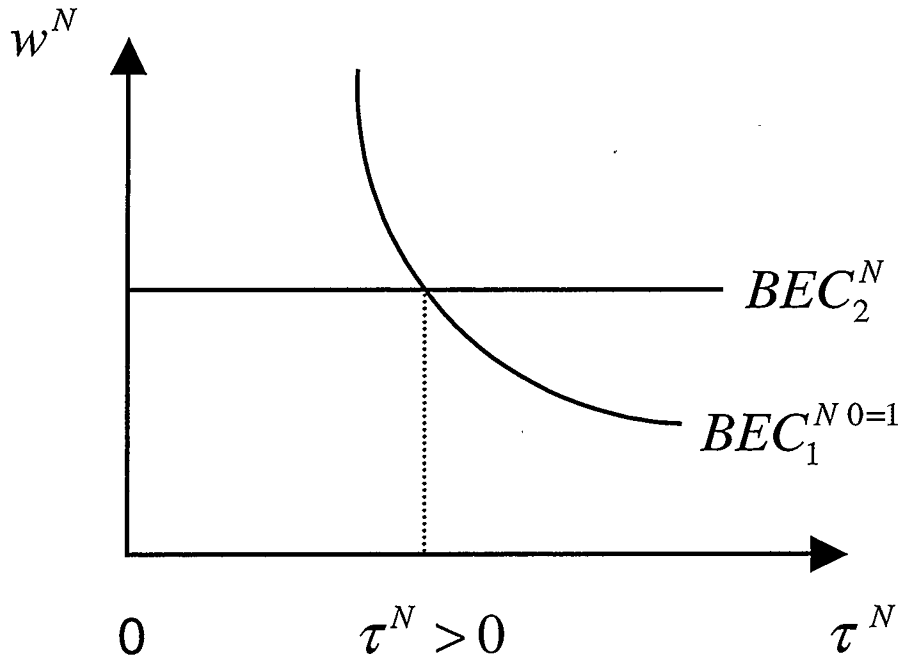


Figure 5.4: No Change in the North after Introduction of Emissions Cap in North



Nevertheless, it would not be accurate to suggest that since neither price nor quantities of the dirty good changed in the long-run that the related global emission levels also did not change. Indeed, the output of the dirty good shifted one to one from the North to the South in response to the tightened emissions cap in the North. Importantly, since the balance of dirty good production shifted to the South where the technology is less efficient, world emissions unambiguously increase. Thus, carbon leakage strictly dominates any possibility of emission reductions!

This possibility of carbon leakage is suggested but not formalized by Hyndman (1998, p.14.)[104] There is also a carbon leakage result in Copeland and Taylor's 1994 and

[104] Hyndman, Richard M., "An Overview of Emissions Trading – Fundamental Concepts and Issues", February 1998

1995 articles, but the underlying reason for such leakage differs. For instance, their 1995 article proposes possible carbon leakage in the South due to an increase in the price for the dirty good, rather than the short run increase and constant long run price discussed above. Also, the 1995 article suggests that a constraint in the North can create self-interested emission reductions in the South, which clearly does not occur in the model discussed here.[105] Nevertheless, while the approach taken in this thesis differs from that taken by others previously, it is interesting to confirm the same carbon leakage result.

5.3 Flexible Mechanisms – Clean Development Mechanism (CDM) and Credits[106]

In addition to the Emissions Trading flexible mechanism within the Kyoto Protocol, the CDM is a further flexible mechanism which claims to induce both wealth transfer (from North to South) and cost minimization benefits (for the emissions-constrained North).[107] Under the CDM, Annex I nations may invest in an emission-reducing project located in a non-Annex I nation in return for credits, provided the project generates both discernable socio-economic benefits for the host country and emission reductions that are additional to those that would occur if the project did not

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[105] Copeland, Brian R. and M. Scott Taylor, "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol", draft January 2001, p. 1

[106] The use of the word credits here is intended to reflect differing properties compared to permits. The actual instrument that results from the Clean Development Mechanism is Certified Emission Reductions, or CERs.

[107] The other flexible mechanism, not discussed here, is Joint Implementation (JI). JI allows Annex I nations to invest in an emission-reducing project located in another Annex I nation in return for credits. The credits generated under this mechanism are called Emission Reduction Units (ERUs). Again, ERUs have characteristics comparable to a credit (or CER) as opposed to a permit (or AAU). For simplicity, I will ignore this third mechanism and its related credits; introducing the JI mechanism should not significantly affect any of my results.

proceed. Of course, various other rules and modalities govern the use of the CDM, but most are in place to ensure the above conditions.

5.3.1 Discussion of the Relationship Between Permits and Credits

A. Northern Emissions-Constraint Flexibility

While the use of both credits and permits are intended to yield positive environmental results, operationally, permits differ greatly from credits. As referenced earlier for instance, the sum of the aggregate permits across countries cannot exceed the emissions cap placed on Annex I nations. On the other hand, the number of *credits* is only limited by the physical and financial constraints faced by individual parties, up to the aggregate expected emissions under a business as usual, or an alternative "baseline", scenario. Also, unlike the finite allocation of permits, credits are created dynamically by any party adhering to the rules of the CDM. Accordingly, a permit-only system constrains Annex I nations to a fixed level of emissions. By adding credits to this system, Annex I nations can generate one additional emissions unit for every credit obtained, thus allowing Annex I nations to exceed their collective allocated emissions cap by the number of credits purchased.

B. Changes in the price of Northern Emissions (τ^N)

Although the physical characteristics differ in many respects as noted above, in theory once credits are certified for use by the appropriate governing authority, both credits and permits represent equivalent *compliance unit* (CU)[108] instruments eligible for use by Northern firms. If credits and permits are fully fungible[109] in this way, then by adding Southern credits to the CU supply against a fixed Northern demand, we can reasonably predict CU prices (in this case, τ^N) to fall. In effect, the price for mitigating or offsetting emissions will fall in the North upon the introduction of credits[110]. Conversely, by introducing credits as a revenue source for the South, the South now faces both credit "revenue" for sales made to the North, as well as an equal per unit opportunity "cost" for any Southern emissions released. Noticeably, since credits and permits are fungible under the Kyoto Protocol, the Southern credit price and the Northern permit price (τ^N) must equalize for equilibrium to be reached.[111]

C. Conditional Gains from Trade in Emission Credits

As described above, the introduction of credits enables the North to face a lower price for marginal emissions abatement. Likewise, through the introduction of credits, the South is able to attract investment in domestic projects that promote technology transfer and socio-economic improvements, while also generating revenue from the

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[108] Compliance units include credits and/or permits, as both are eligible for use by Annex I parties when attempting to meet their imposed compliance obligations.

[109] Fungible is a commonly used term within Kyoto Protocol discussions to identify CUs that are exchangeable on a 1:1 basis (1 permit representing 1 metric tonne of allowable emissions is exactly equivalent to 1 Certified Emission Reduction (or credit) representing 1 metric tonne of reduced emissions.) Various use constraints may alter this slightly but in principle, the CUs are interchangeable without penalty.

[110] By accepting national GHG emissions constraints, national emissions move from being a "free" input, to bearing a cost. It is recognized that compliance with the imposed GHG emissions cap can be met via a number of alternative actions including implementation of emissions abatement technology, factor substitution, CU purchase, etc. The means of compliance will be chosen according to marginal cost of abatement/compliance. This choice will not be explored in detail here – I will assume that all of these options are being pursued as appropriate for profit maximization.

[111] It should be noted that transaction costs and creation costs associated with credits may inhibit the attractiveness of credits relative to permits. If supply of permits is sufficiently strong, for instance, (due to the withdrawal of the US, the "hot air" supply, etc.) it is possible that the price of CU will be too low for CERs to be competitive and CERs will remain out of the emissions trading market.

resulting credits. Accordingly, when the goods price and the number of North and South firms are held constant, it is clear that gains from credit trade exist between the two parties; the distributional and equity gains envisioned by the CDM appear to be plausible as the rich (Northern) Annex I nations "subsidize" the poor (Southern) non-Annex I nations via socio-economic improvements and both income and technology transfers.

In particular, using the two-country framework discussed previously, and combining the North and the South into one diagram, gains from trade between the two countries (holding the number of firms constant) can be shown in Figure 5.5.. The North is represented on the right axis, in its own national emissions and emission price (E^N, τ^N) space, with its corresponding (right) curve indicating the Northern demand for emissions (alternatively, this is the marginal abatement curve seen "backwards"). This curve (as read from the right) is downward sloping since demand for Northern emissions declines as the Northern price of emissions increases. On the other hand, the South is represented on the left axis, in its own national emissions and emission price (E^S, τ^S) space, with its corresponding (left) curve likewise indicating the Southern demand for emissions. Again, this Southern curve is also downward sloping since demand for Southern emissions declines as the price of Southern emissions increases. Finally, the length of the bottom of the diagram represents the cumulative world-level emissions (E^W).

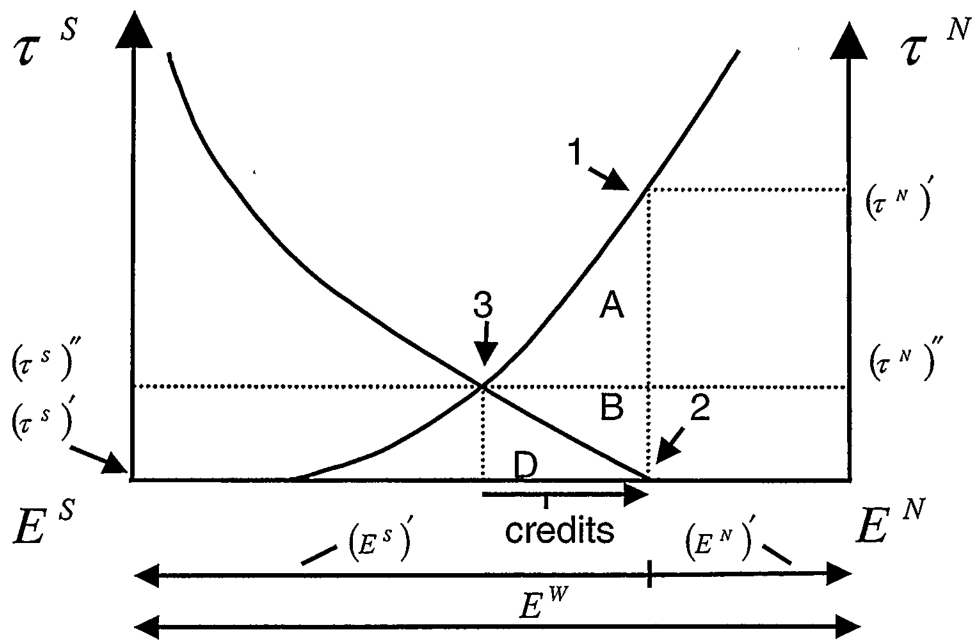
Note that the initial national equilibria occur at points 1 and 2 respectively. At point 1, the North emits an aggregate level of $(E^N)'$ and incurs a price of $(\tau^N)'$. At point 2, the South emits at an aggregate level of $(E^S)'$ and incurs a price of $(\tau^S)'$ equal to zero. By introducing credits (and by holding the number of firms and the goods price constant for this figure), the two countries are able to mutually move to point 3, where the emission prices equilibrate across the two countries such that the North faces a price less than they previously incurred and the South now faces a positive price for emitting. At this point 3, the North emits at a level greater than they did at point 1 and the South emits at a level less than they did at point 2. With the dirty good's price and the number of firms being held constant, world-level emissions do not change.

By moving from the initial equilibriums to this new joint equilibrium at point 3, the North gains areas A, B and D, which together represent the value of the increased profit maximizing output it can generate with the use of credits. However, the North retains a cost of B and D, which represents the amount of total cost incurred for purchasing Southern credits to offset its own increased emissions. Thus, with the introduction of credits (holding the number of firms and the goods price constant), the North is able to achieve a net gain of A, which represents the increased use of emissions at a price lower than it is able to pay.

The South, on the other hand, also gains from the introduction of credits. By moving from its initial equilibrium at point 2 to its new shared equilibrium at point 3, the South gains areas B and D, which together represents the revenue received for the sale of emission reductions (credits). The South, however, gives up area D, which represents the foregone revenue from lower output. Thus, with the introduction of credits (holding the number of firms constant), the South incurs a net gain of B, which represents the revenue received for credits at a price greater than its break-even cost.

Figure 5.5: Impact of Introducing Credits

(holding goods price and number of firms constant)



North gain: A + B + D;	North loss: B + D;	North net gain = A > 0
South gain: B + D;	South loss: D;	South net gain = B > 0

Clean Development Mechanism advocates would be pleased to confirm that gains from trade exist with the presence of credits, holding the number of firms and the product price constant. It is equally important, and perhaps more so for our purposes, however, to determine the implications for global emissions upon the introduction of credits to the permit-only scenario, while allowing for the number of firms as well as the dirty good price to change.

5.3.2 Key Questions Regarding the Impact of CDM Credits

Notionally, the Kyoto Protocol has included sufficient rules and modalities governing the CDM to ensure credits represent true emission reductions from a business as usual scenario, and therefore, do not increase the atmospheric level of GHGs by their existence. Assuming that adequate enforcement exists to ensure the Protocol's rules and modalities are adhered to within the CDM (which I neither suggest nor dispute), it may be appropriate to accept this no-increase postulation at the *project-level*, the level at which the CDM governs. Nevertheless, in the absence of national caps for non-Annex I nations, the Protocol does not appear to have any means for governing emissions activity beyond the *registered* project-level[112]. Then, perhaps we should ask:

1) Could the use of CDM credits alter the investing Annex I nation's emissions activity other than that which is exactly offset by the credits? For instance, could credits enable entry of Northern dirty good firms to the point of Northern carbon leakage?

2) Could the existence of CDM credits alter non-Annex I country emissions activity other than that represented by registered projects? For instance, could credits enable net entry of Southern dirty good firms to contribute to Southern carbon leakage?

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[112] In order for emission reducing projects to be eligible to receive CERs under the CDM, and in accordance with the broader Kyoto Protocol, they must first meet certain conditions and be accepted as a CDM project by the body governing the CDM (the Executive Board). Once the Executive Board accepts a project, it is registered as such, and is placed on the CDM registry. Projects that fail to be registered cannot be awarded CERs. Note that project proponents must account for any increase in emissions as a result of their project. However, this recognition of project-level leakage does not typically consider changes in national emissions resulting from an increase in general economic activity. It instead considers changes in (local) emissions in which a reasonable and immediately identifiable link between the change of emissions and the introduction of the project exist. This is a subtle but very important distinction, especially for the purposes of this paper.

3) Does the altered emissions activity contribute to global carbon leakage? In particular, what is the combined world-level effect of any changes that occur in the North and South?

Current economic theory does not appear to explore these questions. The 2-country plus credits scenario below will explore these questions further.

5.3.3 Two-Country Permit Plus Credits World

A. Impact on Emissions in the North

By extension to the two-country permit-only model discussed in section 5.2.2 above, once again consider a trade model in which the world is divided into 2 countries (North and South) where the South is now able to generate credits for use by the North. Again using a 2-good (clean and dirty), 2-input (emissions and labour), perfectly competitive general equilibrium model, once again assume that only the North is subject to an emissions constraint (cap). Also assume that the Northern firms have more efficient technology and can produce more output (of good 1, the dirty good) with fewer emissions relative to firms in the South.

As already shown, by introducing credits to the permit-only scenario the effective allowable emissions level increases in the North, enabling the short-run (emissions) price imposed on a Northern firm in the dirty sector to decrease.. In this case, since the Northern firms were already at a break-even position before the "credit inflated" change in the emissions constraint, they now experience positive profits enticing entry into the dirty sector in the North. This entry of Northern firms into the dirty sector has positive feedback on the level of Northern emissions, by an amount exactly offset by the aggregate credits that are purchased from the South. Such entry of Northern firms into the dirty sector also translates to raised aggregate output of the dirty good in the North, which then puts short-run downward pressure on the world price for the dirty good. The lowered price of Northern emissions, along with the increased output of the Northern dirty good also generates *excess demand for Southern credits.*

Regardless of the above dynamics, however, recall from the previous discussion that drafters of the Kyoto Protocol have assumed the use of credits would not increase global emissions because any increase in emissions in the North would be directly offset by Southern credits. So long as the Southern credits represent real and additional emission reductions, the world would not experience an increase in global emissions. This appears to be representative for Northern activity – provided credits are "real" at the Southern project level, the Northern cap *requires* that the combined Northern use of credits and permits directly offsets any and all Northern emissions, thereby ensuring that the North remains constrained by its emissions cap (as was required under the permit-only scenario). Accordingly, the first question from section 5.3.2 above appears to be resolved.

B. Impact on Emissions in the South

To understand the likely solutions to questions 2 and 3 from section 5.3.2 above, further study of the effect of credits on emissions activity in the South is required; should leakage[113] exist at the Southern level, it remains entirely possible for global emissions to increase as the result of the CDM under the Kyoto Protocol. In fact, since it is evident that the North will emit up to their emissions cap plus earned "real" Southern credits, the possibility of carbon leakage at the world level rests entirely on whether carbon leakage exists in the South!

Unlike the permit-only scenario, the existence of credits fosters competing effects in the South. Importantly, as credits are introduced the Northern and Southern dirty good firms face "linked" emission prices. This means that Southern firms no longer set the price for the dirty good as they did under the permit-only scenario. Thus, as the Northern dynamics discussed in section 5.3.3 (A) place downward pressure on the Northern break-even price of the dirty good, both nations face *excess demand for the dirty good.* This excess demand in the goods market equilibrium requires entry in both the North and the South dirty good sectors. More Southern firms producing at their same minimum efficient scale of output contributes to increased Southern emissions and global carbon leakage.

Also, as described in section 5.3.3 (A), as credits are introduced the South tends to face *excess Northern demand for credits.* Accordingly, this new revenue source raises

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[113] Leakage, as used here, refers to an increase of emissions not directly controlled by the Kyoto Protocol (as discussed in more detail in the section 5.1.1 above.)

firm level profits, which allows entry in the Southern dirty good market to once again increase Southern emissions and contribute to global carbon leakage.

On the other hand, however, as credits are introduced the (opportunity) cost of emitting increases in the South prompting a tendency towards *excess supply of credits*. Ceteris paribus, firm-level profits are eroded and exit from the dirty industry results. This exit from the industry results in fewer firms generating their minimum efficient scale of output, resulting in decreased emissions; thus, *excess supply of credits* negatively contributes to carbon leakage in the South.

These two final effects compete to determine whether the emissions equilibrium encourages net entry or exit for dirty good firms in the South. The ambiguous emissions equilibrium effect translates to an ambiguous carbon leakage result.

The relative magnitudes of the potentially opposing goods market equilibrium and emissions equilibrium effects will ultimately determine whether the CDM contributes to carbon leakage in the South.

5.4 Summary

Using a general equilibrium modeling approach, this chapter intuitively explored the potential for carbon leakage under the Kyoto Protocol. In particular, a one-country-world was first considered, where carbon leakage is not possible (nor logical) when an emissions constraint is imposed or tightened. On the other hand, the intuition behind the two country permit-only model suggests that global carbon leakage is an unambiguous result of placing an emissions constraint on only one of the two countries. Finally, by adding credits to this latter model, we are unable to intuitively forecast whether or not carbon leakage increases further or decreases at the world level. The formal mathematical models of these intuitive explanations are the subjects of the following chapter.

Chapter 6: Formal Modeling to Test for Carbon Leakage

6.1 Introduction

As discussed in chapter 5, this chapter explores the formal economic modeling behind carbon leakage in each of two scenarios. After introducing features common to all the models, the individual scenarios are explored in detail, including a one-country-world in which leakage cannot occur, a two-country permit-only model, and a two-country permit plus credit model. With a general equilibrium approach, the two-country permit-only model tests whether a change in a Northern emissions constraint results in global carbon leakage. Primarily, the model explores whether such a change fosters conditions to entice growth in the dirty good industry in either the North or the South. In addition, the final "credit" model explores whether the introduction of Southern-generated credits to the Northern permit-only scenario alters the carbon leakage results obtained from the "permit-only" scenario.

6.2 General Firm-Level Features

6.2.1 Dirty Good Sector

Consider perfectly competitive firms with production functions as characterized in Appendix 2, section A2.1. Each firm produces output using two inputs, emissions and labour; unlike Copeland and Taylor (1995), however, this modeling assumes that the marginal product of emissions can go to zero such that it becomes uneconomic to produce beyond a certain level of emissions. By introducing this assumption, the model allows Southern emissions to be determined by price, rather than government imposed quantity constraints.

Such an assumption is reasonable since it is well understood that greenhouse gases (GHGs) are frequently emitted in conjunction with other types of emissions. For instance, particulate matter and other airborne contaminants released through fossil fuel combustion can impair health and productivity of workers, which then drives the marginal product of emissions to zero. In other words, for a given amount of labour, a threshold level of emissions utilized may exist such that it is no longer beneficial, and indeed, may become harmful, to utilize further levels of emission. While this example may sound extreme, it is certainly not beyond the realm of possibility – consider the implications of an intensified Industrial Revolution![114] Alternatively, evidence certainly suggests that firms choose not to emit infinite amounts of greenhouse gases even when the price of emitting is zero. This reality suggests that it is appropriate to assume that firms will emit up to the point where the marginal product of emitting reaches zero.

Indeed, without the existence of environmental, health and safety regulations that impose a positive user-cost for emitting, dirty good firms may be incited to produce at greater than socially desirable levels. Importantly, the demand for environmental improvements such as emission controls rises as income rises. The North, for instance, is likely to have some form of environmental, health or safety regulations in place for the purposes of controlling airborne contaminants such as those referenced above. Such

[114] It is also possible that the marginal product of labour can reach zero and can even be negative. Consider, for instance, the cliché "too many cooks spoil the broth". For the purposes of the modeling presented here, however, this possibility is disregarded.

regulations may effectively curb greenhouse gas emissions even if the regulations do not directly target such emissions. Thus, while a broad regulation directly targeting Northern greenhouse gases does not currently exist, it is perhaps reasonable to suggest that imposing Kyoto Protocol greenhouse gas constraints is akin to tightening an "existing" cap on the North, $\overline{E}^N$. On the other hand, the South has much lower income levels than the North, and is thus much less likely to have production constraining regulations in place for the benefit of the environment.[115]

Returning to the production function, dirty good output (y_1) is represented in the following form, where k is an index denoting the respective country (N for North or S for South; absent in the case of a one-country world), subscript 1 represents the dirty good one (subscript 2 for clean good two), $f(\cdot)$ is the sub-production function, ℓ_1 is labour attributable to good one, e is emissions associated with the production of the dirty good, ϕ is a quasi-fixed cost parameter that allows for initial increasing returns to scale before imposing eventual decreasing returns to scale, v is a variable cost parameter, and α is a scale parameter:

$$y_1^k = \left[\frac{f(\ell_1^k, e^k) - \phi^k}{v^k}\right]^{1/\alpha}, \quad \alpha > 1 \qquad \text{Eqn (1)}$$

$$\left(y_1^k\right)^\alpha v^k + \phi^k = f(\ell_1^k, e^k) \qquad \text{Eqn (2)}$$

[115] This scenario, in which the North has an existing GHG constraint (while the South does not) also avoids the less interesting case in which the North specializes in the clean good and the South specializes in the dirty good.

Within the production function, the sub-production function $f(\cdot)$ is homogeneous of degree one such that an increase in the scale of inputs translates into an equal proportionate increase in $f(\cdot)$ itself. Furthermore, the $f(\cdot)$ function is everywhere monotonically increasing in labour, but it is first increasing in emissions and then decreasing in emissions, as further described and illustrated in Section A2.1 of Appendix 2.

The cost function for good one in country k (C_1^k) takes the usual form, where w and τ represent prices for the labour and emission inputs, respectively, within function $h(\cdot)$.

$$C_1^k = \begin{cases} h(w^k, \tau^k)\left((y_1^k)^{\alpha} v^k + \phi^k\right) & if\ y > 0 \\ 0 & if\ y = 0 \end{cases} \qquad \text{Eqn (3)}$$

Likewise, with positive output, average costs for the dirty good in country k (AC_1^k) are:

$$AC_1^k = \frac{C_1^k}{y_1^k} = h(w^k, \tau^k)\left((y_1^k)^{\alpha-1} v^k + \frac{\phi^k}{y_1^k} \right) \qquad \text{Eqn (4)}$$

where $h(w^k, \tau^k)(y_1^k)^{\alpha-1} v^k$ represents the firm's average variable costs, and $h(w^k, \tau^k)\left(\frac{\phi^k}{y_1^k} \right)$ represents the firm's quasi-fixed costs per unit produced.[116]

In addition, by employing Hotelling's Lemma[117], and using the cost function identified in equation (3), firm level emissions are determined as:

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[116] These are quasi-fixed costs since fixed costs equal zero when output produced equals zero, as inferred by the cost function above [equation (3)].

$$e^k = \frac{\partial C_1^k}{\partial \tau^k} = h'(w^k, \tau^k)\left((y_1^k)^\alpha v^k + \phi^k\right) \qquad \text{Eqn (5)}$$

where $\frac{\partial C_1^k}{\partial \tau^k}$ represents the differentiation of the cost function with respect to emission prices (τ^k) and $h'(\cdot)$ represents $h(\cdot)$ differentiated with respect to τ^k.

The above equations apply for the dirty good industry in each of the three scenarios.

6.2.2 Clean Good Sector

Since the clean good does not consume any emissions during the production process, the production function for a clean-good firm is simply represented as a function of labour. For instance, where k is once again an index denoting North (N) or South (S) and is ignored for the one-country world, ℓ_2 is the labour attributable to the production of clean good output (y_2), and $a_{\ell 2}$ represents the level of labour per unit of clean good output:

$$y_2^k = a_{\ell 2}^k \ell_2^k \qquad \text{Eqn (6)}$$

Further, since price equals unit cost, equation (6) implies that:

$$p_2 = a_{\ell 2}^k w^k \qquad \text{Eqn (7)}$$

Finally, with the clean good as the numeraire such that the world level price for the clean good (p_2) equals 1, equation (7) becomes:

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[117] Hotelling's lemma is discussed in Varian, Hal R., *Microeconomic Analysis, Third Edition*, W.W. Norton & Company, New York, p. 43, 1992

$$w^k = \frac{1}{a_{c2}^k} \qquad \text{Eqn (8)}$$

This condition, in which national wages are defined as the clean sector's marginal product of labour, remains constant through all three of the models discussed in this chapter. Accordingly, for modeling purposes, attention is focused on the dirty industry and w^k is suppressed from the respective cost and related functions. For simplicity, North and South wages are assumed to be equal such that $h(w^k, \tau^k)$ can be written as $\bar{h}(\tau^k)$.[118]

6.3 One-Country-World

As described in section 5.2.1, the one-country-world model explores a one-nation world, which either introduces or tightens an emissions constraint for the dirty good sector.

6.3.1 Firm Level Output

In such a world, firm-level profits are represented with the usual form described in equation (9), with p_1 representing the world-level price of the dirty good (good one).

$$\pi_1 = \begin{cases} y_1 p_1 - h(\tau)\left((y_1)^{\alpha} v + \phi\right) & \text{if} \quad y > 0 \\ 0 & \text{if} \quad y = 0 \end{cases} \qquad \text{Eqn (9)}$$

[118] The model can easily be extended to recognize different wage levels for the North and South countries. In particular, w^k need not be suppressed from the equations, or alternatively, the $h(\tau^k)$ referenced above may be written as $h^k(\tau^k)$ to reflect the applicable cost function for the respective nation.

It follows that price is equal to the long-run marginal cost (LRMC) for an individual firm at the point where profits are maximized:

$$\frac{\partial \pi_1}{\partial y_1} = 0 \quad \Leftrightarrow \quad 0 = p_1 - \alpha\, h(\tau)\, (y_1)^{\alpha-1}\, v$$

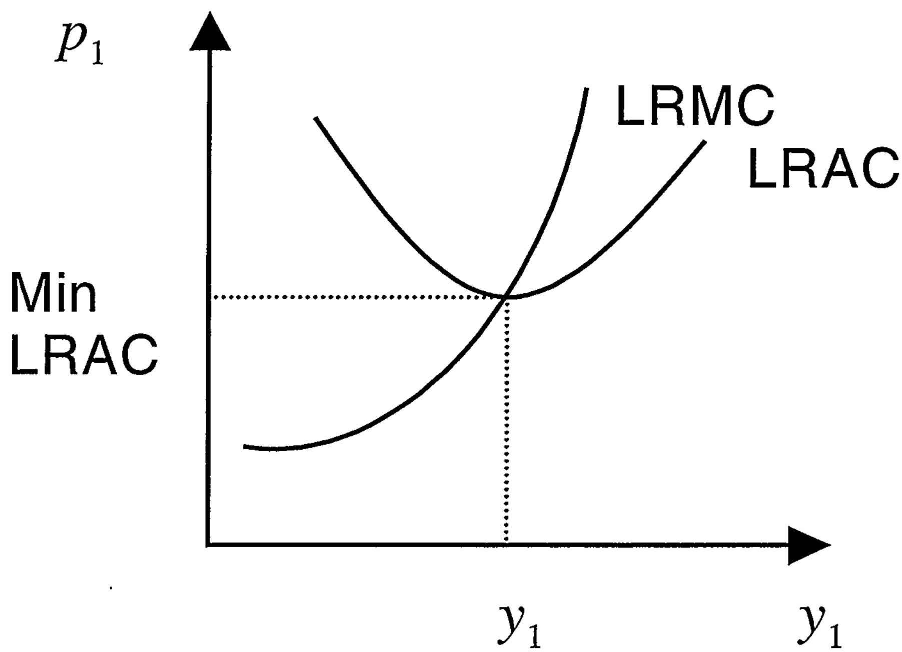
$$p_1 = \alpha \;\; h(\tau)\, (y_1)^{\alpha-1} \qquad \text{Eqn (10)}$$

Likewise, it follows that price is equal to the long-run average cost (LRAC) for an individual, perfectly competitive firm at the point where profits equal zero. Alternatively, using equation (4), such a point is expressed as:

$$p_1 = AC_1 = h(\tau)\left((y_1)^{\alpha-1} v + \frac{\phi}{y_1} \right) \qquad \text{Eqn (11)}$$

In the long-run, a perfectly competitive firm produces where price is simultaneously equal to its LRMC and its LRAC, as shown in (y_1, p_1) space in Figure 6.1.

Figure 6.1: Long-run Production Level of a Competitive Firm



Accordingly, to solve for the optimal level of output per firm, it is appropriate to simultaneously solve the firm's maximum profit condition (also referred to here as LRMC condition) and its zero profit condition (also referred to here as the LRAC condition), as identified in equations (10) and (11) respectively. The result, as shown in section A2.2 of Appendix 2, is:

$$y_1 = \left(\frac{\phi}{v(\alpha - 1)} \right)^{1/\alpha} = \tilde{y}_1 \qquad \text{Eqn (12)}$$

where $\tilde{y}_1$ represents the minimum efficient scale (MES) of output per dirty good firm. This output level occurs where the average cost of production is minimized.

6.3.2 Firm Level Emissions

By substituting the MES level of output [equation (12)] into equation (5) and then simplifying, the firm's level of emissions becomes:

$$e = h'(\tau)\left[\left(\frac{\phi}{v(\alpha-1)}\right)v + \phi\right]$$

$$e = h'(\tau)\left(\frac{\alpha\phi}{\alpha-1}\right) \qquad \text{Eqn (13)}$$

In addition, and as further calculated in Appendix 2 (section A2.3), firm level emissions per unit of output is expressed as:

$$\frac{e}{y_1} = \alpha\, h'(\tau)\, v^{1/\alpha}\left(\frac{\phi}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} \qquad \text{Eqn (14)}$$

6.3.3 Dirty Good Industry-level Break-Even Conditions

To determine the break-even conditions for a firm in the dirty good industry (BEC_1), it is useful to substitute the MES level of output found in equation (12) into either the LRMC condition found in equation (10) or the LRAC condition found in equation (11). Using the former, the BEC for sector 1 becomes:

$$p_1 = \alpha\ v\ h(\tau)\left(\frac{\phi}{v(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}} = \alpha\ h(\tau)\, v^{1/\alpha}\left(\frac{\phi}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}} \qquad \text{Eqn (15)}$$

Totally differentiating equation (15) provides:

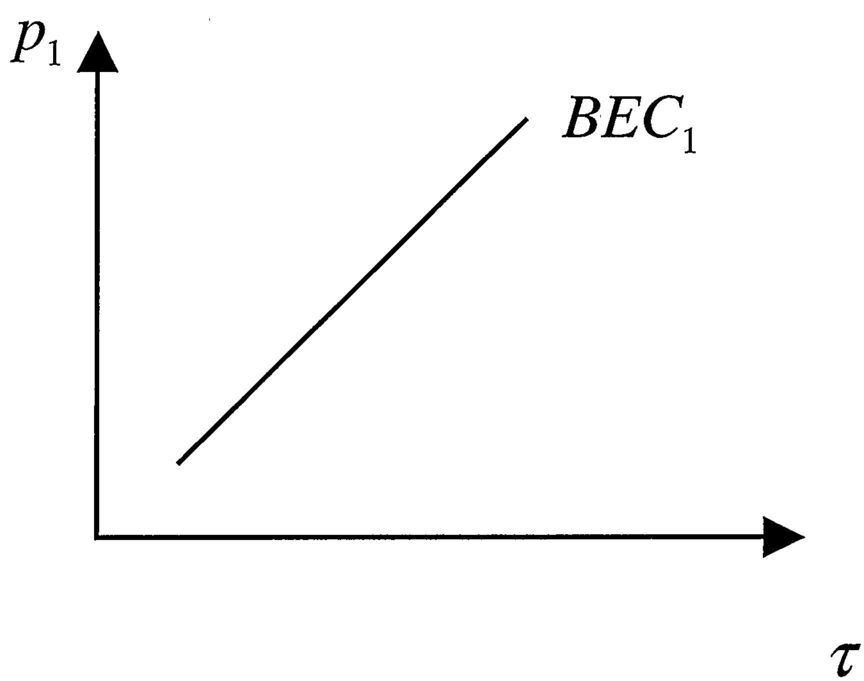
$$dp_1 = \alpha\ v^{1/\alpha}\left(\frac{\phi}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}} h'(\tau)\,d\tau \qquad \text{Eqn (16)}$$

Equation (16) then allows the calculation of the following relationship:

$$\frac{dp_1}{d\tau} = \alpha \; v^{1/\alpha} \left(\frac{\phi}{(\alpha - 1)} \right)^{\frac{\alpha-1}{\alpha}} h'(\tau) \qquad \text{Eqn (17)}$$

In (τ, p_1) space, Figure 6.2 illustrates what equation (17) confirms: as the price of emissions increases, the break-even price increases for the dirty good sector. As profits erode, firms exit the industry, output declines and the price necessarily increases.

Figure 6.2: Dirty Good Break Even Curve in a One-Country-World



6.3.4. Goods Market Equilibrium

The goods market equilibrium (GME) condition requires that supply equals demand in the dirty good industry. For simplicity, assume quasi-linear utility such that world demand for the dirty good is independent of income. Thus:

$$D(p_1) = n_1 y_1$$

$$D(p_1) = n_1 \left(\frac{\phi}{v(\alpha - 1)} \right)^{1/\alpha} \qquad \text{Eqn (18)}$$

where $D(p_1)$ represents world demand for the dirty good (as a function of dirty good price) and n_1 represents the number of firms in the dirty good sector.

By substituting the break-even condition identified in equation (15) into equation (18), p_1 is removed to provide the GME equation:

$$D\left[\alpha \ h(\tau) v^{1/\alpha} \left(\frac{\phi}{\alpha - 1} \right)^{\frac{\alpha - 1}{\alpha}} \right] = n_1 \left(\frac{\phi}{v(\alpha - 1)} \right)^{1/\alpha} \qquad \text{Eqn (19)}$$

Totally differentiating the GME found in equation (19) provides:

$$D'(\cdot)\, h'(\tau)\, \alpha \ v^{1/\alpha} \left(\frac{\phi}{\alpha - 1} \right)^{\frac{\alpha - 1}{\alpha}} d\tau \ - \ \left(\frac{\phi}{v(\alpha - 1)} \right)^{1/\alpha} dn_1 = 0 \qquad \text{Eqn (20)}$$

where $D'(\cdot)$ is demand for the dirty good, differentiated with respect to emission price, τ. Alternatively, equation (20) is expressed as:

$$A_{11}\, d\tau \ + A_{12}\, dn_1 = A_{13}\, d\overline{E} \qquad \text{Eqn (21)}$$

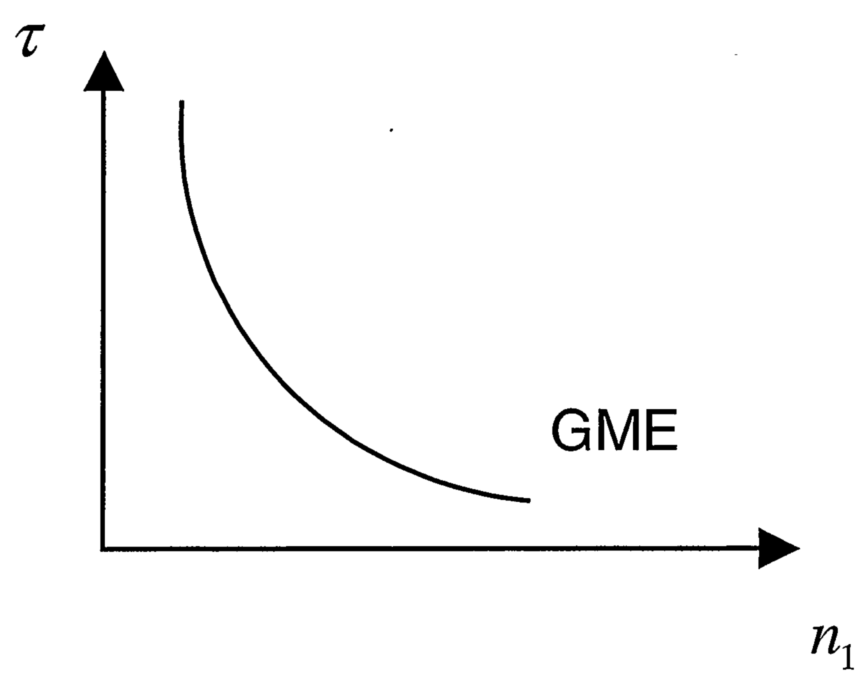
where $\quad A_{11} < 0, \quad A_{12} < 0, \quad A_{13} = 0. \qquad$ Eqn (22)

Equations (20) through (22) reveal:

$$\frac{d\tau}{dn_1} = \frac{-A_{12}}{A_{11}} < 0 \qquad \text{Eqn (23)}$$

Thus, equation (23) confirms the downward slope of the GME curve in (n_1, τ) space as illustrated in Figure 6.3, since as the price of emissions increases, the break-even price level increases, firms exit the dirty good industry, and aggregate output decreases.

Figure 6.3: Goods Market Equilibrium Curve in a One-Country-World



6.3.5 Emissions Equilibrium

Since the one-country-world government has imposed an exogenous cap on national emissions, it is necessary that aggregate emissions equal the capped level for maximum production levels:

$$E = \overline{E} \qquad \text{Eqn (24)}$$

where $\overline{E}$ represents the government imposed national emissions cap, and E represents the actual level of national emissions.

Also, because each firm in the dirty good sector produces the equivalent MES level of output, national emissions are represented as the number of firms multiplied by firm-level emissions:

$$E = n_1 e \qquad \text{Eqn (25)}$$

Using the emissions equations from equation (13) and combining equations (24) and (25), the emissions equilibrium (EE) constraint for the dirty good industry is represented as:

$$\overline{E} = n_1 \, h'(\tau)\left(\frac{\alpha\phi}{\alpha-1}\right) \qquad \text{Eqn (26)}$$

where total national emissions must equal the exogenously set emissions cap, or alternatively, the number of firms multiplied by their own emissions level must (in aggregate) equal the emissions cap.

Differentiating equation (26) and then rearranging provides:

$$n_1\left(\frac{\alpha\phi}{\alpha-1}\right)h''(\tau)\, d\tau \;+\; \left(\frac{\alpha\phi}{\alpha-1}\right)h'(\tau)\, dn_1 \;=\; d\overline{E} \qquad \text{Eqn (27)}$$

where $h''(\tau)$ represents $h'(\tau)$ differentiated by τ.

Alternatively, this equation is represented as the following:

$$A_{21}\, d\tau \;+ A_{22}\, dn_1 \;=\; A_{23}\, d\overline{E} \qquad \text{Eqn (28)}$$

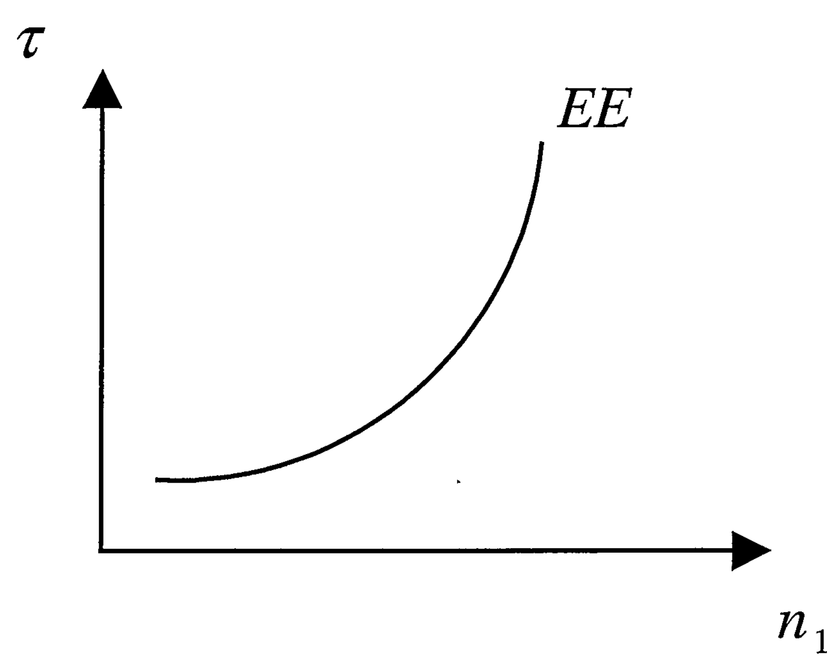
where $$A_{21} < 0, \quad A_{22} > 0, \quad A_{23} = 1.$$ Eqn (29)

Equations (27) through (29) reveal:

$$\frac{d\tau}{dn_1} = \frac{-A_{22}}{A_{21}} > 0$$ Eqn (30)

Thus, equation (30) confirms the upward slope of the EE curve in (n_1, τ) space as shown in Figure 6.4. As more dirty good firms enter the market, there is pressure for short-run aggregate emissions to increase. Since an absolute cap restricts the allowable emissions, however, the price of emissions must increase to provide the necessary negative feedback on emissions.

Figure 6.4: Emissions Equilibrium Curve in a One-Country-World

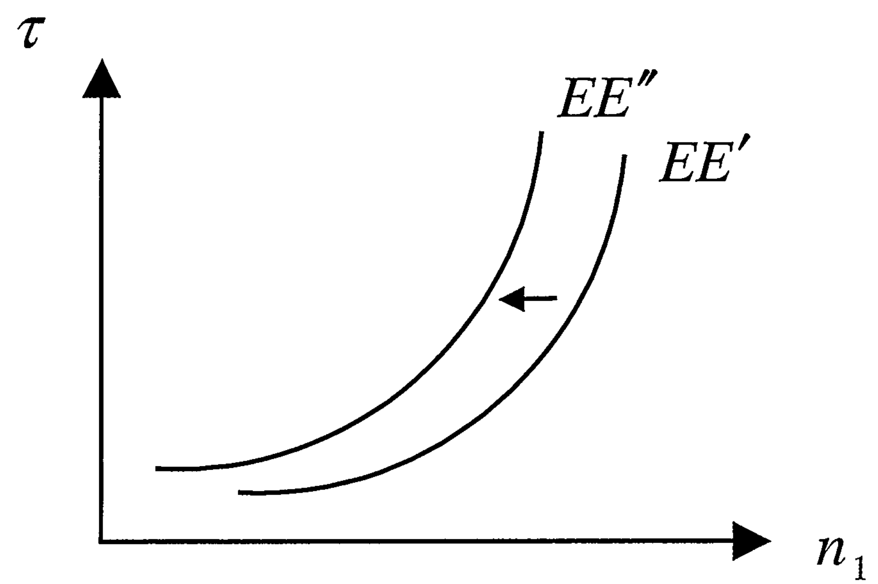


In addition, equations (27) through (29) suggest:

$$\left.\frac{dn_1}{d\overline{E}}\right|_{d\tau=0} = \frac{1}{A_{22}} > 0 \qquad \text{Eqn (31)}$$

Thus, as Figure 6.5 illustrates in (n_1, τ) space below, equation (31) confirms that as the emissions cap is *tightened* ($\overline{E}$ decreases) there is exogenous shift to the left to EE''. In general, the price of emissions increases and more firms exit the market.

Figure 6.5: Shift in Emissions Equilibrium Curve In Response to a Tightening of an Emissions Cap in a One-Country-World



6.3.6 General Equilibrium

Translating the GME and EE conditions [equations (20) and (27)] into matrix form, using the forms represented in equations (21) and (28) respectively, the system of two equations can be simultaneously solved.

$$\begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} d\tau \\ dn_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} d\overline{E} \qquad \text{Eqn (32)}$$

From the signs identified in each of equations (22) and (29), the determinant (Δ) of the above matrix is:

$$\Delta \;=\; A_{11}A_{22} - A_{21}A_{12} \;<\; 0 \qquad \text{Eqn (33)}$$

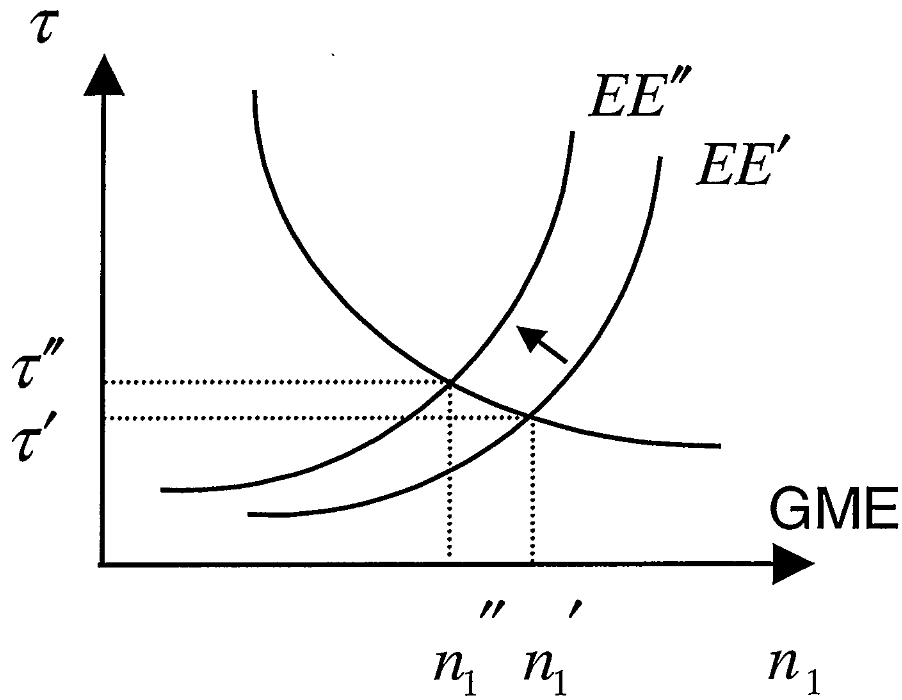
This now allows the calculation of the following relationships:

$$\frac{d\tau}{d\overline{E}} = \frac{-A_{12}}{\Delta} < 0 \qquad \text{Eqn (34)}$$

$$\frac{dn_1}{d\overline{E}} = \frac{A_{11}}{\Delta} > 0 \qquad \text{Eqn (35)}$$

Equation (34) implies that as the emissions constraint is *tightened* ($\overline{E}$ decreases), the price of emissions increases. Likewise, equation (35) confirms that as the emissions cap is *tightened*, firms exit the industry to reduce the total number of firms in the dirty good industry. These effects are illustrated in (n_1,τ) space in Figure 6.6 below:

Figure 6.6: Increase in Emissions Price & Exit of Dirty Good Firms in Response to Tightening of the Emissions Constraint in a One-Country World



Also, recalling equation (16), divide through by the change in emissions constraint:

$$\frac{dp_1}{d\overline{\overline{E}}} = \alpha \; v^{1/\alpha}\left(\frac{\phi}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}} h'(\tau)\frac{d\tau}{d\overline{\overline{E}}} \; < 0 \qquad \text{Eqn (36)}$$

and, using the $\frac{d\tau}{d\overline{\overline{E}}}$ result found in equation (34) above:

$$\frac{dp_1}{d\overline{\overline{E}}} = \alpha \; v^{1/\alpha}\left(\frac{\phi}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}} h'(\tau)\left(\frac{A_{12}}{\Delta}\right) \; < 0 \qquad \text{Eqn (37)}$$

As the emissions constraint ($\overline{E}$) tightens (decreases), equation (37) confirms that price in the dirty good sector must increase to enable firms to continue to break-even with higher emissions fees.

Accordingly, the mathematical results contained in this section confirm the intuition outlined in section 5.2.1 of the previous chapter. In particular, in a one-country-world, as the emissions constraint is exogenously *tightened*, the price of emitting increases, profits are eroded in the dirty good sector, firms exit the dirty good industry, output of good one decreases, and the price of good one increases to a level that allows the dirty good firms to cover their increased price. This one-country-world government succeeds in reducing global emissions.[119]

6.4 Two-Country Permit-Only Model

As described in section 5.2.2, the two-country permit-only model explores a two-nation world in which only one of the two countries introduces or tightens an emissions constraint for its dirty good sector. It is useful to note that this model shares the firm and industry level results of the one-country-world, except this two-country permit-only model is denoted with indices ($k = N, S$), with the North and the South functions being symmetrical to the other. For clarity, the derivations will be repeated below.

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[119] Alternatively, the reduction in emissions could be accomplished through a Pigouvian tax in this one-country-world. According to equation (17), an exogenous increase in τ requires a corresponding increase in the price of the dirty good for the sector to break even. Through the induced increase in the product price, the equilibrium is displaced up and to the left along the goods market equilibrium curve. At the higher product price, there are fewer firms as well as lower emissions per firm. Thus, there are lower aggregate emissions.

6.4.1 Firm Level Output in Each Country

In a two-nation world, firm-level profits are represented in the usual [equation (9)] form, with profits for firms in each country being identified as $k = N$ or $k = S$:

$$\pi_1^k = \begin{cases} y_1^k p_1 - h(\tau^k)\left((y_1^k)^\alpha v^k + \phi^k\right) & if \quad y > 0 \\ 0 & if \quad y = 0 \end{cases} \qquad \text{Eqn (38)}$$

Profit maximization yields the long-run marginal cost (LRMC) condition for an individual firm:

$$\frac{\partial \pi_1^k}{\partial y_1^k} = 0 \quad = p_1 - \alpha\, h(\tau^k)\, (y_1^k)^{\alpha-1}\, v^k$$

$$p_1 = \alpha\; v^k\; h(\tau^k)\, (y_1^k)^{\alpha-1} \quad ,k = N, S \qquad \text{Eqn (39)}$$

Likewise, using equation (4), the long-run average cost (LRAC) condition for an individual, perfectly competitive firm occurs at the point where profits equal zero. Alternatively, such a point is expressed as:

$$p_1 = AC_1^k = h(\tau^k)\left((y_1^k)^{\alpha-1} v^k + \frac{\phi^k}{y_1^k} \right) \qquad \text{Eqn (40)}$$

In the long-run, a perfectly competitive firm in each country produces where its LRMC is equal to its LRAC, as shown previously in Figure 6.1. Accordingly, to solve for the optimal level of output per firm in each country, it is appropriate to simultaneously solve the firm's LRMC condition (profit maximization) and its LRAC condition (zero profits) as identified in equations (39) and (40) respectively. The result, as shown in Appendix 2, section A2.2 in more detail is:

$$y_1^k = \left(\frac{\phi^k}{v^k(\alpha-1)} \right)^{1/\alpha} = \tilde{y}_1^k \quad , \quad k = N,S \qquad \text{Eqn (41)}$$

which also represents the minimum efficient scale (MES) of output per firm in each of the North and the South.

6.4.2 Firm-Level Emissions in Each Country

By substituting the MES level of output obtained in equation (41) into the emissions equation found in equation (4) and then simplifying, the firm's level of emissions in each country becomes:

$$e^k = h'(\tau^k) \left[\left(\frac{\phi^k}{v^k(\alpha-1)} \right) v^k + \phi^k \right]$$

$$e^k = h'(\tau^k) \left(\frac{\alpha\phi^k}{\alpha-1} \right) \quad , \quad k = N,S \qquad \text{Eqn (42)}$$

Southern firms do not face a government imposed emissions cap, and they do not face a positive price for emissions $(\tau^S = 0)$ so they continue to emit until the marginal product of emitting equals zero.[120] This implies that unlike Northern aggregate emissions, which are constrained by policy, Southern aggregate emissions are determined endogenously.

In addition, and as further calculated in Appendix 2 (section A2.3), firm level emissions per unit of output for each country are expressed as:

$$\frac{e^k}{y_1^k} = \alpha\, h'(\tau^k)\, \left(v^k\right)^{1/\alpha} \left(\frac{\phi^k}{\alpha-1} \right)^{\frac{\alpha-1}{\alpha}} \quad , \quad k = N,S \qquad \text{Eqn (43)}$$

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[120] See the discussion about the level of emissions when firms do not incur an input cost for emissions in section 6.2.1.

Finally, assume the North is more efficient (cleaner) than the South due to differing stages of development. We assume that $v^S > v^N$ or $\phi^S > \phi^N$ or both, so that the South has an inferior technology. Even if the emission prices were the same in both countries, this would imply greater emissions per unit of output in the South:

$$\frac{e^S}{y_1^S} > \frac{e^N}{y_1^N} \qquad \text{Eqn (44)}$$

This assumption is important for interpreting the results found later in this Section.

6.4.3 Break-Even Conditions in each Country

To determine the break-even conditions for a firm in the dirty good sector in each country (BEC_1^k), it is useful to substitute the respective MES level of output found in equation (41) into either the profit maximization condition from equation (39) or the zero profit condition from equation (40). Using the former, and since Southern firms do not face a government imposed emissions cap [and, accordingly, they do not bear a positive price for emissions ($\tau^S = 0$)] the Southern BEC becomes:

$$p_1 = \alpha \; v^S \; h(\tau^S)\left(\frac{\phi^S}{v^S(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}$$

$$p_1 = \alpha \; h(0) \left(v^S\right)^{1/\alpha}\left(\frac{\phi^s}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} \qquad \text{Eqn (45)}$$

Note that since all the terms in the Southern BEC [equation (45)] are constants, the world-level price for the dirty good is determined by the Southern dirty good sector. This price is represented as $\hat{p}_1$ in Figure 6.7 below.

Inputting the MES level of output found in equation (41) into the profit maximization condition found in equation (39) the BEC for sector one in the North becomes:

$$p_1 = \alpha \ v^N \ h(\tau^N)\left(\frac{\phi^N}{v^N(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}$$

$$= \ \alpha \ h(\tau^N)\left(v^N\right)^{1/\alpha}\left(\frac{\phi^N}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} \qquad \text{Eqn (46)}$$

Totally differentiating the North break-even curve and rearranging leaves:

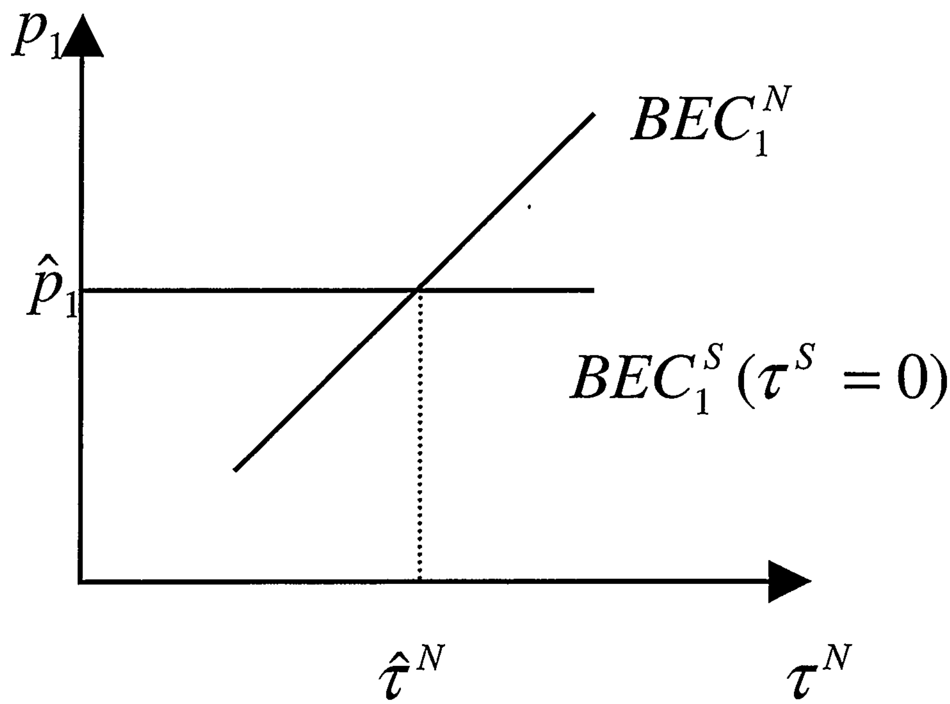
$$dp_1 = \alpha\left(v^N\right)^{1/\alpha}\left(\frac{\phi^N}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} h'(\tau^N)\, d\tau^N \qquad \text{Eqn (47)}$$

This allows the calculation of the following relationship:

$$\frac{dp_1}{d\tau^N} = \alpha\left(v^N\right)^{1/\alpha}\left(\frac{\phi^N}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} h'(\tau^N) \quad > 0 \qquad \text{Eqn (48)}$$

Equation (48) confirms that as the long-run northern price of emissions increases the price of the dirty good also increases. This relationship is represented along with the Southern BEC [equation (45)] in (τ^N, p_1) space in Figure 6.7 below:

Figure 6.7: Industry-Level Break-Even Curves for each of the North and South Dirty Good Industries under a Permit-Only Scenario



6.4.4 North and South General Equilibrium Solutions

Using the break-even constraints for the dirty good sector in each country [as found in equations (45) and (46) and as also represented by Figure 6.7 above], and by considering the emissions equilibrium (EE) and the goods market equilibrium (GME), it is possible to assess whether carbon leakage exists under a two-country permit-only scenario.

A. Break-Even Constraints

From section 6.4.3, it is evident that as the long-run price of emissions rises in the North, the price of the dirty good must also increase to maintain the industry's break-even level. Accordingly, the BEC for the Northern dirty good sector rises. On the other hand, as Figure 6.7 previously illustrated, the price-setting Southern BEC is constant, and thus, horizontal.

Also since p_1 is given by the Southern BEC [equation (45)], together the Southern and Northern [equation (46)] BECs for sector one determine τ^N:

$$\alpha h(0)\left(v^S\right)^{1/\alpha}\left(\frac{\phi^S}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} = \alpha\, h\left(\tau^N\right)\left(v^N\right)^{1/\alpha}\left(\frac{\phi^N}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} \qquad \text{Eqn (49)}$$

This τ^N solution was represented earlier as $\hat{\tau}^N$ in Figure 6.7.

In addition, recalling that Southern firms do not pay a price for emitting ($\tau^S = 0$), recognizing the price of labour (w^k) is given by equation (8), and since the price of Northern emissions (τ^N) is given by equation (49), equilibrium levels of North and South firm-level emissions are provided by emissions equation (42).[121]

Also, note that each of the BECs for the respective North and South dirty good industries are independent of the Northern emissions constraint ($\overline{E}^N$) as well as the number of Northern and Southern firms (n_1^N, n_1^S respectively).

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[121] Note that since the solved form of the variables is not required for the remaining two-country permit plus credit analysis, the subsequent equations will continue with the unsolved variable form.

In particular, by totally differentiating the Southern BEC [equation (45)] for the dirty good sector (which defines price) it can be shown that a change in the Northern emissions cap does not alter the long-run price of the dirty good:

$$\frac{dp_1}{d\bar{E}^N} = 0 \qquad \text{Eqn (50)}$$

This was an expected result; since Southern firms do not pay a positive price for emissions, the long-run price for the dirty good remains at its original level.

Finally, by using the Northern BEC for the dirty good sector [as defined by equation (46)], or by using equation (49) which defines τ^N, it is shown that since price for the dirty good does not rise, the long-run τ^N also does not respond:

$$\frac{d\tau^N}{d\bar{E}} = 0 \qquad \text{Eqn (51)}$$

It should be emphasized that a tightening of the Northern emissions cap does not change the price of Northern emissions.[122]

B. Goods Market Equilibrium

The GME condition requires that dirty good demand equals dirty good supply across the two countries. In particular, it requires that:

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[122] Equation (51) arises because there is not an integrated world emissions market. Correspondingly, the alternative of applying a Pigouvian tax leads to further unconventional effects. In Figure 6.7, if North sets a Pigouvian tax above $\hat{\tau}^N$ it will not be able to compete with South in the production of the dirty good. Consequently, either the North's aggregate output of the dirty good will be driven to zero or the South will become completely specialized in the dirty good (so the price of the dirty good can rise), or both. On the other hand, if the North sets a Pigouvian tax below $\hat{\tau}^N$, either the North will become completely specialized in the dirty good or the South's production will go to zero, or both. A Pigouvian tax set at $\hat{\tau}^N$ is consistent with emission levels varying from zero (with zero output of the dirty good) to high levels (with complete specialization in the dirty good). Consequently, in this two-country model there is not an equivalent Pigouvian tax for each aggregate emissions constraint and associated cap and trade program.

$$D(p_1) = n_1^S y_1^S + n_1^N y_1^N \qquad \text{Eqn (52)}$$

Recall that the price of the dirty good (p_1) is constant as identified in the Southern break-even condition [equation (45)]. By including the MES levels of output for each country [equation (41)] in the above equation and then totally differentiating,

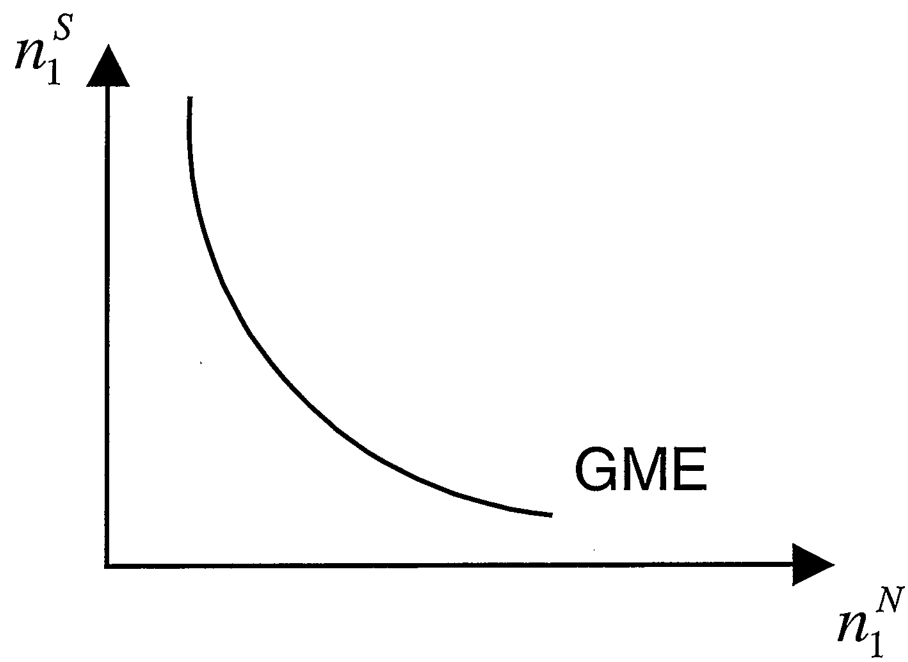
$$0 = \left(\frac{\phi^S}{v^S(\alpha - 1)} \right)^{1/\alpha} dn_1^S + \left(\frac{\phi^N}{v^N(\alpha - 1)} \right)^{1/\alpha} dn_1^N \qquad \text{Eqn (53)}$$

which confirms the following relationship:

$$\left. \frac{dn_1^S}{dn_1^N} \right|_{GME} = -\left(\frac{\phi^N v^S}{v^N \phi^S} \right)^{1/\alpha} < 0 \qquad \text{Eqn (54)}$$

As the above equation suggests, and as the following figure illustrates, the goods market equilibrium (GME) in the permit only scenario is downward sloping in (n_1^N, n_1^S) space. As Northern firms enter the dirty good market, Southern firms must exit the dirty good market in order to maintain the same level of dirty good output.

Figure 6.8: Goods Market Equilibrium in a 2 Country, Permit-Only Scenario



C. Emissions Equilibrium

To determine the emissions equilibrium (EE), it is necessary to consider the emission levels of each country. In the North, for instance, because each firm in the dirty good sector produces at the MES level of output, Northern emissions look like:

$$\overline{E}^N = n_1^N e^N \qquad \text{Eqn (55)}$$

Recalling firm-level emissions from the Northern firms [equation (42)], differentiating the above with respect to $\overline{E}$ and n_1^N allows:

$$d\overline{E}^N = e^N \, dn_1^N \qquad \text{Eqn (56)}$$

Recognizing that the above equation is independent of the number of Southern firms, equation (56) suggests the following relationship:

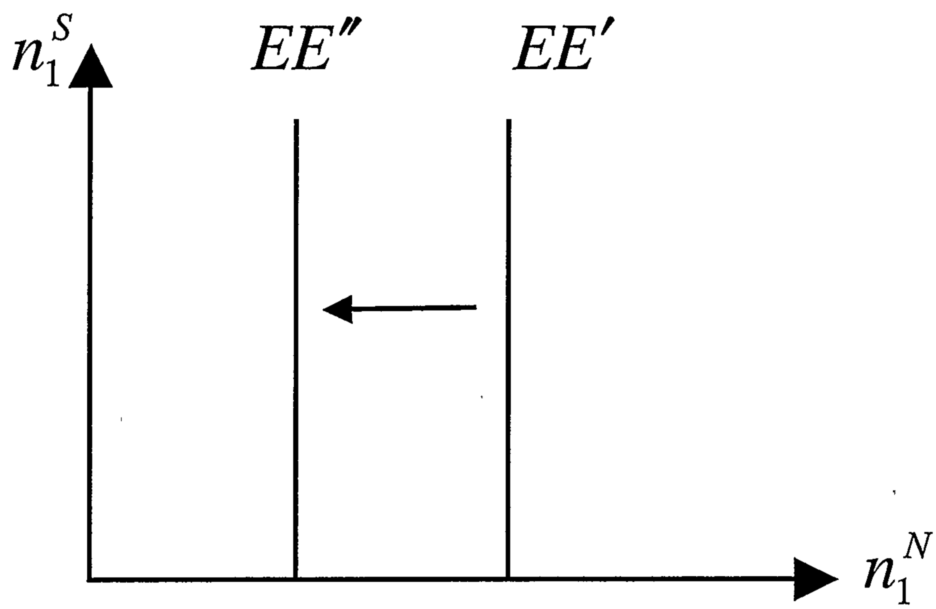
$$\left.\frac{dn_1^S}{dn_1^N}\right|_{EE} = \frac{e^N}{0} = \infty \qquad \text{Eqn (57)}$$

Equation (56) also suggests the following relationship:

$$\left.\frac{dn_1^N}{d\bar{E}^N}\right|_{\substack{EE \\ d\tau^N=0}} = e^N > 0 \qquad \text{Eqn (58)}$$

As Figure 6.9 depicts in (n_1^N, n_1^S) space, the EE curve is defined by the number of Northern firms (and is independent of the number of Southern firms) which confirms that only Northern firms and their related emissions are a function of the Northern emissions constraint. The figure also illustrates equation (58) which suggests that as the Northern emissions constraint is *tightened*, the number of Northern firms decrease:

Figure 6.9: Shift in the Emissions Equilibrium Curve when the Northern Emission Constraint is Tightened in a 2 Country Permit-Only Model



Furthermore, note that equation (55) implies a solution to the number of sector-one firms in the North:

$$n_1^N = \frac{\overline{E}^N}{e^N} \qquad \text{Eqn (59)}$$

By substituting the emissions equation derived earlier [equation (42) plus the w_1^N, τ^N derived earlier] into equation (59) and then simplifying, the number of Northern sector-one firms are now represented in equation (60):

$$n_1^N = \frac{\overline{E}}{h'(\tau^N)\left(\frac{\alpha\phi^N}{\alpha - 1}\right)}$$

$$n_1^N = \frac{\overline{E}(\alpha - 1)}{\alpha\,\phi^N\,h'(\tau^N)} \qquad \text{Eqn (60)}$$

Conversely, using the GME condition provided in equation (52) and using the number of Northern firms as defined in equation (60), the number of Southern firms is:

$$n_1^S = \left[D(p_1) - n_1^N y_1^N\right] / y_1^S \qquad \text{Eqn (61)}$$

Finally, with all the variables now known from equations and calculations identified above, consider the EE condition, in which E^W represents world-level emissions:

$$E^W = \overline{E}^N + n_1^S e^S \qquad \text{Eqn (62)}$$

D. General Equilibrium

Totally differentiating the number of Northern firms [equation (60)] and then rearranging, provides:

$$\frac{dn_1^N}{d\overline{E}} = \frac{\alpha - 1}{\alpha \phi^N \left(\frac{\partial h(\cdot)}{\partial \tau^N} \right)} > 0 \qquad \text{Eqn (63)}$$

As anticipated, if the emissions constraint is *tightened* ($\overline{E}$ decreases) in the North, the number of Northern firms in the dirty sector declines.

Similarly, totally differentiating the number of Southern firms [equation (61)] provides:

$$dn_1^S = \frac{1}{y_1^S}\left[D'(p_1)dp_1 - y_1^N dn_1^N\right] \qquad \text{Eqn (64)}$$

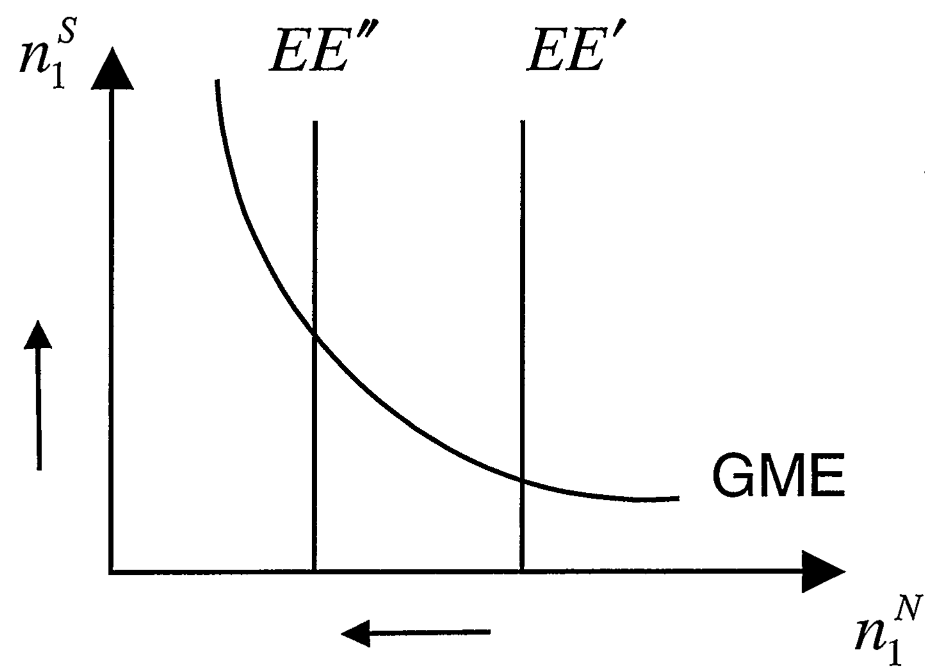
Dividing both sides of equation (64) by $d\overline{E}$ and then using equations (50)and (63) suggests:

$$\frac{dn_1^S}{d\overline{E}^N} = \frac{1}{y_1^S}\left[D'(p_1)\frac{dp_1}{d\overline{E}^N} - y_1^N \frac{dn_1^N}{d\overline{E}^N}\right]$$

$$\frac{dn_1^S}{d\overline{E}^N} = \frac{-y_1^N}{y_1^S}\left(\frac{\partial n_1^N}{\partial \overline{E}^N}\right) < 0 \qquad \text{Eqn (65)}$$

Contrary to the Northern case, therefore, as the Northern emissions constraint is *tightened*, the number of Southern firms increases. Figure 6.10 illustrates the change in Northern and Southern firms in (n_1^N, n_1^S) space below.

Figure 6.10: Exit of Northern & Entry of Southern Dirty Good Firms when the Northern Emissions Constraint is Tightened in a 2 Country Permit-Only World



To confirm that emissions from individual firms (in either country) don't change it is appropriate to totally differentiate equation (42) to show:

$$\frac{de^k}{d\overline{E}^N} = 0 \qquad \text{Eqn (66)}$$

Accordingly, knowing that emission levels do not change at the individual firm level, it is appropriate to use the EE condition [equation (62)] to consider whether carbon leakage exists in this two-country permit-only model:

$$dE^W = d\overline{E}^N + e^S\, dn_1^S$$

$$\frac{dE^W}{d\overline{E}^N} = 1 + e^S \frac{dn_1^S}{d\overline{E}^N} \qquad \text{Eqn (67)}$$

Equation (67) suggests that if $\frac{dE^W}{d\overline{E}^N} = 1 + 0 = 1$, carbon leakage does not occur. To determine the full result, however, equation (65) must be considered within equation (67):

$$\frac{dE^W}{d\overline{E}^N} = 1 - e^S \frac{y_1^N}{y_1^S}\left(\frac{\partial n_1^N}{\partial \overline{E}^N}\right) \qquad \text{Eqn (68)}$$

Combining equation (68) with equation (63) yields,

$$\frac{dE^W}{d\overline{E}^N} = 1 - e^S \frac{y_1^N}{y_1^S}\left(\frac{\alpha - 1}{\alpha \phi^N\, h'(\tau^N)}\right) \qquad \text{Eqn (69)}$$

Since the last term in equation (69) is the reciprocal of Northern emissions equation (42) such that the last term equals $(e^N)^{-1}$, equation (69) can be simplified as:

$$\frac{dE^W}{d\overline{E}^N} = 1 - \frac{e^S y_1^N}{y_1^S e^N}$$

$$= 1 - \frac{e^S}{y_1^S} \Big/ \frac{e^N}{y_1^N} \qquad \text{Eqn (70)}$$

with "1" being the direct effect of a change in the Northern emissions constraint and the final term $\left(\frac{e^S}{y_1^S}\bigg/\frac{e^N}{y_1^N}\right)$ being the indirect effect of such a change. Finally, note that since the price of good one does not change, aggregate output of the dirty good does not change rendering the final term negative. Also, recalling the assumption made in equation (44), which suggests that Northern firms produce the dirty good with fewer emissions than their counterparts in the South, then:

$$\left(\frac{e^S}{y_1^S}\bigg/\frac{e^N}{y_1^N}\right) > 1 \qquad \text{Eqn (71)}$$

Thus, when considering the value of equation (71), equation (70) becomes unambiguously negative:

$$\frac{dE^W}{d\overline{E}^N} = 1 - \frac{e^S}{y_1^S}\bigg/\frac{e^N}{y_1^N} < 0 \qquad \text{Eqn (72)}$$

As the Northern emissions constraint is *tightened*, world emission levels unambiguously *increase* as the indirect effect of carbon leakage overwhelms the direct effect of Northern reductions!

Accordingly, the mathematical results contained in this section 6.4 confirm the intuition outlined in section 5.2.2 of the previous chapter. In particular, in a two-country permit-only scenario, as the emissions constraint is exogenously *tightened*, the short-run price of emissions increases in the North, Northern profits are eroded, Northern firms exit the dirty good industry, output of good one decreases in the North, and the price of good one temporarily increases to reflect the reduced quantity from dirty-good firms in the

North. Unlike the one-country-world, however, the South now sees an increased product price without paying any positive price for emitting. Thus, Southern firms enter the dirty good industry to capture the surplus rents that exist from the raised price. They do so until rents no longer exist, Southern output of the dirty good increases and the world price and world quantities for the dirty good return to their original levels. In effect, the Northern production of the dirty good has shifted to the South where firms do not incur pay a price for emitting; since the South is less efficient, however, the world is exposed to an increased level of greenhouse gas emissions. Net carbon leakage is an unambiguous result of this two-country permit-only model.[123]

6.5 Two-Country Permit Plus Credits Model

As described in section 5.3.3 the two-country permit plus credits model is an extension of the existing two-country permit-only model described in section 6.4 above. This model explores how the introduction of Southern generated credits may affect a Northern permit-only scenario.

In this "credit" model, the price of Northern emissions (τ^N) remains τ^N and the price of Southern emissions becomes tied to that of its Northern neighbour with a dummy parameter that allows for full or partial credits ($\tau^S = \lambda\tau^N$; $0 \leq \lambda \leq 1$). In particular, within this "credit" model, if $\lambda = 1$, full credits exist and the price of emitting equalizes

[123] Notice that the North's real income declines upon tightening of an emissions cap because the allowable "endowment" of emissions has been reduced. Accordingly, if the Northern demand were not quasi-linear, a normal income effect would lead to reduced demand. Recall that the price of the dirty good must remain constant in accordance with equation (45). This reduced demand would then require lowered dirty-good output. This will temper the increase in Southern emissions making the impact on world emissions ambiguous.

across the North and the South. This implies that there is a fully integrated world market in emissions. On the other hand, if $\lambda = 0$, no credits exist (such that $\tau^S = 0$) and the model becomes exactly equivalent to the 2 country permit-only case. For $0 < \lambda < 1$ it can be said that partial credits exist but credit prices will not be fully equalized. Here, there is a partially integrated world market. In particular, if $0 < \lambda < 1$, the South will earn τ^N for credits they generate and thus τ^N can continue to be seen as the marginal benefit of credits or, alternatively, as the marginal benefit of abatement. On the other hand, $\tau^S = \lambda\tau^N$ stands as the marginal cost per tonne of emissions reduction (abatement), or, the marginal cost of credits. This suggests that an optimizing Southern firm will continuously increase λ from zero to one in the absence of impediments in the credit market, the possibility of such will be discussed below.[124]

6.5.1 South

A. Baseline and Actual Emissions as a Function of Output

Before credits are introduced in the two-country permit-only system, Southern firms choose their "business as usual" (BAU) production and related emission levels (without any consideration for potential credits). Alternatively, and within the context of

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[124] Note that λ bears some resemblance to a transfer coefficient on the South. By analogy the transfer coefficient is always equal to 1 in the North. Transfer coefficients are used in environmental economics to relate emissions to ambient air quality when the location of the emitter is relevant. The bigger an emitter's transfer coefficient the greater the influence of its emissions on ambient concentrations of the pollutant. This means that emissions matter most for emitters with high transfer coefficients. If an emitter with a low λ sells a permit for one tonne of emissions to an emitter with a high transfer coefficient the ambient concentration will increase although aggregate emissions will not. If permits are to be traded without increasing ambient concentrations trades have to be prorated according to the transfer coefficients of the parties. While λ is generated by the policy environment in this model, rather than the natural environment, it is analogous to a transfer coefficient in that it prorates the price of emissions in the South relative to the North.

the Clean Development Mechanism of the Kyoto Protocol, it is useful to assume that each Southern firm represents one "project" that has the potential to generate credits. Thus, from the permit-only model, we know that baseline (BAU) Southern firm / project-level emissions (without credits) are represented by equation (5) at $\tau^S = 0$, or where $\tau^S = \lambda\tau^N$ and $\lambda = 0$. Thus, BAU firm-level emissions ($\bar{e}^S$) become:

$$\bar{e}^S = h'(0)\left((y_1^S)^\alpha v^S + \phi^S\right) \qquad \text{Eqn (73)}$$

All the remaining equations reflect the alternative situation, in which at least partial credits have been introduced. For instance, given the discussion above and equation (5), actual Southern firm-level emissions now become:

$$e^S = h'(\lambda\tau^N)\left((y_1^S)^\alpha v^S + \phi^S\right) \qquad \text{Eqn (74)}$$

B. Firm-Level Output

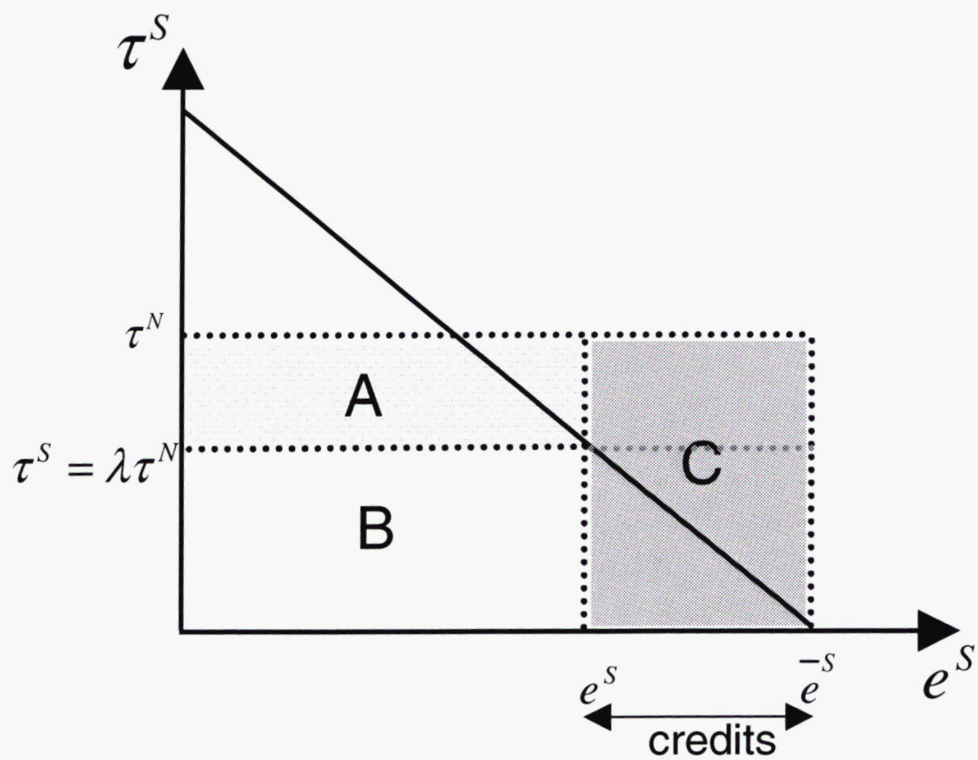
In a two-country permit plus credit world, the Southern profit function previously used in equation (38) must be adjusted (as calculated and described in more detail in section A2.4, Appendix 2) to reflect the net revenue the South receives from credit sales:

$$\pi_1^S = \begin{cases} y_1^S p_1 + \tau^N \bar{e}^S - (1-\lambda)\tau^N e^S - h(\lambda\tau^N)\left((y_1^S)^\alpha v^S + \phi^S\right) & if \quad y_1^S > 0 \\ 0 & if \quad y_1^S = 0 \end{cases} \qquad \text{Eqn (75)}$$

(where $\lambda\tau^N = \tau^S$), $\tau^N \bar{e}^S$ represents revenue from all potential credits (areas A+B+C in Figure 6.11), and $h(\lambda\tau^N)\left((y_1^S)^\alpha v^S + \phi^S\right)$ represents the actual production costs inclusive of emission costs valued at $\tau^S = \lambda\tau^N$ (area B in Figure 6.11). Finally, the $(1-\lambda)\tau^N e^S$

term represents the foregone revenue from a partial rather than a full credit system (area A in Figure 6.11). Thus, the combined effect of these revised terms ensures that if $\lambda > 0$, the South earns revenue for every emission it reduces below its BAU scenario (area C in Figure 6.11), and if $\lambda = 0$, Southern firms have the same profit function as in the two-country permit-only model. Whenever $\lambda > 0$, the presence of credit revenue allows Southern firms to remain competitive even though they have a technological disadvantage [recall the assumption noted in equation (44)].

Figure 6.11 (Partial) Credit Introduction and Southern Dirty-Sector Profits



Max potential credit revenue: A+B+C
Foregone revenue from partial credit system: A;
Emission cost: B;
Credit revenue: C (credits* τ^N)

Substituting $\overline{e}^{S}$ from equation (73), e^{S} from equation (74), and then rearranging provides:

$$\pi_1^S = y_1^S p_1 + \left((y_1^S)^{\alpha} v^S + \phi^S\right)\left[\tau^N h'(0) - (1-\lambda)\tau^N h'(\lambda\tau^N) - h(\lambda\tau^N)\right] \quad \text{Eqn (76)}$$

Labeling $\left((y_1^S)^{\alpha} v^S + \phi^S\right)$ as G, then in the above equation the term $G\tau^N h'(0)$ is represented as A+B+C above, $G(1-\lambda)\tau^N h'(\lambda\tau^N)$ is represented as A, and $G h(\lambda\tau^N)$ includes the area B above.

It follows that the long-run marginal cost (LRMC) condition for an individual Southern firm occurs at the point where profits are maximized:

$$\frac{\partial \pi_1^S}{\partial y_1^S} = p_1 + \alpha\, v^S\, (y_1^S)^{\alpha-1}\left[\tau^N h'(0) - (1-\lambda)\tau^N h'(\lambda\tau^N) - h(\lambda\tau^N)\right] = 0$$

$$p_1 = \alpha\, v^S\, (y_1^S)^{\alpha-1}\left[h(\lambda\tau^N) - \tau^N h'(0) + (1-\lambda)\tau^N h'(\lambda\tau^N)\right] \quad \text{Eqn (77)}$$

Likewise, it follows that the long-run average cost (LRAC) condition for an individual, perfectly competitive Southern firm occurs at the point where profits equal zero. Such a point is expressed as:

$$\pi_1^S = y_1^S p_1 + \left((y_1^S)^{\alpha} v^S + \phi^S\right)\left[\tau^N h'(0) - (1-\lambda)\tau^N h'(\lambda\tau^N) - h(\lambda\tau^N)\right] = 0$$

$$p_1 = \left(v^S (y_1^S)^{\alpha-1} + \frac{\phi^S}{y_1^S}\right)\left[h(\lambda\tau^N) - \tau^N h'(0) + (1-\lambda)\tau^N h'(\lambda\tau^N)\right] \quad \text{Eqn (78)}$$

where $v^S(y_1^S)^{\alpha-1}[h(\lambda\tau^N)-\tau^N h'(0)+(1-\lambda)\tau^N h'(\lambda\tau^N)]$ represents the Southern firm's net average variable costs and $\frac{\phi^S}{y_1^S}[h(\lambda\tau^N)-\tau^N h'(0)+(1-\lambda)\tau^N h'(\lambda\tau^N)]$ represents the Southern firm's net average quasi-fixed costs per unit produced.

In the long-run, a perfectly competitive firm produces where its LRMC is equal to its net LRAC, as previously shown in Figure 6.1. Accordingly, to solve for the optimal level of dirty good output per Southern firm, it is appropriate to simultaneously solve the firm's LRMC condition (profit maximization) and LRAC condition (profits equal zero) as identified by equations (77) and (78) respectively. The result, as shown in Appendix 2, section A2.5 in more detail is:

$$y_1^s = \left(\frac{\phi^S}{v^S(\alpha-1)}\right)^{1/\alpha} = \tilde{y}_1^S \qquad \text{Eqn (79)}$$

Notice that this minimum efficient scale (MES) of output, $\tilde{y}_1^S$, is equal to the permit-only $\tilde{y}_1^S$ found in equation (41). This is true because λ affects the net marginal cost and the net average cost by the same factor of proportionality.

C. Firm-Level Emissions

By substituting the MES level of output found in equation (79) into equation (73), the baseline emissions level for Southern firms becomes:

$$\bar{e}^S = h'(0)\left(\frac{\alpha\phi^S}{\alpha-1}\right) \qquad \text{Eqn (80)}$$

In addition, by substituting the MES level of output found in equation (79) into equation (74) actual firm-level emissions for Southern firms becomes:

$$e^S = h'(\lambda\tau^N)\left(\frac{\alpha\phi^S}{\alpha-1}\right) \qquad \text{Eqn (81)}$$

D. Break-Even Condition

To determine the break-even condition for Southern firms in the dirty good industry (BEC_1^S), it is necessary to substitute the MES level of output identified in equation (79) back into either the LRMC (profit maximization) condition from equation (77) or the LRAC (zero profits) condition from equation (78). Using the former, the BEC for Southern sector-one becomes:

$$p_1 = \alpha\, v^S\left(\frac{\phi^S}{v^S(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[h(\lambda\tau^N) - \tau^N h'(0) + (1-\lambda)\tau^N h'(\lambda\tau^N)\right]$$

$$p_1 = \alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[h(\lambda\tau^N) - \tau^N h'(0) + (1-\lambda)\tau^N h'(\lambda\tau^N)\right] \qquad \text{Eqn (82)}$$

The break-even conditions for the clean sector remain the same as those identified in section 6.2.2.

Totally differentiating (and then rearranging, as more particularly detailed in Section 2.6 of Appendix 2) the break-even condition [equation (82)] for the dirty good industry in the South renders:

$$\alpha\,(v^s)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[h'(\lambda\tau^N)-h'(0)+(1-\lambda)\lambda\tau^N h''(\lambda\tau^N)\right]d\tau^N - dp_1$$
$$= -\alpha\,(v^s)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[(1-\lambda)(\tau^N)^2 h''(\lambda\tau^N)\right]d\lambda \qquad \text{Eqn (83)}$$

Equation (83) can alternatively be expressed as:

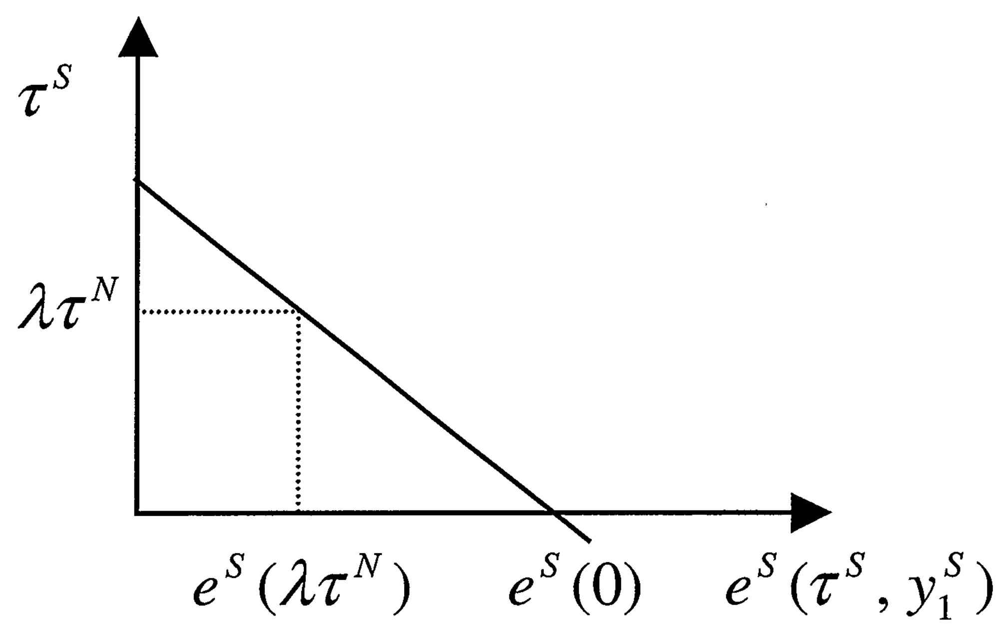
$$B_{11}d\tau^N + B_{12}dp_1 = B_{13}\ d\lambda \qquad \text{Eqn (84)}$$

Therefore, if $\lambda > 0$ equation (83) can alternatively be expressed by equation (84) with,

$$B_{11} < 0, \quad B_{12} = -1, \quad B_{13} > 0 \qquad \text{Eqn (85)}$$

If $\lambda > 0$, it is possible to confirm that the term $h'(\lambda\tau^N) - h'(0)$ in equation (83) is negative since $h'(\lambda\tau^N) < h'(0)$, as shown in (e^S, τ^S) space in Figure 6.12 below.

Figure 6.12: $h'(\lambda\tau^N) < h'(0)$



Recognizing that the level of Southern emissions is directly related to the marginal cost of emissions [recall equation (5)], Figure 6.11 illustrates that the marginal cost of emitting will translate to a lower level of emissions when a positive emissions price exists compared with the level of emissions emitted when a zero emissions price is incurred.

Equations (84) and (85) then allows the calculation of the following relationship, when $\lambda > 0$:

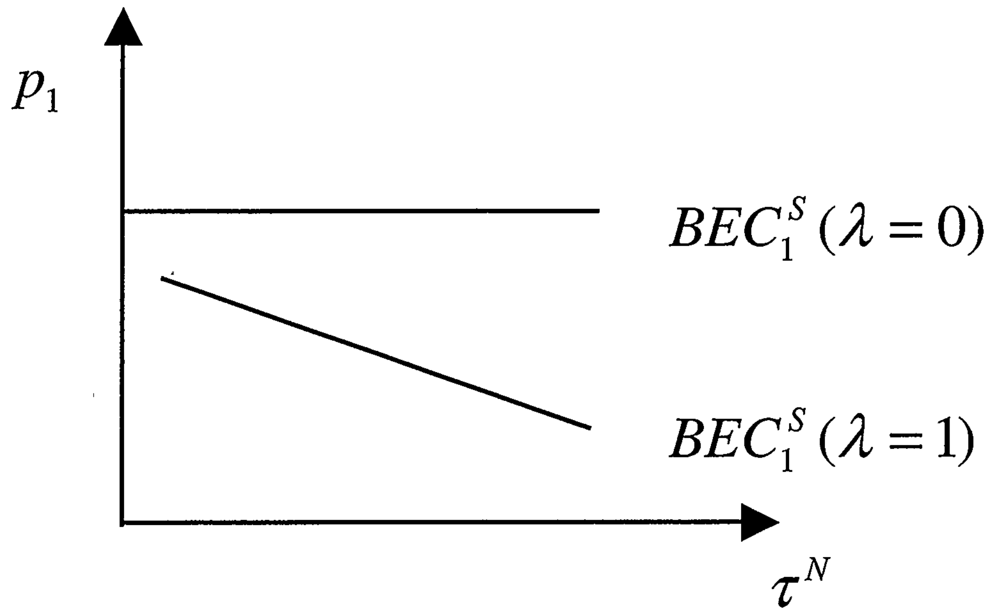
$$\left.\frac{dp_1}{d\tau^N}\right|_{\substack{d\lambda=0 \\ BEC_1^S\,(\lambda>0)}} = \frac{-B_{11}}{B_{12}} < 0 \qquad \text{Eqn (86)}$$

Also, when $\lambda = 0$, it can be shown [using equation (83)] that comparable to the permit-only case, $d\tau^N = 0$. Thus, when $\lambda = 0$:

$$\left.\frac{dp_1}{d\tau^N}\right|_{\substack{d\lambda=0 \\ BEC_1^S\,(\lambda=0)}} = 0 \qquad \text{Eqn (87)}$$

Accordingly, using the slopes identified in equations (86) and (87), the corresponding break-even curves for Southern dirty good firms are represented in (τ^N, p_1) space in Figure 6.13; (when $\lambda = 1$), price for the dirty good decreases as the long-run price of Northern emissions increases, and when $\lambda = 0$ the long-run price for Northern emissions does not change and, thus, the price for the dirty good remains unchanged and the break-even price stays constant for Southern dirty good firms.

Figure 6.13: Break-Even Curves for Southern Dirty Good Firms with and without the Existence of Credits



6.5.2 North

A. Firm-Level Output

In the two-country permit plus credit scenario, the Northern firms face the same firm-level and industry-level BEC results as in the two-country permit-only scenario. The derivations and the related results are considered again here for clarity.

Firm level profits for Northern firms in the dirty sector are represented as:

$$\pi_1^N = y_1^N p_1 - h(\tau^N)\left((y_1^N)^\alpha v^N + \phi^N\right) \qquad \text{Eqn (88)}$$

Profit maximization yields the LRMC condition:

$$\frac{\partial \pi_1^N}{\partial y_1^N} = 0 \quad = p_1 - \alpha\, h(\tau^N)\,(y_1^N)^{\alpha-1}\, v^N$$

$$p_1 = \alpha \;\; v^N \;\; h(\tau^N)\,(y_1^N) \qquad \text{Eqn (89)}$$

Using equation (4), the LRAC condition (in which the firm earns zero profits in the long-run, or alternatively, where price equals a firm's average cost) for a Northern firm in a permit plus credit world is:

$$p_1 = h(\tau^N)\left((y_1^N)^{\alpha-1} v^N + \frac{\phi^N}{y_1^N}\right) \qquad \text{Eqn (90)}$$

Simultaneously solving the LRAC and the LRMC conditions for the Northern firms yields their optimum level of dirty good output, as described in more detail in Appendix 2, section A2.2:

$$y_1^N = \left(\frac{\phi^N}{v^N(\alpha-1)}\right)^{1/\alpha} = \tilde{y}_1^N \qquad \text{Eqn (91)}$$

Notice that once again both the North and the South have symmetrical MES level of output levels for their respective firms. Also, note that the defined emissions level for the dirty good sector firms remains equal to the permit-only scenario as defined in equation (42).

B. Firm-Level Emissions

Substituting the MES level of output found in equation (91) into the emissions equation [equation (4)] and then simplifying, the firm's level of emissions becomes:

$$e^N = h'(\tau^N)\left(\frac{\alpha\phi^N}{\alpha-1}\right) \qquad \text{Eqn (92)}$$

C. Break-Even Condition

Subsequently, it is necessary to substitute $\tilde{y}_1^N$ from equation (91) into either the profit maximization condition [equation (89)] or the zero profit condition [equation (90)] to solve for BEC_1^N. Using the former provides the BEC for the dirty sector in the North:

$$p_1 = \alpha \ v^N \ h(\tau^N) \left(\frac{\phi^N}{v^N(\alpha-1)} \right)^{1/\alpha}$$

$$p_1 = \alpha \, h(\tau^N) \left(v^N\right)^{1/\alpha} \left(\frac{\phi^N}{\alpha-1} \right)^{\frac{\alpha-1}{\alpha}} \qquad \text{Eqn (93)}$$

Totally differentiating the North break-even curve and rearranging leaves:

$$\alpha \left(v^N\right)^{1/\alpha} \left(\frac{\phi^N}{\alpha-1} \right)^{\frac{\alpha-1}{\alpha}} h'(\tau^N) \, d\tau^N - dp_1 = 0 d\lambda \qquad \text{Eqn (94)}$$

Alternatively, equation (94) can be represented in the following manner:

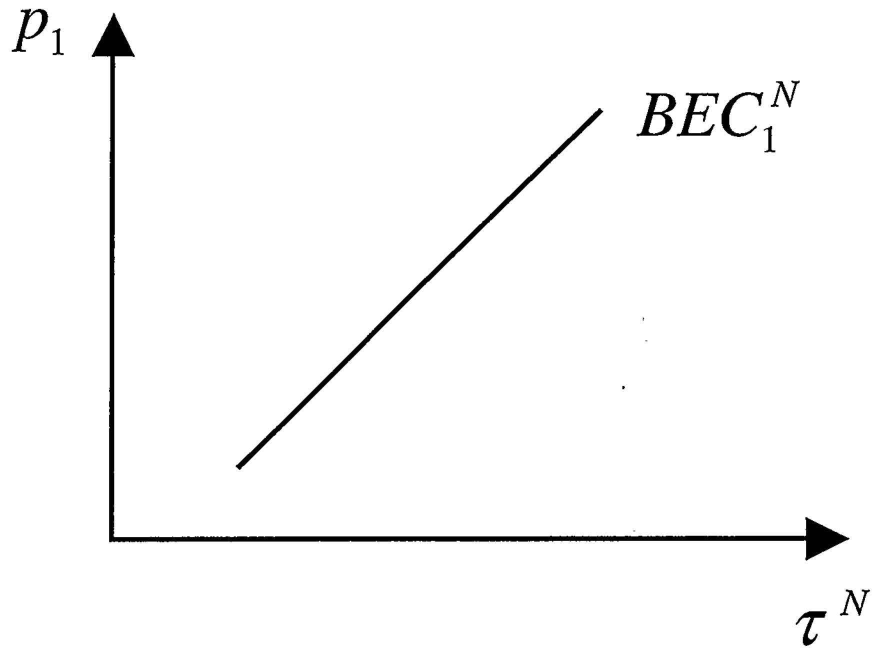
$$B_{21} \, d\tau^N + B_{22} dp_1 = B_{23} d\lambda, \quad \text{where} \quad B_{21} > 0, \quad B_{22} = -1, \quad B_{23} = 0 \qquad \text{Eqn (95)}$$

Equation (95) allows the calculation of the following relationship:

$$\frac{dp_1}{d\tau^N} = \frac{-B_{21}}{B_{22}} > 0 \qquad \text{Eqn (96)}$$

Equation (96) confirms that in (τ^N, p_1) space, as the long-run northern price of emissions increases the price of the dirty good also increases as it is also illustrated in Figure 6.14. The introduction of credits enables movement along the break-even curve as additional supply of compliance units allows for a decrease in Northern emissions price.

Figure 6.14: Break-Even Curve for Northern Firms in the Dirty Good Industry, 2 Country Permit plus Credits Scenario



6.5.3 North & South – General Equilibrium

A. Break-Even Constraints

To begin assessment of the world equilibrium values, it is appropriate to first use the break-even condition in the dirty good sector for each of the South and the North [equations (82) and (93) respectively.]

The differentiated BECs in equations (83) and (94) as represented by equations [(84) and (85)] and (95) respectively, can be translated into matrix form before simultaneously solving:

$$\begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix} \begin{bmatrix} d\tau^N \\ dp_1 \end{bmatrix} = \begin{bmatrix} B_{13} \\ B_{23} \end{bmatrix} d\lambda \qquad \text{Eqn (97)}$$

From the signs identified in each of equations (85) and (95), the determinant (Δ) of the above matrix is:

$$\Delta = -B_{11} + B_{21} > 0 \qquad \text{Eqn (98)}$$

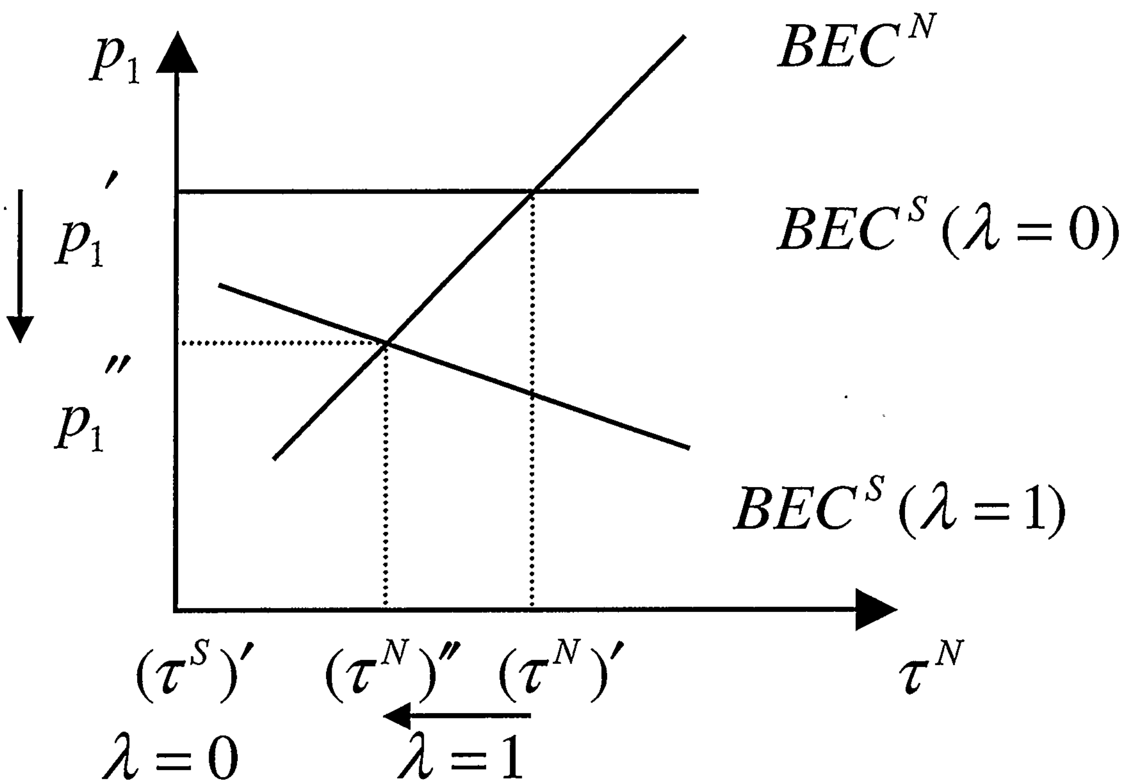
This now allows the calculation of the following relationships:

$$\frac{d\tau^N}{d\lambda} = \frac{-B_{13}}{\Delta} < 0 \qquad \text{Eqn (99)}$$

$$\frac{dp_1}{d\lambda} = \frac{-B_{21}B_{13}}{\Delta} < 0 \qquad \text{Eqn (100)}$$

Equation (99) confirms that as credits are introduced (as λ moves from 0 to 1), the long-run price for emissions in the North decreases due to a greater supply of compliance units available for use by Northern firms. Likewise, equation (100) confirms that as credits are introduced, the long-run price of the dirty good decreases (since the Northern break-even curve lowers with the reduction in τ^N. Both of these effects are shown in (τ^N, p_1) space in Figure 6.15 below.

Figure 6.15: Changes in the Dirty Good Price and the Emissions Price with the Introduction of Credits



In addition, both equations confirm that λ has the same directional effect on both τ^N and p_1, and that they can be equivalently be represented as $\tau^N(\lambda)$ and $p_1(\lambda)$. This will simplify interpretation of subsequent modeling.

B. Goods Market Equilibrium

Consider the condition requiring good one supply equal good one demand:

$$n_1^N y_1^N + n_1^S y_1^S = D(p_1(\lambda)) \qquad \text{Eqn (101)}$$

Substitute in the known y_1^k solutions from equations (79) and (91) to provide the goods market equilibrium (GME) condition:

$$n_1^N\left[\frac{\phi^N}{v^N(\alpha-1)}\right]+n_1^S\left[\frac{\phi^S}{v^S(\alpha-1)}\right]=D(p_1(\lambda)) \qquad \text{Eqn (102)}$$

Totally differentiating equation (102) and rearranging the terms:

$$\left[\frac{\phi^S}{v^S(\alpha-1)}\right]^{1/\alpha} dn_1^S \;+\; \left[\frac{\phi^N}{v^N(\alpha-1)}\right]^{1/\alpha} dn_1^N \;=\; D'(p_1(\lambda))p_1'(\lambda)\, d\lambda \qquad \text{Eqn (103)}$$

This equation (103) can also be expressed as:

$$C_{11}\, dn_1^S \;+\; C_{12}\, dn_1^N \;=\; C_{13}\, d\overline{E}^N \;+\; C_{14}\, d\lambda \qquad \text{Eqn (104)}$$

where $$C_{11}>0,\quad C_{12}>0,\quad C_{13}=0,\quad C_{14}>0 \qquad \text{Eqn (105)}$$

Therefore, the slope of the GME is negative as evident by:

$$\frac{dn_1^S}{dn_1^N}=-\frac{C_{12}}{C_{11}}<0 \qquad \text{Eqn (106)}$$

Further, equation (104) allows the calculation of the following relationships:

$$\left.\frac{dn_1^N}{d\overline{\overline{E}}}\right|_{GME}=0 \qquad \text{Eqn (107)}$$

$$\left.\frac{dn_1^S}{d\overline{\overline{E}}}\right|_{GME}=0 \qquad \text{Eqn (108)}$$

Like the permit-only case, equations (107) and (108) inform that changes in the Northern emissions cap do not affect entry or exit of dirty good firms in either the North or the South countries as part of the goods market equilibrium.

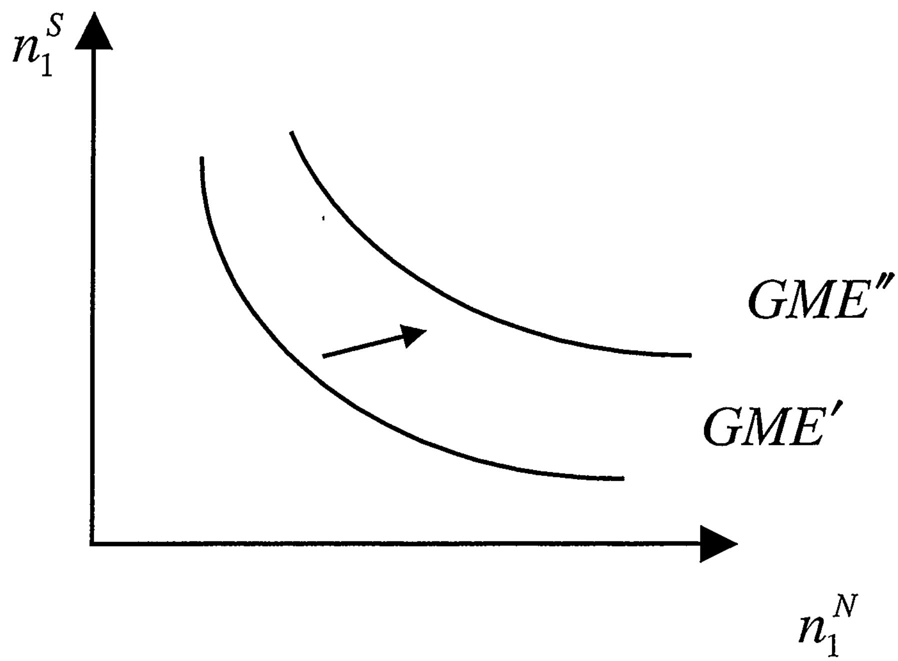
Equations (104) and (105) also suggest the following relationships:

$$\left.\frac{dn_1^N}{d\lambda}\right|_{GME} = \frac{C_{14}}{C_{12}} > 0 \qquad \text{Eqn (109)}$$

$$\left.\frac{dn_1^S}{d\lambda}\right|_{GME} = \frac{C_{14}}{C_{11}} > 0 \qquad \text{Eqn (110)}$$

With the signs known from equation (105), equation (109) suggests that as credits are introduced to the permit-only system with n_1^S constant, Northern firms enter the dirty sector in the North while equation (110) suggests that as credits are introduced to the permit only system with n_1^N constant, Southern firms enter the dirty industry in the South as credit revenue allows growth. Note, however, that for the case in which $\lambda = 1$, the GME will not shift any further. Figure 6.16 illustrates the results shown in equations (109) and (110) in (n_1^N, n_1^S) space below.

Figure 6.16: Shift in the Goods Market Equilibrium with the Introduction of Credits



C. Emissions Equilibrium

To determine how the introduction of credits alters each of the North and South emissions, and therefore, the aggregate world level emissions the emissions equilibrium (EE) constraint must be considered. Equation (55) from the permit-only case now becomes:

$$\overline{E}^N + n_1^S\left[\overline{e}^S - e^S\left(\lambda\tau^N(\lambda)\right)\right] = n_1^N e^N\left(\tau^N(\lambda)\right) \qquad \text{Eqn (111)}$$

where $\left[\overline{e}^S - e^S\left(\lambda\tau^N(\lambda)\right)\right]$ represents the credits generated by a Southern firm and used by Northern firms to offset their emissions. As previously discussed, the first term within $\left[\overline{e}^S - e^S\left(\lambda\tau^N(\lambda)\right)\right]$ represents the maximum potential level of credits, and the second term is the actual level of emissions generated by the South, combining to render the net level of credits available for use by the North.

Furthermore, the results from the break-even curve section above informs that τ^N is a function of λ such that $\tau^N(\lambda)$. Thus, recalling equations (80), (81), and (92) ($\overline{e}^S$, e^S *and* e^N respectively), after simplification equation (111) becomes:

$$\overline{E}^N + n_1^S\left(\frac{\alpha\phi^S}{\alpha-1}\right)\left[h'(0) - h'\left(\lambda\tau^N(\lambda)\right)\right] = n_1^N\left(\frac{\alpha\phi^N}{\alpha-1}\right)h'\left(\tau^N(\lambda)\right) \qquad \text{Eqn (112)}$$

Total differentiation of equation (112) gives the following equation:

$$d\overline{E}^N + \left(\frac{\alpha\phi^S}{\alpha-1}\right)\left[h'(0) - h'\left(\lambda\tau^N(\lambda)\right)\right]dn_1^S - n_1^S\left(\frac{\alpha\phi^S}{\alpha-1}\right)h''\left(\lambda\tau^N(\lambda)\right)\left(\tau^N + \lambda\tau^{N'}(\lambda)\right)d\lambda$$
$$= \left(\frac{\alpha\phi^N}{\alpha-1}\right)h'\left(\tau^N(\lambda)\right)dn_1^N \;+\; n_1^N\left(\frac{\alpha\phi^N}{\alpha-1}\right)h''\left(\tau^N(\lambda)\right)\tau^{N'}(\lambda)\,d\lambda \qquad \text{Eqn (113)}$$

Simplifying equation (113) and re-ordering gives:

$$\left(\frac{\alpha\phi^S}{\alpha-1}\right)\left[h'(0) - h'\left(\lambda\tau^N(\lambda)\right)\right]dn_1^S \;-\; \left(\frac{\alpha\phi^N}{\alpha-1}\right)h'\left(\tau^N(\lambda)\right)dn_1^N \;=\; -d\overline{E}^N \;+$$
$$\left[n_1^S\left(\frac{\alpha\phi^S}{\alpha-1}\right)h''\left(\lambda\tau^N(\lambda)\right)\left(\tau^N + \lambda\,\tau^{N'}(\lambda)\right) + n_1^N\left(\frac{\alpha\phi^N}{\alpha-1}\right)h''\left(\tau^N(\lambda)\right)\tau^{N'}(\lambda)\right]d\lambda \qquad \text{Eqn (114)}$$

The above equation can also be expressed as:

$$C_{21}\,dn_1^S \;+\; C_{22}\,dn_1^N \;=\; C_{23}\,d\overline{E}^N \;+\; C_{24}\,d\lambda \qquad \text{Eqn (115)}$$

where

$$C_{21} > 0,\quad C_{22} < 0,\quad C_{23} = -1,\quad C_{24} \begin{smallmatrix}<\\=\\>\end{smallmatrix} 0 \qquad \text{Eqn (116)}$$

Therefore, the slope of the EE is positive as evident by:

$$\left.\frac{dn_1^S}{dn_1^N}\right|_{EE} = -\frac{C_{22}}{C_{21}} > 0 \qquad \text{Eqn (117)}$$

Notice that when λ=0, C_{21} goes to zero because $e^S = \overline{e}^S$ making the EE curve vertical. As expected, this is the same as in the two-country permit only model.

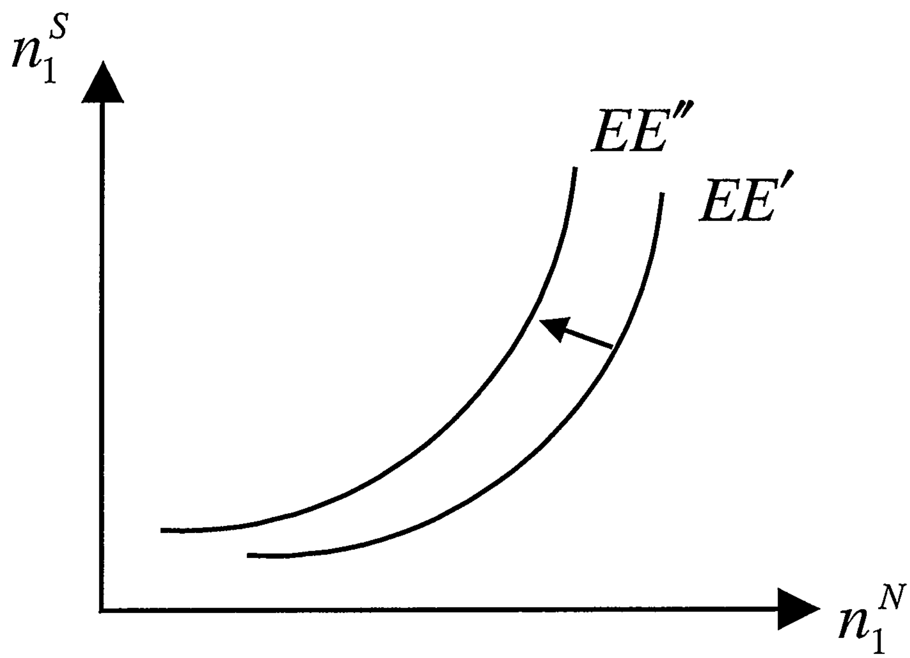
Further, equations (115) and (116) allow the calculation of the following relationships:

$$\left.\frac{dn_1^N}{d\overline{E}^N}\right|_{EE} = \frac{-1}{C_{22}} > 0 \qquad \text{Eqn (118)}$$

$$\left.\frac{dn_1^S}{d\overline{E}^N}\right|_{EE} = \frac{-1}{C_{21}} < 0 \qquad \text{Eqn (119)}$$

This calculation is important since we will see once again that the number of firms in the South are the key determinant for the existence of carbon leakage. Comparable to the permit-only case, equation (118) informs that as the Northern emissions cap is *tightened* with n_1^S held constant, Northern firms exit the dirty goods market. Equation (119) also informs that as the Northern emissions cap is *tightened* with n_1^N held constant, Southern firms enter the dirty good industry. Note, however, that when λ reaches 1, the EE will not shift any further as the result of introducing credits. Figure 6.17 shows this result in (n_1^N, n_1^S) space below.

Figure 6.17: Entry and Exit of Dirty Good Firms in Response to a Tightening of the Northern Emissions Constraint in a 2 Country Permit plus Credit World



Equations (115) and (116) also provide for the following:

$$\left.\frac{dn_1^N}{d\lambda}\right|_{EE} = \frac{C_{24}}{C_{22}} \gtrless 0 \qquad \text{Eqn (120)}$$

$$\left.\frac{dn_1^S}{d\lambda}\right|_{EE} = \frac{C_{24}}{C_{21}} \gtrless 0 \qquad \text{Eqn (121)}$$

With the signs known from equations (120) and (121) unknown, it is uncertain whether Northern firms enter or exit the dirty good sector in the North, and likewise, whether Southern firms enter or exit the dirty good industry in the South as credits are introduced to the permit only system.

D. General Equilibrium

Finally, the system of EE [represented by equation (114) or (115)] and GME [represented by equation (103) or (104)] equations are simultaneously solved using the following matrix form:

$$\begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} dn_1^S \\ dn_1^N \end{bmatrix} = \begin{bmatrix} C_{13} \\ C_{23} \end{bmatrix} d\overline{E}^N + \begin{bmatrix} C_{14} \\ C_{24} \end{bmatrix} d\lambda \qquad \text{Eqn (122)}$$

From the signs identified in each of equations (116) and (105), the determinant of the above matrix is:

$$D = C_{11}C_{22} - C_{21}C_{12} < 0 \qquad \text{Eqn (123)}$$

This now allows the calculation of the following relationships:

$$\frac{dn_1^N}{d\overline{E}} = \frac{-C_{11}}{D} > 0 \qquad \text{Eqn (124)}$$

$$\frac{dn_1^S}{d\overline{E}} = \frac{C_{12}}{D} < 0 \qquad \text{Eqn (125)}$$

Equations (124) and (125) confirm that when the Northern country *tightens* their emissions constraint on the dirty good sector, the combined EE and GME effect is a decrease in Northern firms and an increase of Southern firms in the dirty good market. This confirms the result obtained from the permit-only scenario.

In addition, equations (122) and (123) allow the calculation of the following relationships:

$$\frac{dn_1^N}{d\lambda} = \frac{C_{11}C_{24} - C_{21}C_{14}}{D} \gtrless 0 \qquad \text{Eqn (126)}$$

$$\frac{dn_1^S}{d\lambda} = \frac{C_{14}C_{22} - C_{12}C_{24}}{D} \gtrless 0 \qquad \text{Eqn (127)}$$

Equations (126) and (127) suggest that as credits are introduced to a permit-only scenario, the combined EE and GME effect is an ambiguous change in both the Northern firms and the number of Southern firms in the dirty good market. Thus, the introduction of credits may reinforce or moderate the carbon leakage attributable to the permit-only scenario. In this permit plus credit model, because Northern emissions are constrained by their respective Northern cap (plus "borrowed" credits) the existence of carbon leakage again rests entirely on how credits affect the number of Southern firms:

$$E^W = \overline{E}^N + n_1^S \overline{e}^S \qquad \text{Eqn (128)}$$

Therefore the number of Southern firms in the dirty good sector arising from equation (127) determine the existence of overall world carbon leakage.

As the table below illustrates, the result is uncertain as the EE may work to reinforce or completely negate the GME's clear effect of encouraging growth of dirty good firms in the dirty good market.

Table 6.1: The Effect of Credit Introduction on Entry/Exit of Firms

Introduction of Credits ($\lambda\uparrow$)	**#of Northern Firms in Dirty Good Sector**	**# of Southern Firms in Dirty Good Sector**
EE	Ambiguous	Ambiguous
GME	Increase	Increase
Combined Effect	Ambiguous	Ambiguous

Further, as Figures 6.18 and 6.19 illustrate in (n_1^N, n_1^S) space, the relative magnitude of these two potentially opposing forces will ultimately determine whether the introduction of credits generates carbon leakage. However, it remains possible for the EE to shift left, in which case, carbon leakage will certainly occur.

Figure 6.18: Case where Growth in South's Dirty Good Industry Leads to Additional Carbon Leakage in the 2 Country Permit plus Credits World

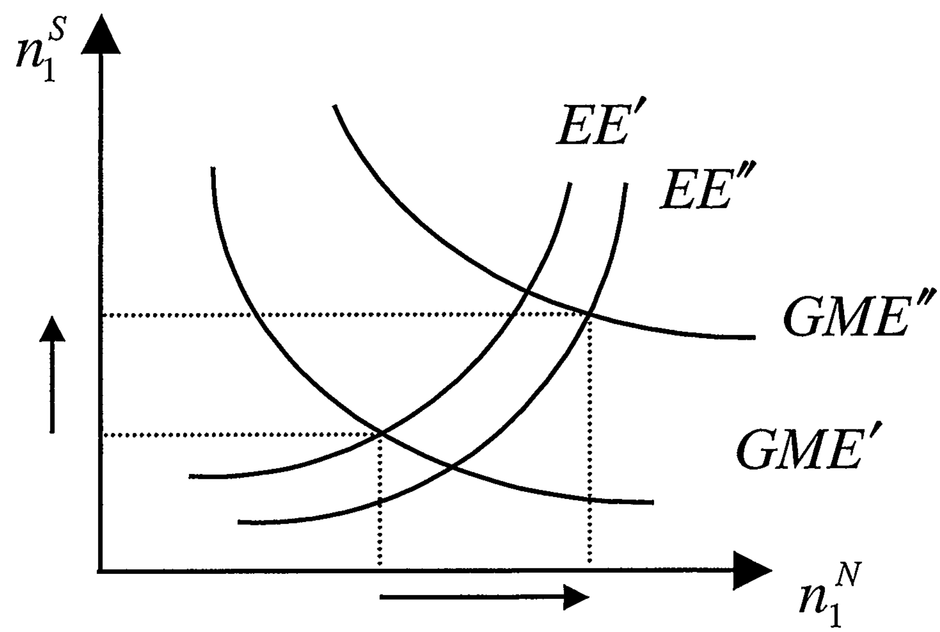
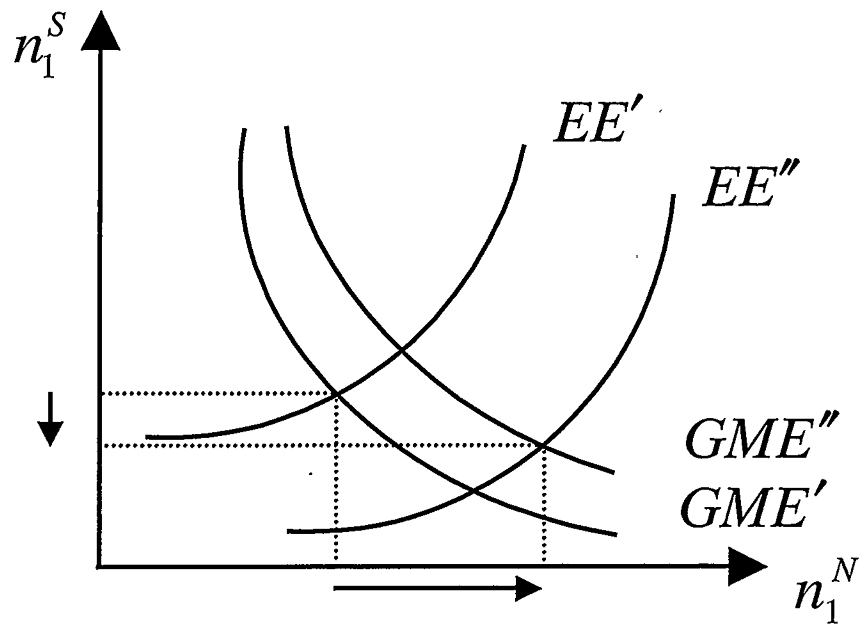


Figure 6.19: Case where Exit in South's Dirty Good Sector Negates Carbon Leakage in the 2 Country plus Credits World



It is possible, however, to gain further insight into the conditions under which carbon leakage is more or less likely to occur. In particular, recognizing that Northern emissions are constrained by the Northern emissions cap and the level of purchased Southern credits, any global carbon leakage will again rest entirely on the exit or entry of Southern dirty good firms in response to the introduction of credits. Accordingly, it is useful to explore equation (127) in more detail. The mathematical derivation and representation of this equation is provided in detail in Appendix 2, section A2.7. The results, are repeated here in equation (129),

$$\frac{dn_1^S}{d\lambda} = \frac{-\tau^N e^{S'}(\tau^S)}{D\Delta y_1^S}\left\{(1-\lambda)e^N D(p_1)\left[\varepsilon_1^d\left(\frac{\tau^N e^N}{p_1 y_1^N}\right) + \sigma_1^N\ \eta_e^N\right] + n_1^S\left[y_1^N\left(\bar{e}^S - e^S\right) + e^N y_1^S\right]\right\}$$

where $\varepsilon_1^d < 0$ is the elasticity of demand with respect to price for the dirty good, $\eta_e^N < 0$ is the elasticity of Northern emissions with respect to the Northern emissions price, and σ_1^N is the Northern share of the dirty good market.

Equation (129)'s representation of equation (127) now allows for an intuitive interpretation of the factors that affect whether exit or entry occurs in the Southern dirty good sector. In particular, $\varepsilon_1^d\left(\frac{\tau^N e^N}{p_1 y_1^N}\right)$ represents *excess demand for the dirty good* which motivates an increase in Southern dirty good firms. In Figures 6.18 and 6.19, this term supports the GME's movement to the right (up). The term $\sigma_1^N\ \eta_e^N$ represents *excess demand for Southern credits*, which also motivates an increase in Southern dirty good firms. This term supports movement of the EE curve to the left (up), the case in which carbon leakage most certainly occurs. To the contrary, the term $n_1^S\left[y_1^N\left(\bar{e}^S - e^S\right) + e^N y_1^S\right]$ pulls the EE to the right (down). This final term represents *excess supply of Southern credits* and, accordingly, motivates a decrease of Southern dirty good firms. When these forces are combined, it is ambiguous whether there is net entry or exit from the Southern dirty good sector. Nevertheless, if the magnitude of the terms are such that:

$$(1-\lambda)e^N D(p_1)\left[\varepsilon_1^d\left(\frac{\tau^N e^N}{p_1 y_1^N}\right) + \sigma_1^N\ \eta_e^N\right] \;>\; n_1^S\left[y_1^N\left(\bar{e}^S - e^S\right) + e^N y_1^S\right] \quad \text{Eqn (130)}$$

then $\frac{dn_1^S}{d\lambda} > 0$ and Southern dirty good firms enter the market as a result of introducing credits to the permit-only system. With net entry of Southern dirty good firms, additional global carbon leakage results.

Aside from the broader condition provided in equation (130), however, equation (129) suggests that the larger in magnitude are the elasticity of demand for the dirty good with respect to its price (ε_1^d), and the elasticity of Northern emissions with respect to the Northern price of emissions (η_e^N), the more likely it is that Southern firms enter the dirty good sector and carbon leakage exists.

If λ is increased progressively from zero to one through the introduction of a credit system, the overall effects of the credit system are ambiguous in terms of the impact on world emissions. While aggregate emissions could decline, it is also possible that they could rise in spite of the fact that the North and South are now integrated in a world emissions market.[125] Furthermore, the result provided in equation (129) also suggests that the closer λ is to 1, the more likely that Southern firms exit the dirty good industry and the environment benefits with reduced global emissions. On the other hand, the result also suggests that the closer λ is to 0, the more likely that Southern firms enter the dirty good industry and net global carbon leakage results. By implication, this model

[125] We have seen that world emissions rise, remain the same, or fall depending on whether the number of Southern firms increases, remains constant, or decreases. While the North has an aggregate cap, the South does not. Because the number of Southern firms is variable, and each Southern firm brings its own "business as usual" baseline-level emissions, there is no hard cap on the Southern country. Moreover, even with fully integrated emissions trading between the North and the South, a tightening of the Northern cap unambiguously leads to an increase in world emissions as the emissions equilibrium curve shifts to the left and displaces the equilibrium along the goods market equilibrium curve comparable to Figure 6.6.

suggests that any effort (intentional or otherwise) to de-link the Southern cost of emitting from the Northern emissions price is more likely to be harmful to the environment.

6.5 Summary

This chapter explored the mathematical foundation for the intuition discussed in chapter 5. Using general equilibrium theory, three models were presented with the final two testing for the presence of carbon leakage.

In the one-country-world, it was shown that as the government introduced or tightened an emissions constraint for the dirty good sector, the number of dirty good firms decreased, and thus aggregate emissions also decreased. The one-country-world government succeeded in reducing their emissions. Clearly, this model precludes carbon leakage.

The two-country, permit only model on the other hand, had a very different result. In particular, as the North imposed or tightened an emissions cap on its dirty good sector, Northern firms exited the dirty good industry and Southern firms entered the dirty good industry. Since world price and quantity levels did not change for the dirty good in the long-run, the output reduction that occurred as producers exited in the North was exactly offset by the output increase that occurred as producers entered in the South. Because Southern production is more emissions intensive, the world experienced a net increase in emissions. Unfortunately, the governments of these two nations failed to achieve reduced world-level emissions, and instead, faced unambiguous global carbon leakage.

The two-country permit plus credit model explored how the introduction of credits to the permit-only scenario would affect emission levels. Again resting primarily on the increase or decrease in Southern dirty-good firms (or, in the context of the Clean Development Mechanism, the increase or decrease in "projects"), it is ambiguous whether or not additional carbon leakage occurs as a result of introducing credits. Essentially, through excess demand for the dirty good the goods market equilibrium encouraged entry of Southern dirty good firms into the dirty good sector. On the other hand, however, it is uncertain whether the emissions equilibrium encouraged or discouraged entry into the dirty good sector because the emissions equilibrium generates counteracting pressures that push toward both excess demand for credits and excess supply of credits. In addition, further exploration of drivers for entry into the Southern dirty good sector revealed for instance that the fuller the implementation of credits, the more likely that exit of Southern dirty good firms occurs and the environment benefits. Alternatively, the closer λ is to 0, the more likely that entry of Southern dirty good firms occurs and global carbon leakage results.

Exploring these three models allows some important insights into the Kyoto Protocol and its relationship to changes in global GHGs. Such insights will be discussed as part of the following and concluding chapter.

Chapter 7: Concluding Remarks

7.1 Overview

The Kyoto Protocol as an international attempt to address a key global environmental concern. A fairly broad scientific consensus has led to a call for action by heads of state. Economic theory suggests that international cooperation for this common good issue is warranted. As this thesis suggests, however, the design of an international agreement is especially important in ensuring that the environmental objective is achieved.

7.2 Scientific Summary of Climate Change

Chapter 2 introduces the greenhouse effect and its relationship to global warming. It is clear that both of these phenomena are necessary for the earth to sustain temperature levels necessary for human existence. Greenhouse gases (GHGs) contribute to the warming caused by the greenhouse effect and the growing concern is that humans are affecting the concentration of such gases and, in so doing, are contributing to an enhanced and accelerated warming that is unprecedented in the history of known climate change cycles.

Since the culmination of evidence is rather difficult to interpret, however, national governments have relied upon the Intergovernmental Panel on Climate Change (IPCC). In each of their three formal Assessment Reports, this United Nations' body has concluded, with increased confidence and alarm, that human-induced climate change is occurring; the body warns that the earth is beginning to feel the effects at its most extreme and sensitive areas, and that the earth will continue to feel significant effects long after we reach stabilization of atmospheric greenhouse gases. The reports from the IPCC have galvanized the attention of national leaders.

7.3 Summary of the Political History behind Climate Change

Even before the official reports from the IPCC emerged, international meetings on climate change began. The reports from the IPCC, however, strengthened the resolve for action by national leaders. The United Nations Framework Convention on Climate Change (UNFCCC) was the first comprehensive effort to establish targets to reduce GHGs. It also outlined key principles such as precautionary measures, differentiated responsibilities between the developed and developing nations, sustainable development, and other principles, which have continued to play an important focus for climate change efforts today.

Recognizing the importance of strengthening and deepening the GHG reduction targets beyond those that were in the UNFCCC, however, heads of state agreed to the Kyoto Protocol, which set an absolute cap on GHG emissions for each of the developed countries beginning in the years 2008-2012. In an effort to minimize the costs of mitigation for the constrained countries and to promote sustainable development in the lesser-developed countries, the Kyoto Protocol included flexible mechanisms such as Emissions Trading among the constrained countries, Joint Implementation between the constrained countries and the Clean Development Mechanism (CDM) to engage the unconstrained countries. This final mechanism allows the lesser-developed nations to generate credits when they reduce their emissions. Such credits can be used for compliance by the constrained countries.

Since subsequent documentation and agreements, including the Marrakech Accords for instance, have failed to fulfill all the outstanding questions about the Kyoto Protocol, however, further international negotiations continue. Importantly, the Protocol and its supporting documents will not come into force until (1) a sufficient number of countries sign the Protocol (this requirement has already been surpassed), and (2) of those countries that sign, there must be at least.55% of the developed countries' emissions represented (this target is yet to be fulfilled). As the Protocol is not yet in force, nations of the world continue to monitor the positions of each national government. With the United States refusing to participate, Russia had become an integral player since the Kyoto Protocol will not enter into force without their participation. Since Canada recently ratified the Protocol, Russia's moves on this issue are being watched with great interest.

7.4 Literature Review Summary

Since the nature of GHGs means that one metric tonne of GHGs released in Australia has exactly the same effect on Australia as one metric tonne of GHGs released in Canada, GHGs are a good example of transboundary, and in fact, global pollutants. Thus, their release by any one party affects the atmosphere and climatic conditions enjoyed by all parties – this common property resource problem is perhaps the grandest example of tragedy of the commons!

A preferred approach by economists in solving such an issue is of course, the use of market-based mechanisms. Dales (1968) is often credited with formally introducing the concept of emissions permits or effluent charges. This work later evolved into formal theoretical modeling. Copeland and Taylor are important contributors to this field, including, for instance, their 1994 article "North-South Investment Flows and Optimal Environmental Polities", in which they explored local pollution, income levels and trade between a North and South country. They later expanded this work with their 1994 article "Trade and Transboundary Pollution" to include trade in international permits, international income transfers and international pollution controls. They took this work further with their 1995 article "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol". This latter article provided inspiration for this thesis, which not only considers a varied approach to the general equilibrium model but also takes the work further to consider the implication of credits in a Kyoto based model.

7.5 Modeling Results

The two input, two good, two country general equilibrium models presented in this thesis attempt to reflect the Kyoto Protocol by simplifying the world into the constrained North, the unconstrained South, and emissions free versus emissions-intensive goods. After introducing a one-country-world for comparison purposes, a two-country permit-only model is considered, followed by a two-country permit plus credit model.

Importantly, the two-country models considered in this paper employ a key assumption that differs from that which Copeland and Taylor have imposed in their modeling. In particular, the two-country models assume that the unconstrained Southern firms will produce at the point where their marginal product of emissions equals zero. Copeland and Taylor on the other hand, have assumed that the marginal product of emissions will not ever reach zero, and thus, take a different approach. While Copeland and Taylor's work imposes quantity constraints on all countries, the assumption here imposes a price of zero on Southern emissions. Furthermore, the theoretical modeling of credit introduction appears to be a new consideration in this field.

The one-country-world modeling shows that when a one-country-world government imposes an emissions constraint, the emissions price increases, profits for the dirty good industry decline, and exit from the industry occurs leaving less output and fewer emissions. The one-country-world succeeds in reducing emissions.

The two-country permit only world, however, suggests that when a constrained North and an unconstrained South co-exist, Northern production effectively shifts to the South where a zero emissions price exists. If the assumption that Southern firms produce with greater emissions intensity than their Northern counterparts is reasonable, it becomes unambiguous that when the North assumes or tightens an emissions cap, world-level emissions increase!

In the final two-country permit plus credit model, it is found that upon introduction of credits to the permit-only model, it is ambiguous whether or not further carbon leakage exists. While Northern emission levels are guaranteed to be constrained by their respective emissions cap, Southern activity is altered and the change may or may not result in carbon leakage. While the goods market equilibrium encourages entry of Southern firms into the dirty good sector through excess demand for the dirty good, it is uncertain whether the emissions equilibrium encourages entry into or exit from the dirty good sector. Both excess Northern demand for credits and excess Southern supply of credits exist to leave the overall effect on emissions equilibrium ambiguous. Factors suggest however, that the fuller the implementation of credits the more likely that exit of Southern dirty good firms occurs and the environment benefits. Alternatively, the more restricted are credits (the closer λ is to 0) the more likely that entry of Southern dirty good firms occurs and global carbon leakage results. Also the larger the magnitude of the elasticity of demand for the dirty good with respect to its price, as well as the larger the magnitude of the elasticity of emissions with respect to its price, the more likely that Southern firms enter the dirty good market upon introduction of credits and global carbon leakage results.

It is also worth noting that the two-country permit plus credit model ensures that *any release* of emissions in the South, whether it is within or beyond the registered CDM project level, is accounted for and an (opportunity) cost at the shadow value of Southern emissions ($\lambda\tau^N$) is assigned. This differs slightly from the anticipated reality of the CDM, however, since the CDM is only able to monitor emission levels within an identified project boundary. Any entry arising from economic growth (whether such growth occurs in another (dirty) sector or in another manner that is less identifiable with the particular project) is not likely to be controlled by the CDM or the Kyoto Protocol.

As a result of having more economic activity in the dirty sector, more emissions will occur.[126]

7.6 Discussion

While the results from the modeling presented above clearly imply that the Kyoto Protocol may not be successful as it is currently drafted, one must be careful in accepting such results without further consideration. In particular, the modeling above has assumed that goods are fully tradable without cost, that technology is static without transfer between regions, and that transaction costs are equal to zero. Such assumptions are not necessarily reflective of reality and the modeling results must be interpreted with those assumptions and realities in mind.

7.6.1 Technology Considerations

The Kyoto Protocol encourages technology transfer from the North to the South, with a particular emphasis of such transfer through the CDM[127]. Nevertheless, the modeling in this thesis assumes that advances in technology do not occur in either the North or the South. Because some level of uncertainty exists, however, today (in advance of compliance requirements) we are seeing many Northern firms investing in technological research and development with a focus on reducing GHG and other emissions. Such firms have received sufficient signals from their respective governments

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[126] Nevertheless, when any new dirty good firms enter in response to economic growth, in the short run it will be difficult for such firms to defend a dirty-good baseline under a project-by-project accounting system. Thus, until they have established a suitable history, it will be difficult for them to access credit revenue.

[127] While the CDM does not necessarily require technology transfer to be a condition of awarding credits to a project, it remains advantageous to the crediting process if such transfer exists.

to anticipate further emission constraints, and with this understanding, such investments become worthwhile.

Naturally, if either technology transfer from the North to the South, and / or technological advancement occurs such that it is easier to reduce emissions in either the North or the South, the modeling results will change. In particular, the North would be able to maintain a greater level of "dirty" good output (or supply a greater volume of a clean substitute), and / or the South would be able to produce more output at an improved rate of emissions per output. Either of these instances would assist in counteracting carbon leakage.

7.6.2 Costlessly Tradable Goods

Furthermore, the modeling assumes that goods are fully tradable across nations. Again, this may or may not be reflective of reality. In particular, thermal electricity generation cannot readily be moved from the North to some areas in the South because the necessary thermal feedstocks may not be present, and / or the transmission infrastructure may not be in place. Likewise, oil and gas producers cannot always transplant their production to Southern regions because the oil and gas reserves necessary for supply may not exist at competitive levels. In addition, social pressures may negatively affect product demand if a company chooses to change location of their goods production on the basis of environmental costs or prices. Furthermore, it is likely that even if goods are tradable, they are not mobile without incurring some level of transaction costs.

7.6.3 Transaction Costs

The modeling discussed here also assumes that transaction costs equal zero. While this may affect capital mobility, as referenced above, transaction costs can also play an important role in the creation and transfer of credits. In particular, it has been questioned whether Northern firms will find Southern credits to be of any value as a part of their compliance strategy.

In a scenario where permit supply sufficiently outweighs permit demand, for instance, it is possible that credits will remain outside the market. Since a large portion of the possible supply of credits can only be generated by incurring a cost, while permits have been allocated to nations without a tangible charge, credits rely on market forces inflating prices before they can be competitive with permits. Accordingly, to conduct the analysis, it was assumed that the combined production costs and the anticipated transaction costs associated with generating CERs is low enough to keep the price of credits competitive with permits.

This is especially important to recognize since many analysts expect a number of key factors to put downward pressure on the forward price of *compliance units (CU)*,[128] making it increasingly difficult for credits to remain competitive. In particular, two key political realities facing the Kyoto Protocol include the United States' recent objection to assuming an emissions cap,[129] and the existence of "hot air" in some Economies in

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[128] As used previously, compliance units are meant to refer to permits and / or credits, with either of them for use by Northern firms against their carbon constraints.

[129] Under the Kyoto Protocol, the United States represented a very significant Annex I party that generated large levels of emissions. Without the United States' involvement, the demand for compliance units decreases dramatically.

Transition.[130] Both of these factors contribute to lower CU demand relative to supply, and therefore, lower CU prices. As the CU price falls, credits will play an ever-decreasing role in the market, and the perceived value of the CDM will similarly deteriorate. Therefore any possible benefits stemming from the credit system would tend to become increasingly tenuous.

7.6.4 Limitations on Full Credit Introduction

As previously referenced in Chapter 3, some nations have advocated for required "supplementarity" in which constrained nations do not have full access to the credit market, and are instead required to ensure emission compliance through domestic action. Some European nations, for instance, have suggested that the use of foreign credits be restricted to less than 50% of the required emission reductions. This proposal is a clear exogenous constraint on the use of credits.

Other constraints or "market wedges" such as transaction costs may also exist to "de-link" Northern and Southern emission prices such that the price of Southern emissions remains less than that of its Northern neighbour.

It may be argued that such forces lead to a partial credit system (where $\lambda < 1$). In such a case, the permit plus credit model suggests that the likelihood of environmental

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[130] Under the Kyoto Protocol, nations such as Russia have been granted "Economies in Transition" status. The Kyoto Protocol recognizes that these nations should experience significant growth relative to their 1990 baseline, and it was agreed that these nations should not be unduly constrained by too tight of an emissions cap. Accordingly, the emissions caps were set to allow for the anticipated economic (and associated emissions) growth. Unfortunately, many of these countries did not experience the level of economic growth that was anticipated; the permits they have been allocated under the Kyoto Protocol exceed the emissions they are likely to generate. The gap between the emissions and the level of allocated permits is referred to as "hot air". As the level of hot air increases across the Economies in Transition nations, the offered supply of compliance units increases while an equal demand for compliance units decreases.

gain is decreased, and instead, the likelihood of carbon leakage increases. If this is a reasonable interpretation, the attractiveness of supplementarity declines considerably!

7.6.5 Political Trade-offs

While the perceived value of credits may deteriorate from a strict environmental perspective, the CDM's value of promoting technology transfer, sustainable development and wealth transfer from the developed countries to the lesser-developed countries remains a strong principle worthy of pursuing in the minds of many political leaders; after all, such principles are embodied within the UNFCCC and the subsequent Kyoto Protocol. Conversely, many leaders in developed countries believe that it is important and necessary to generate emission reductions in their own state with minimal use of the flexible mechanisms.[131] Clearly, these competing interests will continue to erode any potential benefits of the CDM.

In addition, while the modeling results suggest that the environment may be made worse off with the imposition of a Northern cap, this may be a temporary sacrifice for long term gain. In addition to the distributional gains that may result from the CDM, Northern political leaders may feel that they must take this necessary first step before the remaining countries can be encouraged to assume an emissions cap. Such movement and pressure is already being seen on the margin in the ongoing international negotiations. The involvement of lesser-developed countries is also a pre-condition for involvement by

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[131] This issue is often referred to as "supplementarity"; the European Union for instance, has been a strong supporter of supplementarity, advocating for developed nations to generate the balance of reductions in their home state with only marginal use of the flexible mechanisms.

the current United States government. Perhaps initial involvement by developing countries, such as China, may begin during the second commitment period, 2013-2017. Further engagement may occur gradually as the lesser-developed countries gain the capacity to assume such constraints. In the ideal, it may be possible for all countries to assume an emissions cap such that the agreement reflects the one-country-world model.

7.7 Areas for Further Research

Anthropogenically-enhanced climate change, global pollutants, the Kyoto Protocol, and their vast array of accompanying issues are relatively recent advancements that remain largely under-developed within formal economic theory. Depending on the particular issue at hand, this is an issue that transcends the historical divisions of environmental economics and international trade economics. Accordingly, climate change and the Kyoto Protocol may offer unique opportunities for collaborative efforts between the two fields. Furthermore, economists with a focus on industrial organization are also likely to play an increasing role as the international agreements and the resulting greenhouse gas markets develop further. As is relatively common with many economic issues, the Kyoto Protocol offers an interesting package of environmental, commercial, and political issues ripe for economic exploration.

In particular, any of the issues referenced above such as transaction costs, limitations on full credits, costlessly tradable goods, and especially technology considerations may be explored within a formal model. It may also be of interest to explore they dynamic nature of the political response to climate change. For instance, the

Kyoto Protocol initially only provides an emission reduction target for Annex I nations during the period 2008 – 2012. Parties are expected to negotiate further commitments for each subsequent five-year period, with the next compliance period occurring in 2013 – 2017. The long-run framework provided in this thesis is not representative of this very discrete and uncertain characteristic of the Kyoto Protocol.

Accordingly, it would be useful to explore how these five-year periods affect credit-investment decisions, political posturing (with respect to emission reduction target setting – perverse incentives), enforcement capabilities, etc..

Furthermore, with each five- year target renewal, the possibility of entry into or exit from the Kyoto Protocol increases. This, again, invites several interesting questions. For instance, is there a threshold level of participation for the Protocol to be self-enforcing? Under what circumstances might unconstrained Parties volunteer to assume a constraint?

In addition, at the recent World Summit, interested groups explored varying metrics under which currently unconstrained Parties could assume an emissions constraint. It was suggested, for instance, that developing countries could reduce their emissions based on a per capita target. Such a target would be "easier" for population-rich developing countries to reach (while also accommodating economic growth) rather than the absolute emission levels that developed Parties are currently targeting. If developing countries were to accept this metric, the implications may be significant, especially as it pertains to carbon leakage. On the other hand, if developed nations also assumed per capita emission targets, the implications will again, be significant.

There are many issues that remain unexplored with respect to the Kyoto Protocol, and this field is certain to be an area of tremendous interest moving forward!

7.8 Final Remarks

Clearly, addressing climate change at the international level, in conjunction with principles such as differentiated responsibilities, is not a simple or easy task. Nevertheless, the results and caveats from the modeling of this thesis should not be readily dismissed. It is important for political leaders to understand that this (perhaps) first step in the Kyoto Protocol, however costly it may be, may or may not generate net emission reductions at the global level, and that significant progress on global participation must occur before any meaningful reductions can transpire with some level of confidence. Since it is not entirely reasonable to ask the poorest nations to assume an emissions constraint when their citizens are going hungry, however, alternative solutions may be necessary if addressing climate change remains an urgent and critical issue for the earth.

References

Antweiler, W., Brian R. Copeland and M. Scott Taylor, "Is Free Trade Good for the Environment", forthcoming

Benarroch, Michael and Henry Thille, "International Trade with Cross-Border Pollution Externalities" December 4th, 1997

Blaine, Thomas W. "Global Climate Change" 1996. Ohio State University Extension Fact Sheet (CDFS-186-96) http://ohioline.osu.edu/cd-fact/0186.html

Caplan, Arthur J., Christopher J. Ellis, Emilson C.D. Silva, "Winners and Losers in a World with Global Warming: Non-cooperation, Altruism and Social Welfare", Journal of Environmental Economics and Management 37, 256-271 (1999)

Chambers, Paul E. and Richard A. Jensen, "Transboundary Air Pollution, Environmental Aid, and Political Uncertainty", *Journal of Environmental Economics and Management* V. 43, pp 93-112, 2002

Commission of the European Communities, "Proposal for a Directive of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC", Brussels, October 23rd, 2001

Copeland, Brian R. and M. Scott Taylor, "Free Trade and Global Warming: A Trade Theory View of the Kyoto Protocol", draft January 2001

Copeland, Brian R. and M. Scott Taylor, "North – South Trade and the Environment", *The Quarterly Journal of Economics* V109(3) pp. 755 - 787, August 1994

Copeland, Brian R. and M. Scott Taylor, "Trade & Transboundary Pollution", *The American Economic Review* V85(4) pp. 716-737, September 1995

Copeland, Brian R. and M. Scott Taylor, "Trade, Spatial Separation and the Environment", *Journal of International Economics,* V. 47, 1999. pp. 137-168

Dales, J.H. "Land, Water, and Ownership", *Canadian Journal of Economics*, November 1968, reprinted with permission in Dorfman, Robert and Nancy S. Dorfman, *Economics of the Environment: Selected Readings"* 3rd Edition W.W. Norton & Company (New York, London) 1993, pp. 225-240

European commission press release "EU Honours Commitment to Early EU Ratification of the Kyoto Protocol" Brussels, March 4, 2002

European Commission press release "The Kyoto Protocol and Climate Change" Brussels, March 4, 2002

European Environmental Agency, "EU reaches CO_2 stabilisation target despite upturn in greenhouse gas emissions", News Release April 29, 2002 (Copenhagen) available at http://org.eea.eu.int/documents/newsreleases/greenhouse_gas_emission

Global Change Strategies International, "Background Document for National Workshop on CDM and JI: COP 7 Results" Spring 2002

Government of Canada, *2001 Canada's 3rd National Report on Climate Change – Actions to Meet Commitments Under the United Nations Framework Convention on Climate Change* , Minister of Public Works & Government Services, 2001.

Government of Canada, *Climate Change Plan for Canada*, November 2002. Also found at http://climatechange.gc.ca/plan_for_canada/plan/pdf/full_version.pdf

Government of Mexico, *Mexico – First National Communication for the United Nations Framework Convention on Climate Change*, 1997

Government of Mexico, *Mexico – Second National Communication for the United Nations Framework Convention on Climate Change*, 2001a

Government of Mexico, "Mexico – Second National Communication for the United Nations Framework Convention on Climate Change", 2001b presented to delegates at the 7th Conference of the Parties in Marrakech, Morocco

Grossman, Gene M. and Alan B. Krueger, "Economic Growth and the Environment", *The Quarterly Journal of Economics* Volume 110 Issue 2 (May 95) pp. 353-337

Hahn, Robert W., *The Economics of Climate Change*, Washington D.C., AEI Press, 1998.

Harris, Jonathan and Codur, Anne-Marie, "The Economics of Climate Change" *Environmental and Natural Resource Economics: A Contemporary Approach*, Houghton-Mifflin, forthcoming.

Hyndman, Richard M., "An Overview of Emissions Trading – Fundamental Concepts and Issues", February 1998. Mimeo

International Panel on Climate Change, *First Assessment Report. 1990* composed of three volumes including (i) "Scientific Assessment of Climate Change – Report of Working Group I, JT Houghton, GJ Jenkins and JJ Ephraums (Eds), Cambridge University Press, UK; (ii) "Impacts Assessment of Climate Change – Report of Working Group II" W.J. Mc G Tegart, G.W. Sheldon, D.C. Griffiths (Eds), Australian Government Publishing Service, Australia; and (iii) The IPCC Response Strategies – Report of Working Group III" Island Press, USA.Intergovernmental Panel on Climate Change, "Summary for Policy Makers – A Report of Working Group I of the International Panel on Climate Change" from *Climate Change 2001 – The Scientific Basis,* Contribution of Working Group I to the *Third Assessment Report of the International Panel on Climate Change* edited by JT Houghton, Y Ding, DJ Griggs, M Noguer, PJ van der Lindon, and D Xiaosu. Cambridge University, UK 2001

Intergovernmental Panel on Climate Change, "Technical Summary – A Report Accepted by Working Group I of the International Panel on Climate Change but not approved in detail" from *Climate Change 2001 – The Scientific Basis,* Contribution of Working Group I to the *Third Assessment Report of the International Panel on Climate Change* edited by JT Houghton, Y Ding, DJ Griggs, M Noguer, PJ van der Lindon, and D Xiaosu. Cambridge University, UK 2001

Intergovernmental Panel on Climate Change, *Third Assessment Report of the International Panel on Climate Change – Climate Change 2001*, including the contribution from Working Group I *Climate Change 2001 – The Scientific Basis*, the contribution from Working Group II *Climate Change 2001 - Impacts, Adaptation & Vulnerability,* and the contribution from Working Group III *Climate Change 2001 – Mitigation*, Cambridge University Press, UK 2001.

Kyoto Protocol to the United Nations Framework Convention on Climate Change

List, John A. and Charles F. Mason, "Optimal Institutional Arrangements for Transboundary Pollutants in a Second- Best World: Evidence from a Differential Game with Asymmetric Players", *Journal of Environmental Economics and Management* 42, pp. 277-296

Lopez, Ramon, "The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization", *Journal of Environmental Economics and Management*, 27, pp. 163-184, 1994

Moomaw, William R. and Gregory Unruh, "Are Environmental Kuznets Curves Misleading Us?", Tufts University, Medford, Massachusetts

Muller, Benito "The Global Climate Change Regime: Taking Stock and Looking Ahead", forthcoming in the *Yearbook of International Co-Operation on Environment and Development*, London: Earthscan, forthcoming August 2002 p. 2 http://www.wolfson.ox.ac.uk/~mueller

Nordhaus, William D. "Economic Approaches to Greenhouse Warming," *Global Warming: Economic Policy Approaches* edited by RD Dornbush and JM Poterba, 33-68. Cambridge, MA: MIT Press 1991.

Nordhaus , William D. and Zili Yang "A Regional Dynamic General Equilibrium Model of Alternative Climate Change Strategies", *American Economic Review*, Vol 86 Issue 4 (September 96), pp. 741-765

Office of the Press Secretary (White House) "Text of a Letter from the President to Senators Hagel, Helms, Craig, and Roberts", March 13, 2001

Sohngen, Brent, "Climate Change: Science, Policy, and Economics" 1998. Ohio State University Extension Fact Sheet (AE-3-98) http://ohioline.osu.edu/ae-fact/0003.html

Stevens, Brandt and Adam Rose, "A Dynamic Analysis of the Marketable Permits Approach to Global Warming Policy: A Comparison of Spatial and Temporal Flexibility", *Journal of Environmental Economics and Management*, 2001

The Marrakech Accords and the Marrakech Declaration, advance unedited version November 2001.

Union of Concerned Scientists "Frequently Asked Questions about Global Warming", 2001 http://www.ucsusa.org/warming

Union of Concerned Scientists "The Science of Global Warming", 2001 http://www.ucsusa.org/warming

United Nations Framework Convention on Climate Change

United Nations Framework Convention on Climate Change, Article 1; http://unfccc.int/resource/conv/conv_003.html

United Nations Framework Convention on Climate Change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact17.html

United Nations Framework Convention on Climate Change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact18.html

United Nations Framework Convention on Climate Change "fact sheets" found at the website, http://unfccc.int/resource/iuckit/fact19.html

United Nations Framework Convention on Climate Change resource, ""Kyoto Protocol: Total carbon dioxide emissions of Annex I Parties in 1990, for the purposes of Article 25 of the Kyoto Protocol", found at the website, http://unfccc.int/resource/kpco2.pdf

United Nations Framework Convention on Climate Change resources found at the website, http://unfccc.int/resource/process/components/response/baaction.html

United Nations Framework Convention on Climate Change resources found at the website, http://unfccc.int/resource/process/components/response/landmarks.html

United Nations Framework Convention on Climate Change resources found at the website, http://unfccc.int/resource/process/components/response/respkp.html

United Nations Framework Convention on Climate Change Secretariat's note for the 13th Session of the UNFCCC Subsidiary Body for Implementation, "National Communications from Parties included in Annex I to the Convention: Greenhouse Gas Inventory Data from 1990 to 1998", September 2000

United Nations Framework Convention on Climate Change website http://unfccc.int/resource/process/components/institution/ipcc.html

United Nations Framework Convention on Climate Change website, http://unfccc.int/resource/process/components/response/respconv.html

United Nations, United Nations Framework Convention on Climate Change, Secretariat press release "Kyoto Protocol receives 100th ratification", December 18th, 2003

United States of America, *Climate Action Report – 1997 Submission of the United States of America Under the United Nations Framework Convention on Climate Change*, Department of State Publication 10496, Bureau of Oceans and International Environmental Scientific Affairs, Office of Global Change, released July 97

Unteroberdoerster, Olaf, "Trade and Transboundary Pollution: Spatial Separation Reconsidered", *Journal of Environmental Economics and Management* V. 41, pp 269-285, 2001

Varian, Hal R., *Microeconomic Analysis, Third Edition*, W.W. Norton & Company, New York, p. 43, 1992

Varilek, Matt and Nina Marenzi, "Greenhouse Gas Price Scenarios for 2000-2012: Impact of Different Policy Regimes", IWOe Discussion Paper No. 96, November 2001, Institute for Economy and the Environment, University of Gallen

Viguier, Larent *The U.S. Climate Change Policy: A Preliminary Evaluation*, Policy Brief No. 1, Le Centre français sur les Etats-Unis, March 2002

Appendix 1 – North American Case Studies

A1.1 Canadian Assessment

Canada became a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. As part of Canada's commitment under the UNFCCC, Canada was obliged to generate "national communications" as means of providing the UNFCCC secretariat (and, in fact, the world) with updates on Canada's climate change mitigation and adaptation responses as encouraged by the UNFCCC[132]. Two previous communications were released in 1993 and in 1997. This section provides information sourced directly from Canada's most recent national communication, *2001 Canada's 3rd National Report on Climate Change – Actions to Meet Commitments Under the United Nations Convention on Climate Change,* (referred to herein as the Third Assessment Report – TAR). Canada's particular national circumstance as it relates to the climate change issue, will be followed by a summary of emission trends. For perspective, the section closes with a brief discussion about Canada's vulnerability to potential climate change impacts.

Canada has a northern climate with a dispersed population over vast ranges of land. It boasts an export-oriented economy, due in large part to Canada's enrichment of natural resources. While these are typically envied characteristics that stimulate images of an untouched paradise or a land of great wealth, these "attributes" combine to leave Canada with significant greenhouse gas liabilities that are not easily addressed.

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[132] Government of Canada, *2001 Canada's 3rd National Report on Climate Change – Actions to Meet Commitments Under the United Nations Framework Convention on Climate Change* , Minister of Public Works & Government Services, 2001, p. 1.

Canada's northern climate comprises both extreme hot and cold seasons with accompanying heating and cooling requirements; both these requirements consume significant energy volumes supplied in part by fossil fuels. In addition, Canada has a high share of energy intensive industries coupled with significant production and refining of natural resources (TAR p. 11). While directly emitting GHGs themselves, these activities also put additional pressure on energy demand which further contributes to increased emission levels. Furthermore, in 1999 Canada exported 37% of its economic output, 40% of which was derived from energy-intensive production (TAR p. 12). This leaves Canada in the difficult position of generating emissions through the production of output enjoyed by other nations.

Given the above, it is understandable that Canada's per capita anthropogenic emissions are rather high. In particular, although Canada only has 0.5% of the world's population, it generates 2.2% of the world's GHG emissions. This translates to the ninth highest per capita GHG emissions in the world, and the second highest across the G8 nations (TAR p. 9). Nevertheless, global focus is not on per capita emissions, but instead, on emission levels relative to 1990 levels (please see the chapter focusing on climate change policy for further information on international policy and objectives).

For the 1990 to 1999 reporting period, Canada's GHG emissions continued to rise from the previous decade but at a decreasing rate, averaging 1.7% growth per year (TAR p. 24). The 15% growth over the decade appears to be promising compared to the decade's 25% growth in GDP, but is rather high when compared to the 10% population growth and the 13% energy growth over the same time period (TAR p. 26). Canadian emission projections to 2010 do not appear to be especially optimistic either; assuming the maintenance of existing government policies and programs, TAR projects Canadian emissions to be 705 million tonnes of carbon dioxide equivalent GHGs compared to 607 million tonnes emitted in 1990 (p. 89). While these projections are dependent on future government policies, economic conditions, etc. it is clear that Canada will continue to contribute to the accumulation of atmospheric GHGs for some time to come.

Though it may appear that Canada has made little progress, it is not for lack of incentive. In the words of the government, "[t]he magnitude, timing and regional impacts of climate change could have serious repercussions on Canada's natural resources, wildlife habitat, social and economic systems, and infrastructure, as well as on the health and well-being of Canadians" (TAR p. 3). The Canadian arctic has already warmed between .5 and 1.5 degrees Celsius, reducing the coverage and thickness of sea ice, thawing permafrost areas, altering the distribution and composition of northern species, etc. (TAR p. 95). Such changes are expected to broaden and increase in intensity as temperatures continue to climb. For instance, the report projects that central areas of Canada will experience more frequent and intense heat conditions, low-lying coastal areas will be afflicted with risks due to sea-level rises, surface and groundwater levels will be threatened, concerns for soil moisture and erosion levels are likely to increase, etc. (TAR p. 3, 95). Since Canada recognizes that it is vulnerable to warming temperatures, climate change will continue to be an important issue for the nation, regardless of the actions and positions of other nations.

A1.2 United States of America (USA)

Like Canada, the USA also became a signatory to the UNFCCC in 1992, and has accordingly, generated national communications for submission to the UNFCCC secretariat. Again, the information provided in this section is sourced from the second communication, *Climate Action Report – 1997 Submission of the United States of America Under the United Nations Framework Convention on Climate Change*, herein referred to as the Second Climate Action Report (CAR)[133]. Similar to the explanation for Canada, this section will summarize national·circumstances; emission trends and vulnerability for the USA.

CAR has articulated national characteristics and circumstances very much like those claimed by Canada. For instance, the USA has professed to be "uncommonly rich in land resources" (CAR p. 11), as well as to bearing a wide variety of climate conditions including sub-tropical and tundra. As with the Canadian position, heating and cooling demands are said to be important drivers of emission levels (CAR p. 26). Furthermore, since the USA holds abundant resources of all fossil fuels, they like Canada, have specialized in relatively energy-intensive production activities that further increase the national GHG emissions.

Unlike Canada, the USA is the world's largest energy producer and consumer in the world, which certainly equates to large GHG emission levels. To compound this dilemma, energy consumption has nearly doubled in the USA since 1960, and would

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[133] United States of America, *Climate Action Report – 1997 Submission of the United States of America Under the United Nations Framework Convention on Climate Change*, Department of State Publication 10496, Bureau of Oceans and International Environmental Scientific Affairs, Office of Global Change, released July 97

have grown further save for the efficiency gains achieved during that period (CAR p. 12). Also, demographic trends in the USA have led to a 57% growth in the number of households since 1970 (CAR p. 34). This, of course, puts additional pressures on energy demand and related GHG emissions.

In 1997 the USA was the third most populous country in the world at 265 million people, growing at an average of 1% per year since 1970 (CAR p. 33-34). Since 1960, the USA has averaged an increase in their GDP of 3% per year. This GDP / population growth ratio, as well as the above factors, have contributed to the USA holding the fifth highest per capita emissions in the world (Canada's TAR p. 10)

For the reporting period 1990 to 1995, the USA's GHG emissions increased annually by 1% to a cumulative increase of 5.9%. In particular, the net GHG emissions in 1990 were approximately 1,458 million tonnes carbon (5,346 million tonnes carbon dioxide equivalent – CO2e) compared to 1,599 million tonnes (5,864 million tonnes CO2e) in 1995 (CAR p. 52). While the report failed to propose a projection of emission levels out to 2010, Viguier suggests an increase of approximately 463 million tonnes carbon (1,698 million tonnes CO2e) by the year 2010.[134] Nevertheless, future projections may be especially difficult in this case, because history has shown that annual GHG emissions are largely correlated with the health of the USA's economy, with increased energy consumption during recoveries and reduced consumption during slowdowns (CAR p. 52).

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[134] Viguier, Larent *The U.S. Climate Change Policy: A Preliminary Evaluation*, Policy Brief No. 1, Le Centre français sur les Etats-Unis, March 2002 p. 4

Very much like Canada, the USA is not isolated from potential impacts of climate change. Examples of USA vulnerabilities include sea level rises affecting coastal areas (which have experienced accelerated population growth over the past few decades), changes in the hydrological cycle affecting water supplies, temperature extremes affecting heat related mortality levels, changing patterns in infectious diseases, etc. (CAR pp. 20, 140, 150). Like Canada, the USA's vulnerability to the anticipated climate change effects will force the nation's leaders to come to terms with the issue, regardless of the action they choose (or choose not to) take.

A1.3 Mexico

Mexico also signed the UNFCCC in 1992 with subsequent ratification in 1993. Accordingly, the country has generated its first national communication, *Mexico – First National Communication for the United Nations Framework Convention on Climate Change*[135], herein referred to as M1NC, and has subsequently provided its second national communication, *Mexico – Second National Communication for the United Nations Framework Convention on Climate Change* in both hard copy[136] and summarized presentation format[137], herein referred to as M2P. Drawing from these documents, this section will once again review Mexico's national circumstances, relevant emission trends and perceived vulnerabilities to climate change.

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[135] Government of Mexico, *Mexico – First National Communication for the United Nations Framework Convention on Climate Change*, 1997

[136] Government of Mexico, *Mexico – Second National Communication for the United Nations Framework Convention on Climate Change*, 2001a

[137] Government of Mexico, "Mexico – Second National Communication for the United Nations Framework Convention on Climate Change", 2001b presented to delegates at the 7th Conference of the Parties in Marrakech, Morocco

Mexico has a varied but somewhat moderate climate relative to both Canada and the USA, with the temperature range typically falling between ten and twenty six degrees Celsius. Rather than focusing on the level of natural resources endowed to Mexico, they have boasted their inclusion in the list of 12 "megadiverse countries", which together comprise 60-70% of all the world's species (M1NC p. 23). In particular, Mexico claims to have the fourth greatest biodiverse ecosystem of the world within its borders (M2P p. 22).

Forestry, agriculture and energy generation are important industries for Mexico, and the nation's emissions are reflective of this. The nation's energy usage, however, is not directly comparable to that of its northern neighbour's; firewood remains the primary biofuel used in rural Mexico and 31.4% of the population still cooks with firewood (M2P p. 24).

In 1995, Mexico held the eleventh largest population at 91.2 million people (M1NC p. 23). Also, the nation placed thirteenth in the world in terms of national emission levels, which placed them first amongst Latin American nations. While these latter placements are disappointing, achieving seventieth rank in the world in 1998 on an emissions per capita basis adds some perspective (M2P p. 15).

In 1990, Mexico emitted 520 million tonnes of carbon dioxide equivalent, compared to 686 million tonnes in 1996 (M2P pp 11, 14). This rather high 32% growth over the six year period is not expected to weaken into the future. Assuming a medium GDP growth (at 4.5%), the nation anticipates emissions of 879 million tonnes in 2010. This represents a 69% growth in GHG emissions over the 1990-2010 period. While this seems significantly larger than both Canada and the USA, as a lesser-developed country Mexico lacks the full range of technological efficiencies afforded both Canada and the USA, and thus, higher emissions result.

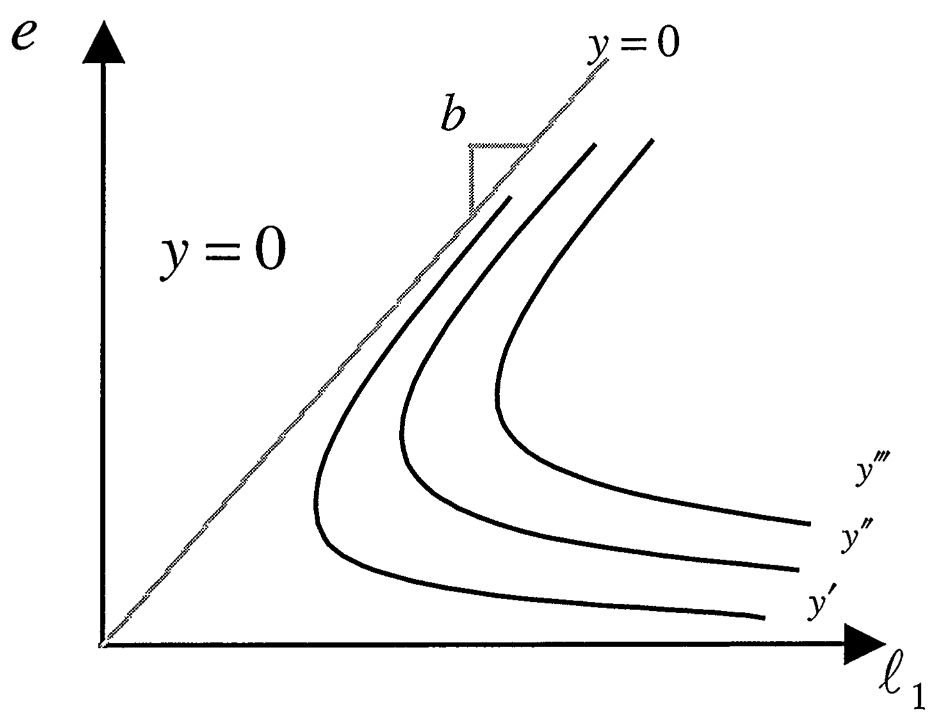
These higher emissions levels also concern Mexican officials. Because Mexico places importance on agriculture, forestry and other weather dependant industries, the nation will also feel the anticipated effects of climate change. For instance, the first national communication expects nearly 50% of Mexico's vegetation cover will undergo change. Also, over 48% of the nation is highly vulnerable to desertification. Furthermore, Mexico has concerns with agriculture, meteorological drought, water resources, coastal regions, etc. (M1NC p. 10). Thus, as with Canada and the USA, Mexico recognizes that it is not immune to the anticipated adverse impacts of climate change, and has expressed an appreciation for mitigation efforts.

Appendix 2 – Supplementary Mathematical Modeling

A2.1 $f(\ell_1, e)$ within the Production Function

Positively sloped isoquants occur when one of the inputs has a negative marginal product and the other has a positive marginal product, as depicted in (ℓ_1, e) space by the following figure, where $e \geq b\ell_1$ for $y \geq 0$.

Figure A2.1: Isoquants of the $f(\ell_1, e)$ Function



Assuming a modified Cobb-Douglas form, for instance:

$$f(\ell_1, e) = e^{\gamma}\left(\ell_1 - \frac{e}{b}\right)^{1-\gamma}$$

it is useful to confirm the function has expected properties:

$$e = 0 \quad \Rightarrow \quad f(\ell_1, e) = 0$$
$$\ell_1 = \frac{e}{b} \quad \Rightarrow f(\ell_1, e) = 0$$

Furthermore, by differentiating the function:

$$df(\ell_1, e) = \left[e^{\gamma-1}\left(\ell_1 - \frac{e}{b}\right)^{1-\gamma} - \left(\frac{1-\gamma}{b}\right) e^{\gamma}\left(\ell_1 - \frac{e}{b}\right)^{-\gamma} \right] de \; + \; \left[e^{\gamma}(1-\gamma)\left(\ell_1 - \frac{e}{b}\right)^{-\gamma} \right] d\ell_1$$

$$\frac{df(\ell_1, e)}{f(\ell_1, e)} = \left\{ \frac{\gamma}{e} - \frac{1-\gamma}{b}\left(\ell_1 - \frac{e}{b}\right)^{-1} \right\} de \; + \; \left\{ (1-\gamma)\left(\ell_1 - \frac{e}{b}\right)^{-1} \right\} d\ell_1$$

it can be shown that the marginal rate of technical substitution, representing the slope of the isoquants, (i.e., the rate at which emissions must be substituted for labour to keep output constant) is:

$$\left.\frac{de}{d\ell_1}\right|_{\frac{df(\ell_1,e)}{f(\ell_1,e)}=0} = \frac{-(1-\gamma)\left(\ell_1-\frac{e}{b}\right)^{-1}}{\frac{\gamma}{e}-\frac{(1-\gamma)}{b}\left(\ell_1-\frac{e}{b}\right)^{-1}}$$

$$= \frac{\gamma-1}{\left(\ell_1-\frac{e}{b}\right)\left(\frac{\gamma}{e}\right)+\frac{(\gamma-1)}{b}}$$

$$= \frac{1}{\frac{\gamma}{e(\gamma-1)}\left(\ell_1-\frac{e}{b}\right)+\frac{1}{b}}$$

Finally, by setting the denominator equal to zero it is shown where the slope goes to infinity:

$$\frac{\gamma}{e(\gamma-1)}\left(\ell_1-\frac{e}{b}\right) = -\frac{1}{b}$$

$$\gamma b\left(\ell_1-\frac{e}{b}\right)=-e(\gamma-1)$$

$$\gamma b\ell_1-\gamma e=-e\gamma+e$$

$$\gamma b\ell_1=e$$

This confirms that the slope goes to infinite along the constraining ray (recall $e=b\ell_1$ where b is the slope of the constraining ray above). It is straightforward to allow the marginal product of labour to become negative in this framework. In Figure A2.1 the isoquants would fall between two positively sloped rays from the origin. Due to the scarcity of labour, however, situations where the wage and marginal product of labour are equal to zero will not be observed in the model.

A2.2 Firm-level Output

To solve for the optimal level of output per firm, it is appropriate to simultaneously solve the firm's LRMC and its LRAC as identified in equations (10) and (11) respectively, and again in equations (39) and (40), and again in equations (90) and (91) from Chapter 6. For the one-country-world, it is appropriate to ignore the k index denoting either the North or South country.

$$h(\tau^k)\left((y_1^k)^{\alpha-1}v^k + \frac{\phi^k}{y_1^k}\right) = \alpha\, v^k\; h(\tau^k)\;(y_1^k)^{\alpha-1}$$

$$\alpha\, v^k\;(y_1^k)^{\alpha-1} = (y_1^k)^{\alpha-1}v^k + \frac{\phi^k}{y_1^k}$$

$$\alpha\, v^k\;(y_1^k)^{\alpha} = (y_1^k)^{\alpha}v^k + \phi^k$$

$$(y_1^k)^{\alpha}\left(\alpha v^k - v^k\right) = \phi^k$$

$$\Rightarrow \quad (y_1^k)^{\alpha} = \left(\frac{\phi^k}{v^k(\alpha-1)}\right)$$

A2.3 Emissions Per Unit of Output

Using equations (12) and (13) or equations (41) and (42) from Chapter 6, the emissions per unit of output is calculated as follows: (For the one-country-world, it is appropriate to ignore the k index denoting either the North or South country.)

$$\frac{e^k}{y_1^k} = \frac{h'(\tau^k)\left(\frac{\alpha\phi^k}{\alpha-1}\right)}{\left(\frac{\phi^k}{v^k(\alpha-1)}\right)^{1/\alpha}}$$

$$= \frac{\alpha\phi^k}{\alpha-1}\left(\frac{v^k(\alpha-1)}{\phi^k}\right)^{1/\alpha} h'(\tau^k)$$

$$= \alpha\, h'(\tau^k)\left(v^k\right)^{1/\alpha}\left(\frac{\phi^k}{\alpha-1}\right)^{\frac{\alpha-1}{\alpha}} \quad , \quad k = N, S$$

A2.4 Southern Profit Function to Allow for the Introduction of Credits

To assess the introduction of credits and the implications for Southern firm-level profits consider the following equation, as earlier represented in Chapter 6 as equation (75):

$$\pi_1^S = \begin{cases} y_1^S p_1 + \tau^N \bar{e}^S - (1-\lambda)\tau^N e^S - h(\lambda\tau^N)\left((y_1^S)^\alpha v^S + \phi^S\right) & if \quad y_1^S > 0 \\ 0 & if \quad y_1^S = 0 \end{cases} \qquad \text{Eqn (131)}$$

Note that if $\lambda = 1$ such that credits have been introduced, then with positive output,

$$\pi_1^S = y_1^S p_1 + \tau^N \bar{e}^S - h(\tau^N)\left((y_1^S)^\alpha v^S + \phi^S\right)$$

which suggests that Southern firms gain revenue from all potential credits created up to the business as usual emissions level ($\tau^N \bar{e}^S$) and they forego such revenue for every actual emission released as part of total cost, $h(\tau^N)\left[(y_1^S)^\alpha v^S + \phi^S\right]$.

Alternatively, if $\lambda = 0$ and credits have not been introduced to the permit-only scenario, then with positive output:

$$\pi_1^S = y_1^S p_1 + \tau^N \left(\overline{e}^S - e^S\right) - h(0)\left((y_1^S)^\alpha v^S + \phi^S\right)$$

Recognizing that since credits have not been introduced, Southern firms remain in a business as usual scenario and their actual emissions are equal to their baseline emissions ($\overline{e}^S = e^S$). Therefore, with positive output the above equation becomes:

$$\pi_1^S = y_1^S p_1 - h(0)\left((y_1^S)^\alpha v^S + \phi^S\right)$$

This result is exactly equivalent to equation (38) in which $\tau^k = \tau^S = 0$.

For the case in which credits are only partially introduced to the system such that $0 < \lambda < 1$ and $0 < \tau^S < \tau^N$, an intuitive and diagrammatic explanation can be found in Chapter 6, Section 6.5.1, B.

Finally, it is appropriate to determine how the introduction of credits affects firm-level profits, holding price and emission prices constant:

$$\pi_1^S = y_1^S p_1 + \tau^N \overline{e}^S - (1-\lambda)\tau^N \left(\frac{\alpha\phi^S}{\alpha - 1}\right) h'(\lambda\tau^N) - h(\lambda\tau^N)\left(\left(\frac{\phi^S}{v^S(\alpha-1)}\right) v^S + \phi^S\right)$$

$$\frac{\partial \pi_1^S}{\partial \lambda} = -\left(\tau^N\right)^2 \left(\frac{\alpha\phi^S}{\alpha-1}\right) h''(\lambda\tau^N) + \tau^N \left(\frac{\alpha\phi^S}{\alpha-1}\right) h'(\lambda\tau^N) + \lambda\left(\tau^N\right)^2 \left(\frac{\alpha\phi^S}{\alpha-1}\right) h''(\lambda\tau^N)$$
$$-\tau^N h'(\lambda\tau^N)\left(\frac{\phi^S}{\alpha-1} + \frac{\alpha\phi^S - \phi^S}{\alpha-1}\right)$$

$$\frac{\partial \pi_1^S}{\partial \lambda} = \tau^N \left(\frac{\alpha\phi^S}{\alpha-1}\right)\left[-\tau^N h''(\lambda\tau^N) + h'(\lambda\tau^N) + \lambda\tau^N h''(\lambda\tau^N) - h'(\lambda\tau^N)\right]$$

$$\frac{\partial \pi_1^S}{\partial \lambda} = -(1-\lambda)\left(\tau^N\right)^2\left(\frac{\alpha\phi^S}{\alpha-1}\right)h''(\lambda\tau^N) \quad > 0$$

Thus, holding both good and emission prices constant, it is rational for individual Southern firms to create credits and enter the "credit market". This is an important condition for the question of carbon leakage and its relationship to credit introduction to be interesting.

A2.5 Southern Firm Level Output for the Credit Scenario

To solve for the optimal level of output per Southern firm in the two-country permit plus credit scenario, it is appropriate to simultaneously solve the firm's LRMC and its LRAC as identified in equations (77) and (78) from Chapter 6.

$$\alpha\, v^S\ (y_1^s)^{\alpha-1}\left[h(\lambda\tau^N) - \tau^N h'(0) + (1-\lambda)\tau^N h'(\lambda\tau^N)\right] =$$

$$\left(v^S (y_1^s)^{\alpha-1} + \frac{\phi^S}{y_1^S}\right)\left[h(\lambda\tau^N) - \tau^N h'(0) + (1-\lambda)\tau^N h'(\lambda\tau^N)\right]$$

$$\alpha\, v^S\ (y_1^s)^{\alpha-1} = \left(v^S (y_1^s)^{\alpha-1} + \frac{\phi^S}{y_1^S}\right)$$

$$\phi^S \alpha\, v^S\ (y_1^s)^{\alpha} = v^S (y_1^s)^{\alpha} + \phi^S$$

$$\alpha\, v^S\ (y_1^s)^{\alpha} - v^S (y_1^s)^{\alpha} = \phi^S$$

$$(y_1^s)^{\alpha}\left(v^S(\alpha-1)\right) = \phi^S$$

$$y_1^s = \left(\frac{\phi^S}{v^S(\alpha-1)}\right)^{1/\alpha} = \tilde{y}_1^S$$

which is the same minimum efficient level of output as under the 2 country permit only scenario!

A2.6 Differentiation of the Southern Break-Even Curve when Credit Introduction is Considered

Differentiating the Southern break-even curve as represented by equation (82) provides:

$$dp_1 = \alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[\lambda h'(\lambda\tau^N) - h'(0) + (1-\lambda)h'(\lambda\tau^N) + (1-\lambda)\lambda\tau^N h''(\lambda\tau^N)\right]d\tau^N$$

$$+\, a\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[\tau^N h'(\lambda\tau^N) - \tau^N h'(\lambda\tau^N) + (1-\lambda)\left(\tau^N\right)^2 h''(\lambda\tau^N)\right]d\lambda$$

Rearranging provides:

$$-dp_1 +$$

$$\alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[\lambda h'(\lambda\tau^N) - h'(0) + h'(\lambda\tau^N) - \lambda h'(\lambda\tau^N) + \lambda\tau^N h''(\lambda\tau^N) - \lambda^2\tau^N h''(\lambda\tau^N)\right]d\tau^N$$

$$= -\alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[\tau^N h'(\lambda\tau^N) - \tau^N h'(\lambda\tau^N) + \left(\tau^N\right)^2 h''(\lambda\tau^N) - \lambda\left(\tau^N\right)^2 h''(\lambda\tau^N)\right]d\lambda$$

Further rearranging allows:

$$-dp_1 + \alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[h'(\lambda\tau^N) - h'(0) + (1-\lambda)\lambda\tau^N h''(\lambda\tau^N)\right]d\tau^N$$

$$= -\alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[(1-\lambda)\left(\tau^N\right)^2 h''(\lambda\tau^N)\right]d\lambda$$

This final equation is represented as equation (83) in the text.

A2.7 Conditions for Growth in the Southern Dirty Good Sector to be More or Less Likely such that Additional Carbon Leakage Occurs

Reconsidering equation (127) and its respective constituents:

$$\frac{dn_1^S}{d\lambda} = \frac{C_{14}C_{22} - C_{12}C_{24}}{D} \gtrless 0 \text{ ; where}$$

$$D = C_{11}C_{22} - C_{21}C_{12} < 0 \qquad C_{11} = \left[\frac{\phi^S}{v^S(\alpha-1)}\right]^{1/\alpha} = y_1^S$$

$$C_{12} = \left[\frac{\phi^N}{v^N(\alpha-1)}\right]^{1/\alpha} = y_1^N \qquad C_{14} = D'(p_1(\lambda))p_1'(\lambda)$$

$$C_{21} = \left(\frac{\alpha\phi^S}{\alpha-1}\right)\left[h'(0) - h'\left(\lambda\tau^N(\lambda)\right)\right] = \bar{e}^S - e^S \qquad C_{22} = -\left(\frac{\alpha\phi^N}{\alpha-1}\right)h'\left(\tau^N(\lambda)\right) = -e^N$$

$$\begin{aligned} C_{24} &= n_1^S\left(\frac{\alpha\phi^S}{\alpha-1}\right)h''\left(\lambda\tau^N(\lambda)\right)\left(\tau^N + \lambda\,\tau^{N'}(\lambda)\right) + n_1^N\left(\frac{\alpha\phi^N}{\alpha-1}\right)h''\left(\tau^N(\lambda)\right)\tau^{N'}(\lambda) \\ &= n_1^S e^{S'}(\tau^S)\left(\tau^N + \lambda\,\tau^{N'}(\lambda)\right) + n_1^N e^{N'}(\tau^N)\tau^{N'}(\lambda) \end{aligned}$$

$$\frac{d\tau^N}{d\lambda} = \tau^{N'}(\lambda) = \frac{-B_{13}}{\Delta} < 0 \qquad \frac{dp_1}{d\lambda} = p_1'(\lambda) = \frac{-B_{21}B_{13}}{\Delta} < 0 \qquad \Delta = -B_{11} + B_{21} > 0$$

$$\begin{aligned} B_{11} &= \alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[h'(\lambda\tau^N) - h'(0) + (1-\lambda)\lambda\tau^N h''(\lambda\tau^N)\right] \\ &= \frac{1}{y_1^S}\left[e^S - \bar{e}^S + e^{S'}(\tau^S)(1-\lambda)\tau^S\right] \end{aligned}$$

$$B_{13} = -\alpha\left(v^s\right)^{1/\alpha}\left(\frac{\phi^S}{(\alpha-1)}\right)^{\frac{\alpha-1}{\alpha}}\left[(1-\lambda)\left(\tau^N\right)^2 h''(\lambda\tau^N)\right] = -\frac{e^{S'}(\tau^S)}{y_1^S}(1-\lambda)\left(\tau^N\right)^2$$

$$B_{21} = \alpha \left(v^N\right)^{1/\alpha} \left(\frac{\phi^N}{\alpha - 1}\right)^{\frac{\alpha-1}{\alpha}} h'(\tau^N) = \frac{e^N}{y_1^N}$$

Substituting the appropriate inputs:

$$\frac{dn_1^S}{d\lambda} = \frac{1}{D}\left\{ -D'(p_1(\lambda)) \frac{e^{S'}(\tau^S)\left(e^N\right)^2}{\Delta y_1^S y_1^N}(1-\lambda)\left(\tau^N\right)^2 \right.$$
$$\left. - y_1^N \left[n_1^S e^{S'}(\tau^S)\left(\tau^N + \lambda\, \tau^{N'}(\lambda) \right) + n_1^N e^{N'}(\tau^N)\tau^{N'}(\lambda) \right] \right\}$$

$$= \frac{1}{D}\left\{ -D'(p_1(\lambda)) \frac{e^{S'}(\tau^S)\left(e^N\right)^2}{\Delta y_1^S y_1^N}(1-\lambda)\left(\tau^N\right)^2 \right.$$
$$\left. - y_1^N \left[n_1^S e^{S'}(\tau^S)\left(\frac{\tau^N \Delta y_1^S}{\Delta y_1^S} + \lambda \frac{e^{S'}(\tau^S)}{\Delta y_1^S}(1-\lambda)\left(\tau^N\right)^2 \right) + n_1^N e^{N'}(\tau^N) \frac{e^{S'}(\tau^S)}{\Delta y_1^S}(1-\lambda)\left(\tau^N\right)^2 \right] \right\}$$

Simplifying and rearranging provides:

$$\frac{dn_1^S}{d\lambda} = \frac{1}{D\Delta y_1^S}\left\{ -D'(p_1(\lambda)) \frac{e^{S'}(\tau^S)\left(e^N\right)^2}{y_1^N}(1-\lambda)\left(\tau^N\right)^2 \right.$$
$$- y_1^N \left[n_1^S e^{S'}(\tau^S)\left(\tau^N \left[-e^S + \bar{e}^S - e^{S'}(\tau^S)(1-\lambda)\tau^S + \frac{e^N y_1^S}{y_1^N} \right] \right. \right.$$
$$\left. \left. \left. + \lambda\, e^{S'}(\tau^S)(1-\lambda)\left(\tau^N\right)^2 \right) + n_1^N e^{N'}(\tau^N) e^{S'}(\tau^S)(1-\lambda)\left(\tau^N\right)^2 \right] \right\}$$

$$= \frac{-\tau^N e^{S'}(\tau^S)}{D\Delta y_1^S}\left\{D'(p_1(\lambda))\frac{(e^N)^2}{y_1^N}(1-\lambda)\tau^N + y_1^N\left[n_1^S\left(-e^S + \bar{e}^S - e^{S'}(\tau^S)(1-\lambda)\tau^S + \frac{e^N y_1^S}{y_1^N} + \lambda e^{S'}(\tau^S)(1-\lambda)\tau^N\right) + n_1^N e^{N'}(\tau^N)(1-\lambda)\tau^N\right]\right\}$$

$$= \frac{-\tau^N e^{S'}(\tau^S)}{D\Delta y_1^S}\left\{D'(p_1(\lambda))\frac{(e^N)^2}{y_1^N}(1-\lambda)\tau^N + y_1^N\left[n_1^S\left(\bar{e}^S - e^S + e^{S'}(\tau^S)(1-\lambda)(\lambda\tau^N - \tau^S) + \frac{e^N y_1^S}{y_1^N}\right) + n_1^N e^{N'}(\tau^N)(1-\lambda)\tau^N\right]\right\}$$

$$= \frac{-\tau^N e^{S'}(\tau^S)}{D\Delta y_1^S}\left\{D'(p_1(\lambda))\frac{(e^N)^2}{y_1^N}(1-\lambda)\tau^N + y_1^N\left[n_1^S\left(\bar{e}^S - e^S + \frac{e^N y_1^S}{y_1^N}\right) + n_1^N e^{N'}(\tau^N)(1-\lambda)\tau^N\right]\right\}$$

$$= \frac{-\tau^N e^{S'}(\tau^S)}{D\Delta y_1^S}\left\{(1-\lambda)e^N D(p_1)\left[\frac{p_1 D'(p_1(\lambda))}{D(p_1)}\left(\frac{\tau^N e^N}{p_1 y_1^N}\right) + \left(\frac{y_1^N n_1^N}{D(p_1)}\right)\frac{e^{N'}(\tau^N)\tau^N}{e^N}\right] + n_1^S\left[y_1^N\left(\bar{e}^S - e^S\right) + e^N y_1^S\right]\right\}$$

$$\frac{dn_1^S}{d\lambda} = \frac{-\tau^N e^{S'}(\tau^S)}{D\Delta y_1^S}\left\{(1-\lambda)e^N D(p_1)\left[\varepsilon_1^d\left(\frac{\tau^N e^N}{p_1 y_1^N}\right) + \sigma_1^N\,\eta_e^N\right] + n_1^S\left[y_1^N\left(\bar{e}^S - e^S\right) + e^N y_1^S\right]\right\}$$

where $\varepsilon_1^d < 0$ is the elasticity of demand with respect to price for the dirty good, $\eta_e^N < 0$ is the elasticity of Northern emissions with respect to the Northern emissions price, and $\sigma_1^N > 0$ is the Northern share of the dirty good market. This final equation is represented as equation (129) in the text; these results are discussed further in the final portion of Chapter 6, section 6.5.3 D.