The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?

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July 27, 1998

This research results from our involvement in Stanford University's Energy Modeling Forum 16 Study. The authors are indebted to James Deaker and Robert Parkin for their research assistance. We have benefited from discussions with Jae Edmonds, Henry Jacoby, David Montgomery, William Nordhaus, Stephen Peck, Thomas Rutherford, and John Weyant. Funding was provided by EPRI. The results presented here are solely those of the individual authors.

1. Introduction

The Kyoto Protocol represents a milestone in climate policy.[1] For the first time, negotiators have attempted to lay out emission reduction targets for the early part of the 21st century. The goal is for Annex 1 (developed countries plus economies in transition) to reduce their aggregate anthropogenic carbon dioxide equivalent emissions by at least 5 percent below 1990 levels in the commitment period 2008 to 2012. The Protocol, however, has yet to enter into force. To do so will require ratification by 55 countries representing 55 percent of total Annex 1 CO_2 emissions in 1990.

As each country considers ratification, important questions will arise. High up on the US list is the issue of economic costs. The Senate, for example, has stated that "any Protocol should be accompanied by a detailed financial analysis of impacts on the economy."[2] Not surprisingly, US negotiators had hardly returned from Kyoto before the first hearings were scheduled on Capitol Hill. Although the issue of costs is but one of many important considerations, policy makers are keenly interested in the economic implications of ratification.

This paper is intended to help clarify our understanding of compliance costs. The focus is on three questions, which we believe to be of particular relevance: What are the near-term costs of implementation? How significant are the so-called "flexibility provisions"? And, perhaps most importantly, is the Protocol cost-effective in the context of the long-term goals of the Framework Convention?[3]

Unfortunately, the answers to these questions will not come easily. It has always been difficult to calculate the economic costs of implementing climate policy. Kyoto has done little to simplify matters. Indeed, it raises at least as many questions as it resolves. These questions fall into two categories: those related to the near-term implementation of the Protocol and those related to the evolution of climate policy over the longer term.

The Protocol is unclear on a number of topics. These include the rules governing emission trading, joint implementation (JI), the Clean Development Mechanism (CDM), and the treatment of carbon sinks. In addition, there is a weak knowledge base regarding the costs of sink enhancement and of controlling several of the relevant trace gases. Until these issues are clarified, analyses will be highly speculative.

Calculating the costs of Kyoto is also complicated by the issue of "what happens next?" Energy sector investments are typically long-lived. Today's investment decisions are not only influenced by what happens during the next decade, but also by what happens thereafter. In order to estimate the costs of implementing emission cuts in the first commitment period, assumptions are required concerning the longer-term requirements. Unfortunately, the international negotiation process offers little guidance on this issue. This further complicates the process of analysis.

We do not wish to suggest that economic analysis is premature at the present time. Uncertainty is rarely an excuse for paralysis. It does mean, however, that we must be careful to highlight the tentative nature of the projections and focus, to the extent possible, on the insights for decision making. Here, sensitivity analysis can be particularly useful. For example, in the case of several of the flexibility provisions (emission trading, joint implementation and the Clean Development Mechanism), we explore a variety of scenarios regarding constraints on the purchase of carbon emission rights. While the exact magnitude of the benefits will continue to be debated, the insights, nevertheless, appear to be quite robust.

We also examine the Protocol in the context of the longer-term goal of the Framework Convention, i.e., the stabilization of greenhouse gas concentrations in the earth's atmosphere. A particular concentration goal can be reached through a variety of emission pathways. Considerable effort has been devoted to trying to understand the characteristics of cost-effective pathways.[4] It is interesting to examine Kyoto in the context of this work. The price tag for moving forward may be formidable. Consistent with the Framework Convention, it is essential that "policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible costs."[5]

2. The model

This analysis is based on MERGE (a model for evaluating the regional and global effects of greenhouse gas reduction policies).[6,7] MERGE is an intertemporal market equilibrium model. It combines a bottom-up representation of the energy supply sector together with a top-down perspective on the remainder of the economy. Savings and investment decisions are modeled as though each of the regions maximizes the discounted utility of its consumption subject to an intertemporal wealth constraint. Each region's wealth includes not only capital, labor and exhaustible resources, but also its negotiated international share in carbon emission rights.

For the present version of the model, known as MERGE 3.0, we have adopted 10-year time intervals through 2050 and 25-year intervals through 2100. Geographically, the world is divided into nine geopolitical regions: 1) the USA, 2) OECDE (Western Europe), 3) Japan, 4) CANZ (Canada, Australia and New Zealand), 5) EEFSU (Eastern Europe and the Former Soviet Union), 6) China, 7) India, 8) MOPEC (Mexico and OPEC) and, 9) ROW (the rest of world). Note that the OECD (regions 1 through 4) together with EEFSU constitute Annex 1 of the Framework Convention.

Particularly relevant for the present analyses, MERGE provides a general equilibrium formulation of the global economy. We model the possibility of international trade in carbon emission rights. This is sometimes known as "where" flexibility. It would allow regions with high marginal abatement costs to purchase emission rights from regions with low marginal abatement costs. In addition, MERGE can be used to examine the related issue of "when" flexibility - intertemporal transfers of carbon emission rights.

We also model international trade in oil, natural gas, and energy-intensive basic materials. We are therefore able to examine issues related to "carbon leakage". Such leakage can occur through a variety of pathways. For example, Annex 1 emission reductions will result in lower oil demand, which in turn will lead to a decline in the international price of oil. As a result, non-Annex 1 countries may increase their oil imports and emit more than they would otherwise.

The present version of the model includes the notion of endogenous technical diffusion. Specifically, in the electric sector, the near-term adoption of high-cost carbon-free technologies leads to accelerated future introduction of lower cost versions. The model also includes both price-induced and non-price conservation. For most regions and time periods, the AEEI (autonomous energy efficiency improvement) rate is taken to be 40% of the rate of GDP growth. By 2100, this leads to regional energy-GDP ratios that are much closer to each other than they were in 1990.

In calibrating MERGE for the present analysis, several supply- and demand-side parameters were adjusted so that the global emissions baseline would approximate the Intergovernmental Panel on Climate Change (IPCC) central case "no policy" scenario (IS92a).[8] Figure 2.1 shows carbon emissions for each region in the reference case scenario. For more on the model and its key assumptions, see our website:

http://www-leland.stanford.edu/group/MERGE/

3. Treatment of sinks and non-CO_2 greenhouse gases

Few issues have engendered as much confusion as that of carbon sinks. Key questions include their definition, the extent to which they are included in the Protocol, the amount currently being sequestered, their time profile, and the costs of sink enhancement.

The Protocol states that Annex 1 commitments can be met by “the net changes in greenhouse gas emissions from sources and removal by sinks resulting from direct human-induced land use change and forestry activities limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period.”[9] The confusion results from alternative interpretations regarding the treatment of soil carbon, an issue flagged for further study in the Protocol. Their inclusion may result in large increases in the international legal definition of sink potential.

The quality of the data is uneven. The supply curves for sink enhancement are particularly questionable. The degree of confidence concerning current and predicted future levels of carbon sequestration varies enormously across regions of the globe. Not surprisingly, information is most reliable (albeit still poor) for Annex 1 countries. Comparatively little effort has been made to collect such data elsewhere.

As placeholders, we have adopted the values shown in Table 1. To provide some perspective, in order for the US to reduce industrial carbon emissions by 7% below 1990 levels in 2010, it would have to reduce emissions by approximately 550 million tons below its reference trajectory. Sink enhancement would satisfy 9 percent of this obligation. For purposes of the present analysis, we assume that this sink enhancement is costless.

Table 1. **Sink Enhancement** (million metric tons of carbon annually)

USA	50
OECDE	17
Japan	0
CANZ	50
EEFSU	34

CO_2 is by far the most important of the greenhouse gases. In addition, the Protocol includes five other trace gases (methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride). Given the scarcity of reliable emissions and cost data, the treatment of the non-CO_2 greenhouse gases is also problematic. For purposes of the present analysis, we assume that each gas is reduced proportionately. With this proportionality assumption, the inclusion of the non-CO_2 greenhouse gases does not affect the requirements for CO_2 reductions.

As with our treatment of sinks, we do not include the costs of abating the non-CO_2 greenhouse gases in our estimates of the costs of complying with the Protocol. Clearly, an important next step would be to develop supply curves for the cost of abating non-CO_2 greenhouse gases and for sink enhancement. Neither of these costs is included in the present version of MERGE.

4. “Kyoto Forever”

We begin with an examination of a “Kyoto Forever” scenario. This is a case in which the Kyoto constraints on Annex 1 countries are maintained throughout the 21st century. With regard to non-Annex 1 emissions, we assume they will continue to be bounded by their business-as-usual baseline (Figure 2.1). The latter constraint is imposed in order to prevent carbon leakage. Later on, we will explore the impact of relaxing this constraint.

Numerous studies have shown that global mitigation costs can be reduced substantially by allowing emission reductions to take place wherever it is cheapest to do so - regardless of geographical location.[10] The Kyoto Protocol includes several provisions allowing for a limited amount of "where" flexibility. These include emission trading and joint implementation among Annex 1 countries. They also include provisions for a Clean Development Mechanism (CDM) that is intended to facilitate joint implementation between Annex 1 and non-Annex 1 countries.

As with the definition of sinks, the Protocol leaves many critical details unresolved. For example, it remains unclear whether there will be limits on the extent to which a country can rely upon the purchase of emission rights to satisfy its obligations. The Protocol states that "the Conference of the Parties shall define the relevant principles, modalities, rules and guidelines …"[11] Similar ambiguity surrounds the Clean Development Mechanism. Again, the elaboration of "modalities and procedures" is left to a future meeting of the Conference of the Parties.[12]

In this section, we explore three scenarios: 1) no trading, 2) Annex 1 trading plus CDM, and 3) full global trading. These three options are representative of alternative implementations of the Kyoto Protocol. Each has its own advocates and opponents, but we do not consider them equally likely. In our opinion, there is little likelihood of enticing all major countries to participate in a global market in emission rights during the initial commitment period (2008-2012).

The full global trading scenario places an upper bound on the CDM's potential to reduce GDP losses. In calculating the potential size of the contribution from a CDM, we therefore calculate this upper bound on the export of emission rights from non-Annex 1 regions. Because of the difficulties in implementation of the CDM, however, we assume that only 15% of the potential would be available for purchase through this mechanism. This is a highly subjective estimate. Given the complexities of the CDM, however, we are not inclined to assign a higher value

Figure 4.1 reports the incremental value of carbon emission rights to the US in 2010 and 2020. We focus first on 2010. In the most constrained scenario, the US must satisfy its emission reduction requirements within its own geographical boundaries. In this case, the value of emission rights approaches $240 per ton. With Annex 1 trading plus CDM, the value drops to slightly less than $100 per ton. As might be expected, the value of emission rights is lowest with full global trading. Here, it falls below $70 per ton.

For the two scenarios in which trading is permitted, the value of emission rights increases in 2020. This is because EEFSU's projected emissions lie below its negotiated constraint for 2010. It has been allocated more emission rights than it needs to satisfy its internal obligations. By 2020, however, EEFSU's economic growth is expected to be such that it no longer enjoys an excess of emission rights. As a result, there is more competition for emission rights in the international marketplace, and there is an increase in their price.

Another way to view the costs of abatement is to show the GDP losses. Figure 4.2 contains those for the US. Losses are highest in the absence of trade. Here, they exceed $80 billion dollars in 2010. This is approximately one percent of US GDP. To the extent that trade is introduced, losses decline. In the most optimistic scenario (full global trade), losses are approximately $20 billion or one-quarter of one percent of GDP in 2010.

Of the three scenarios, "Annex 1 trading plus the CDM" is most consistent with the Protocol as it currently stands. However, the US Senate has stated that the US should not be a signatory to the Protocol if it does not mandate specific commitments for developing countries.[13] If this were to result in full global emission trading, we move in the direction of the right-most bar of Figure 4.2.

There is, however, strong sentiment among many parties to the Framework Convention to substantially limit the extent to which Annex 1 countries can meet their obligation through the purchase of emission rights. Several influential developing countries have expressed strong opposition to the concept altogether. Figure 4.2 shows the costs of the no trading scenario. We now turn to the case where trading is permitted, but with limitations on the purchase of emission rights.

5. Limits on the purchase of carbon emission rights

Figure 5.1 shows our estimates of the percentage of the US emission reduction obligation that would be satisfied through the purchase of emission rights under base case assumptions. With full global trading (the least-cost of our three scenarios), trading is used to satisfy more than 50% of the US obligation. But suppose that limits are placed on the purchase of emission rights? For example, suppose that international negotiators agree that Annex 1 buyers can satisfy only one-third of their obligation through this means. What would be the impact on GDP losses?

Figure 5.2 compares three cases. All assume full global participation in an international market for carbon emission rights, but only the first assumes no limits on the amount a country can buy. The second and third case are based upon the one-third limitation. We further make the distinction between a buyers' market and a sellers' market. With the former, sellers of emission rights are price takers. Buyers exert sufficient market power to hold the international price to the marginal cost of abatement in the selling countries. However, since a country is only able to satisfy one-third of its obligation through the purchase of emission rights, it must eventually rely on its own domestic marginal abatement capabilities to meet its obligations. Hence, there is an important distinction between the international price and the domestic price. Conversely, with a sellers' market, buyers face but one price. Here, the rents accrue to the sellers.

Figure 5.3 shows the GDP losses associated with the three scenarios. Note that losses in 2010 are two and one-half to three times higher with the constraint on the purchase of carbon emission rights. That is, the benefits from "where" flexibility are greatly diminished. The message is clear. Developing country participation in the market for carbon emission rights is a necessary, but by no means a sufficient condition for reaping the full benefits of "where" flexibility. To achieve a cost-effective solution, buyers must also be unconstrained in the manner in which they fulfill their obligation.

Also note that the distribution of the rents makes a difference to GDP losses. US losses are 25% higher in 2020 when market power resides with the sellers. The analysis provides an additional message for Annex 1 buyers. If at a given point in time, low-cost sellers are concentrated among a few countries (e.g., EEFSU), they may have considerable potential for extracting monopoly rents.

6. The issue of carbon leakage

The Kyoto Protocol refers specifically to the period centered about 2010. During this period, the onus for emission reductions falls on Annex 1. No specific obligations are imposed on countries outside Annex 1, and there is the possibility of "leakage". That is, the reductions in Annex 1 might be partially offset by increased emissions from China, India, Brazil and other countries that do *not* belong to Annex 1.

In this section, we examine the potential for leakage through international fuel markets and through the migration of energy-intensive industries. We therefore drop the assumption that non-Annex I countries are constrained to their reference case emissions. Two variants on the reference scenario are reported. In the first, the only trade impact of the Protocol consists of limiting the ability of the Annex 1 countries to import oil and gas. There is a lower international price of these goods, and there is a modest increase in price-induced demands by non-Annex 1 countries. However, there is no international trade in carbon emission rights, and there is no international migration of production within the energy-intensive sectors (EIS).

The second alternative is the same as the first, except that we now permit EIS trade. For a description of how the model has been modified to account for international trade in the energy-intensive sectors, see Appendix A. Figure 6.1 summarizes the overall results. According to this figure, neither of the two trade alternatives leads to a dramatic increase in carbon emissions outside Annex 1. Apparently there is an international leakage problem, but it appears to be of manageable dimensions.

Figure 6.2 suggests a somewhat different interpretation. Here we report the EIS trade scenario, and we compare the impact upon production-consumption ratios in each region. Under the reference case, these ratios are close to unity (the horizontal line) in most regions. The bars in Figure 6.2 show that the Protocol could lead to serious competitive problems for EIS producers in the USA, Japan and OECD Europe. The Protocol would lead to significant reductions in their output and employment, and there would be offsetting increases in regions with low energy costs. One can easily anticipate calls for protection against "unfair competition". In its present form, the Protocol could lead to acrimonious conflicts between those who advocate free international trade and those who advocate a low-carbon global environment.

7. Evaluating Kyoto in the context of the longer-term goal

The objective of the Framework Convention is "the stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system."[14] The drafters of the Protocol focused exclusively on the initial steps to be taken by Annex 1 countries. Little attention was paid to the ultimate goal. We now examine the Protocol in the context of a long-term stabilization objective.

From Figure 2.1 it is clear that the "Kyoto Forever" scenario will fail to stabilize global emissions and concentrations. A particular concentration target can be achieved through a variety of emission pathways. In this section, we explore three pathways for stabilizing concentrations at 550ppmv (twice preindustrial levels) by 2100. We stress, however, that the issue of what constitutes "dangerous interference" has yet to be determined. Indeed, it is likely to be the subject of intense scientific and political debate for decades to come. Hence, our choice of a target is meant to be purely illustrative.

Our three pathways are intended to illustrate the benefits of "when" flexibility. They are titled: 1) "Kyoto followed by arbitrary reductions"; 2) "Kyoto followed by least-cost"; and, 3) "least-cost". As their names imply, the first two are designed to be consistent with the Protocol during the first commitment period. The third assumes a clean slate in the choice of emissions pathway throughout the 21st century.

For the first scenario, we assume that Annex 1 countries reduce emissions through 2030 at the same rate as the OECD during the first decade of the 21st century (2% per year). During this period, non Annex-1 countries are permitted to emit up to their reference case levels. By 2020, emissions in the developing nations are larger than those in Annex I. We then choose a pathway to stabilization which represents a relatively smooth transition to the target. As for the post-2030 burden-sharing scheme, we assume that between 2030 and 2050 all regions move to equal per capita emission rights (based on their 1990 population). Equal per capita emission rights have been proposed as one approach to international fairness, but there are others that might also serve to separate the issue of equity from that of economic efficiency.

With "Kyoto followed by least-cost", the Protocol is adopted for the initial commitment period. Thereafter, the most cost-effective pathway is followed for stabilizing concentrations at 550ppmv. With "least-cost", the most cost-effective pathway for stabilizing concentrations at 550ppmv is followed from the outset. The latter two scenarios adopt the same proportionate burden-sharing scheme as the first.

All three scenarios assume Annex 1 trading plus the CDM. However, they differ as to the timing of developing country involvement in the international market for carbon emission rights. By definition, least-cost assumes that emission reductions will be made where it is cheapest to do so, regardless of the geographical location. Hence, in the least-cost scenario, we assume global emission trading from the outset. In the case of "Kyoto followed by least-cost", we assume that global emission trading is delayed until after the first commitment period. With "Kyoto followed by arbitrary reductions", global emission trading does not begin until 2030, the year that developing countries agree to lower their emissions below business-as-usual.

Global carbon emissions. Figure 7.1 shows global carbon emissions for the reference case and the three stabilization scenarios. Following a least-cost strategy from the outset results in an emissions pathway that tracks the reference path through 2010 and then departs at an increasing rate thereafter. There are several reasons why a gradual transition to a less carbon-intensive economy is preferable to one involving sharper near-term reductions.

Concentrations at a given point in time are determined more by cumulative, rather than year-by-year, emissions. Indeed, a concentration target defines an approximate carbon budget, i.e., an amount of carbon that can be emitted between now and the date at which the target is to be reached. At issue is the optimal allocation of the budget. Reasons for relying more heavily on the budget in the early years include: 1) providing more time for the economic turnover of existing plant and equipment, 2) providing more time to develop low-cost substitutes to carbon-intensive technologies, 3) providing more time to remove carbon from the atmosphere via the carbon cycle, and 4) the effect of time discounting on mitigation costs.[15]

We next turn to the two scenarios where we adopt the Protocol for the first commitment period. Notice that the two emission pathways behave quite differently post-2010. "Kyoto followed by least-cost" follows the least-cost pathway once the Protocol's constraints are relaxed. "Kyoto followed by arbitrary reductions", on the other hand, bears no resemblance to the least-cost pathway. What is striking about Figure 7.1 is that with a 550ppmv target, the Protocol is inconsistent with the most cost-effective mitigation pathway, i.e. "least-cost". Indeed, it appears that the ultimate target would have to be considerably lower than 550ppmv for the Protocol to be justified in terms of cost-effectiveness.

Near-term losses. It is instructive to look at the incremental value of emission rights for the three stabilization scenarios (Figure 7.2). With the least-cost path, the value is relatively low in the early years ($11 per ton of carbon in 2010), and it rises gradually over time. With "Kyoto followed by least-cost", the value is $130 per ton in 2010 and then tracks the least-cost path thereafter. In the case labeled "Kyoto followed by arbitrary reductions", the incremental value of emission rights starts at about $160 per ton and it remains high.

Figure 7.3 shows US GDP losses in 2010 and 2020 under the three stabilization scenarios. Notice that GDP losses in 2010 differ for the two scenarios involving the initial adoption of the Protocol. Because of the long-lived nature of energy investments, investors are concerned both with what happens in the initial commitment period and what happens thereafter. In the case of the more rapid transition away from the baseline ("Kyoto followed by arbitrary reductions"), investors will be forced to invest more heavily in high–cost substitutes in the early years. With "Kyoto followed by least-cost", they will have more flexibility.

It is striking by how much GDP losses can be lowered under the "least-cost" scenario. This strategy involves a more gradual transition away from the baseline in the early years. It relieves much of the pressure for premature retirement of existing plant and equipment and for dependence on high-cost substitutes (both on the supply- and demand-sides of the energy sector). Relative to the reference case, the US also receives some benefits as an oil importer. Recall that a carbon constraint decreases the overall demand for oil and lowers its price on the international market.

Global losses. Finally, it is instructive to examine losses from a global perspective (Figure 7.4). For purposes of the present comparison, we focus on the present value of consumption losses over the 21st century discounted to 1990 at 5 percent. The relative magnitude of the cumulative losses for the three stabilization scenarios comes as no surprise given the previous discussion. "Kyoto followed by arbitrary reductions" is by far the most expensive of the three paths. "Kyoto followed by least-cost" is a considerable improvement, but is still 40% more expensive than embarking on the most cost-effective mitigation pathway from the outset.

What is surprising is that "Kyoto Forever" turns out to be more expensive than "Kyoto followed by least cost" or "least cost". "Kyoto Forever" results in sharper global emission reductions during the early decades of the 21st century. It does not, however, succeed in stabilizing emissions, much less concentrations. By contrast, the other scenarios all lead to stabilization at 550ppmv. In other words, "Kyoto Forever" ends up costing more, and it buys less long-term protection.

8. Further comments

Some suggest that models such as MERGE tend to *overestimate* the costs of mitigation. They argue that, when prospects for technical progress are incorporated, the costs of a carbon constraint, even a sharp near-term constraint, will be minimal. We, too, are optimistic about the outlook for technical innovation. Indeed, such innovation is embedded both in our reference case and in the policy scenarios. The disagreement is over the rate at which such progress will occur. We do not believe that economically competitive substitutes will become available at such a rate as to trivialize the costs of a Kyoto-like Protocol.

A more valid concern may be that we are *underestimating* the costs of a carbon constraint. There are several reasons why this may be the case. To begin with, optimization models assume that decision makers have perfect foresight. That is, they assume that investors are fully informed about the nature of future constraints, and act accordingly. Given the present state of uncertainty, this is highly unlikely. Models such as MERGE also tend to ignore short-term macro shocks. For example, the higher energy prices brought about by a carbon constraint are likely to be inflationary. If this leads to higher interest rates, investment may be dampened. The result would be a slowdown in economic growth.

In addition, we assume that policies will be efficient. That is, market mechanisms will be chosen over "command and control" approaches to accomplishing environmental objectives. Whereas, in recent years, there has been an increasing trend toward market mechanisms, the approach to be taken with climate policy is by no means assured. Moreover, even if such a commitment were made, we have no assurances that the requisite international institutions will be available when needed.

Although it is easy to quibble over the numbers, the real value of analyses lies more in insights than in numerical values. And, indeed we believe that the current exercise has yielded several insights that may be of value to those charged with interpreting the current proposal. Here, we summarize what we have learned:

- First, it is extremely unlikely that a "Kyoto Forever" scenario will stabilize emissions -- much less concentrations. Non-Annex 1 emissions are quickly overtaking those of the OECD and the economies in transition. Hence, meeting the stabilization goal of the Framework Convention will eventually require the participation of developing countries.

- International cooperation through trade in emission rights is essential if we are to reduce mitigation costs. The magnitude of the savings will depend on several factors. These include the number of countries participating in the trading market, the shape of each country's marginal abatement cost curve, and the extent to which buyers can satisfy their obligation through the purchase of emission rights.

- With regard to the latter, limitations on the purchase of emission rights may be especially costly. In the example explored here, limiting purchases to one-third of a country's obligation increased GDP losses by a factor of at least two and one-half in the year 2010. If proponents of such limitations are successful, they may seriously reduce the benefits from "where" flexibility.

- The issue of monopoly power in markets for emission rights may turn out to be important. This is most likely to occur if trading is limited to Annex 1 and the majority of inexpensive emission rights are concentrated in a small number of countries. If these countries were successful in organizing a sellers' cartel, they might be able to extract sizable rents.

- The near-term costs of the Protocol will depend on expectations regarding the future. Energy investments are typically long-lived. Today's investment decisions are not only influenced by what happens during the next decade, but also by what happens thereafter. Hence, analyses which focus solely on 2010 may be underestimating the costs of Kyoto.

- Finally, and perhaps most importantly, unless the concentration target for CO_2 is well below 550ppmv, the Protocol appears to be inconsistent with a cost-effective long-term strategy for stabilizing CO_2 concentrations. Rather than requiring sharp near-term reductions, it appears that a more sensible strategy would be to make the transition at the point of capital stock turnover. This would eliminate the need for premature retirement of existing plant and equipment and would provide the time that is needed to develop low-cost, low-carbon substitutes.

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Appendix A. Modeling international trade in the energy-intensive sectors

MERGE 3.0 has recently been modified to include the possibility of trade in EIS (energy-intensive sectors). EIS is an aggregate including ferrous and non-ferrous metals, chemicals, nonmetallic minerals, paper, pulp and print. This aggregate does not include the energy-intensive industry of petroleum refining. The model may be run either with or without EIS trade.

The new feature is introduced in a way that preserves the basic simplifying characteristics of the ETA-MACRO submodel. That is, energy, capital and labor are substitutes that enter into an aggregate production function. They produce a numeraire good which may be used for consumption, investment and interindustry payments for energy costs.

It is assumed that trade will continue to represent a relatively small amount of each region's total internal demand for EIS. The GTAP (General Trade Analysis Program, 1992) data base is employed to estimate each region's EIS demands. In all other respects, the model is the same as MERGE 3.0.

For projecting the impact of the Kyoto protocol, each region is taken to be self-sufficient at base year energy prices. Changes in the location of production are attributed primarily to changes in the cost of energy. At base year prices in the USA, 85% of the cost of EIS consisted of non-energy inputs (labor, shipping, capital, iron ore, etc.), and 15% of the cost consisted of energy inputs (half electric and half non-electric). Under these conditions, a doubling of energy prices would imply only a 15% increase in the cost of EIS. This is why it is assumed that the demand for EIS is inelastic with respect to the price of energy. For projecting future demands, the income elasticity is taken to be 0.5.

For modeling purposes, we have supposed that the marginal supplies of EIS in all regions are determined by the same international technology that prevails in the USA. Each region has the same energy-EIS production ratio. For non-energy inputs, each supply curve is linear. Its positive slope serves the same purpose as an Armington elasticity describing substitution between foreign and domestic goods. This is the way in which we avoid penny-switching as a characteristic solution mode.

The slope of the non-energy supply curve is described as a Heckscher-Ohlin fraction. If this fraction is unity, EIS is viewed as a perfectly homogeneous commodity. Small changes in energy costs will then lead to large changes in the international location of production. If this fraction is less than unity, the supply function is less elastic, and the changes in location will be less dramatic. (See Figure A.1.)

Figure 2.1 Regional Carbon Emissions -- reference case

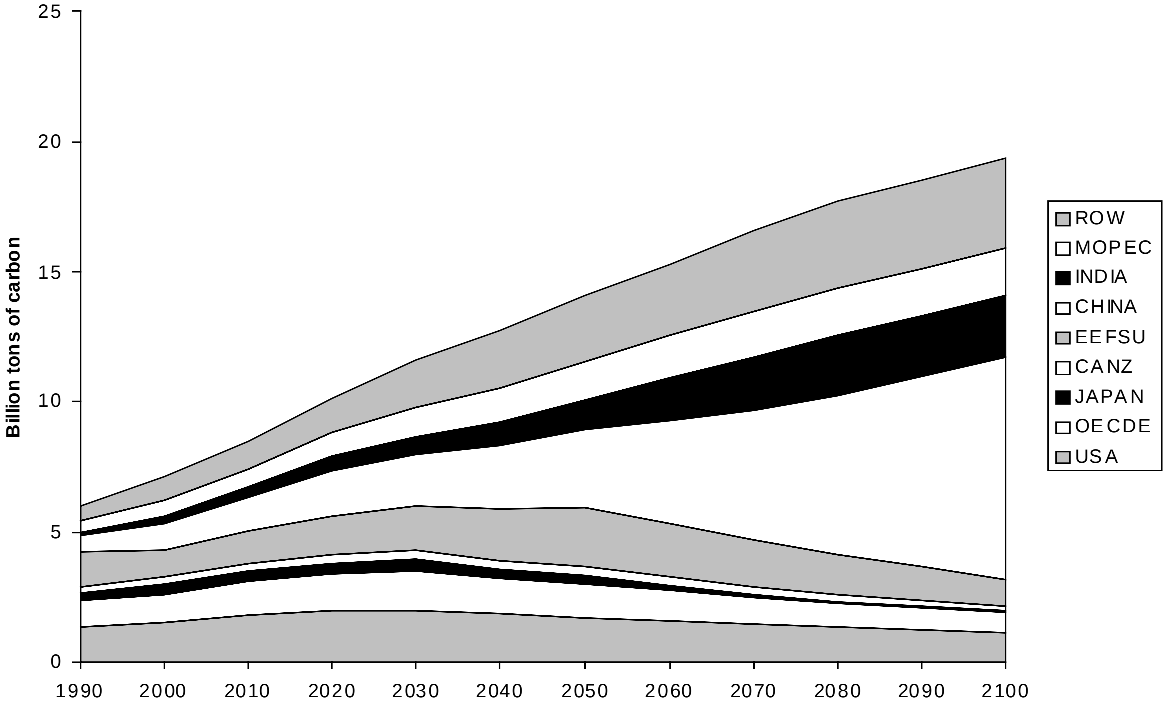

Figure 4.1 Incremental Value of Carbon Emission Rights in US Under Kyoto Forever

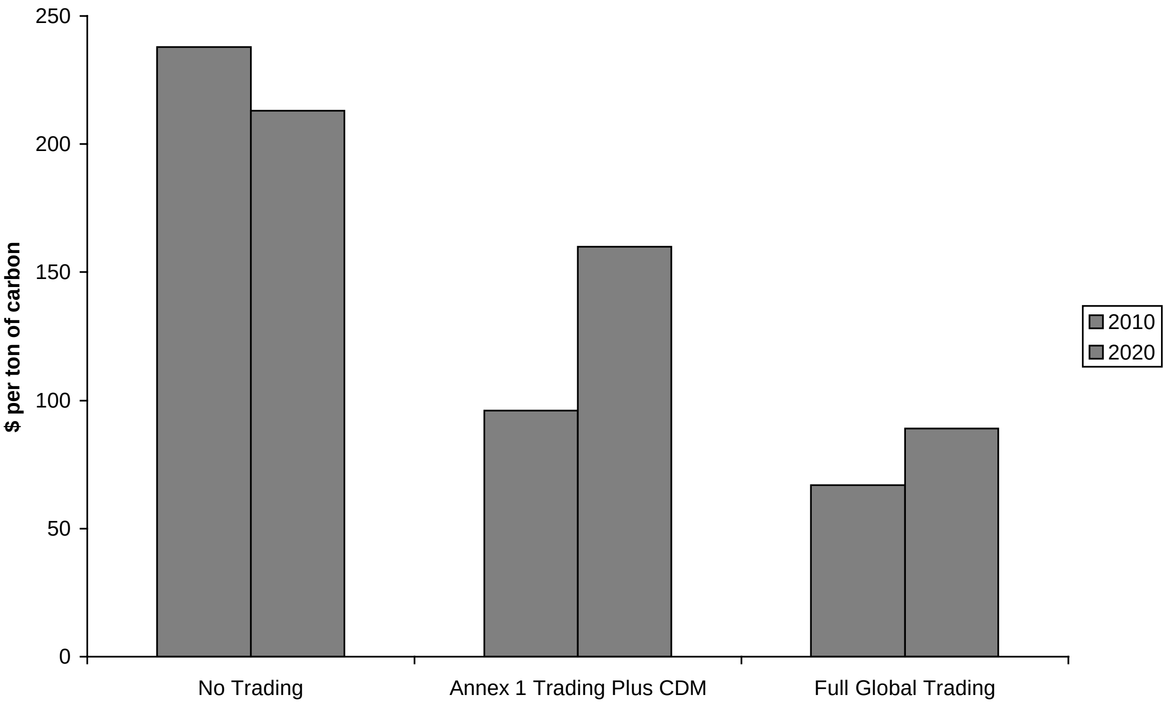

Figure 4.2 Annual US GDP Losses Under Kyoto Forever
($ billions)

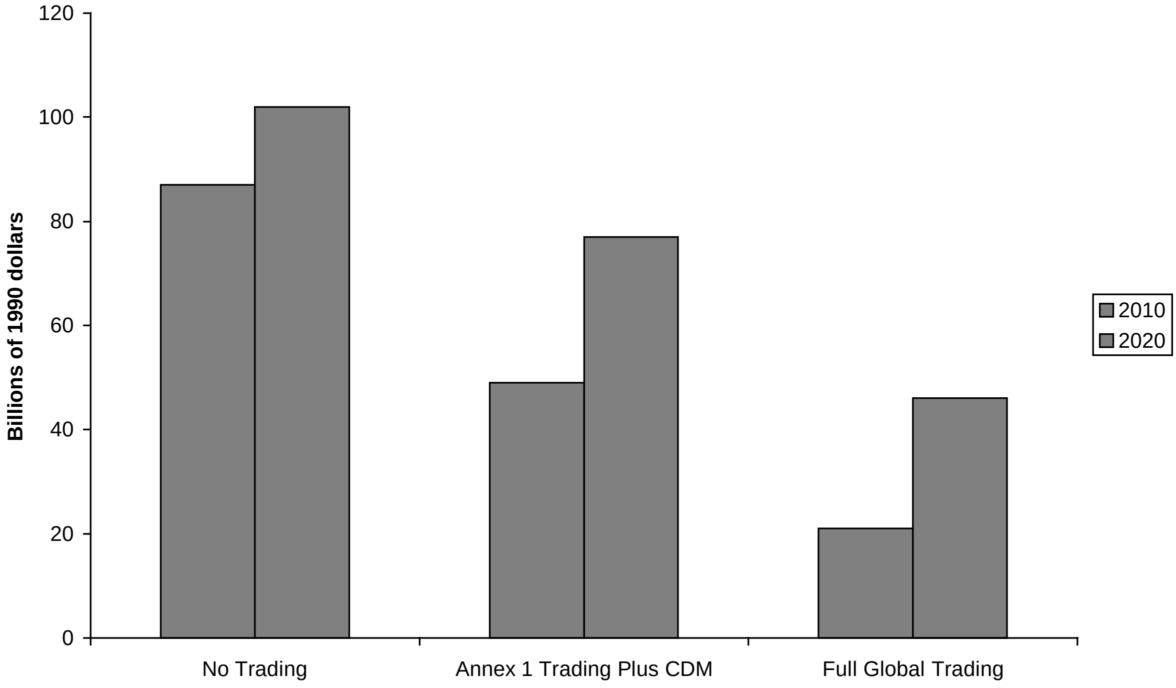

Figure 5.1 Percent of US Obligation Satisfied Through the Purchase of Emission Rights

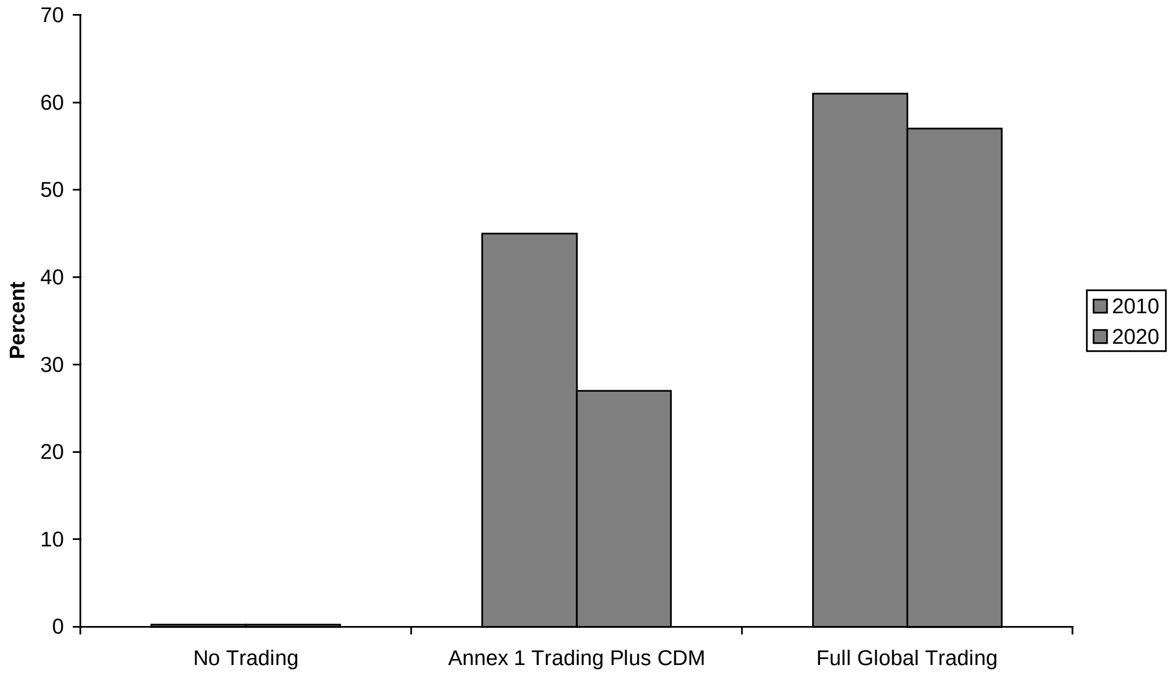

Figure 5.2 Incremental Value of Carbon Emission Rights With and Without Limits on the Purchase of Emission Rights -- Kyoto Forever

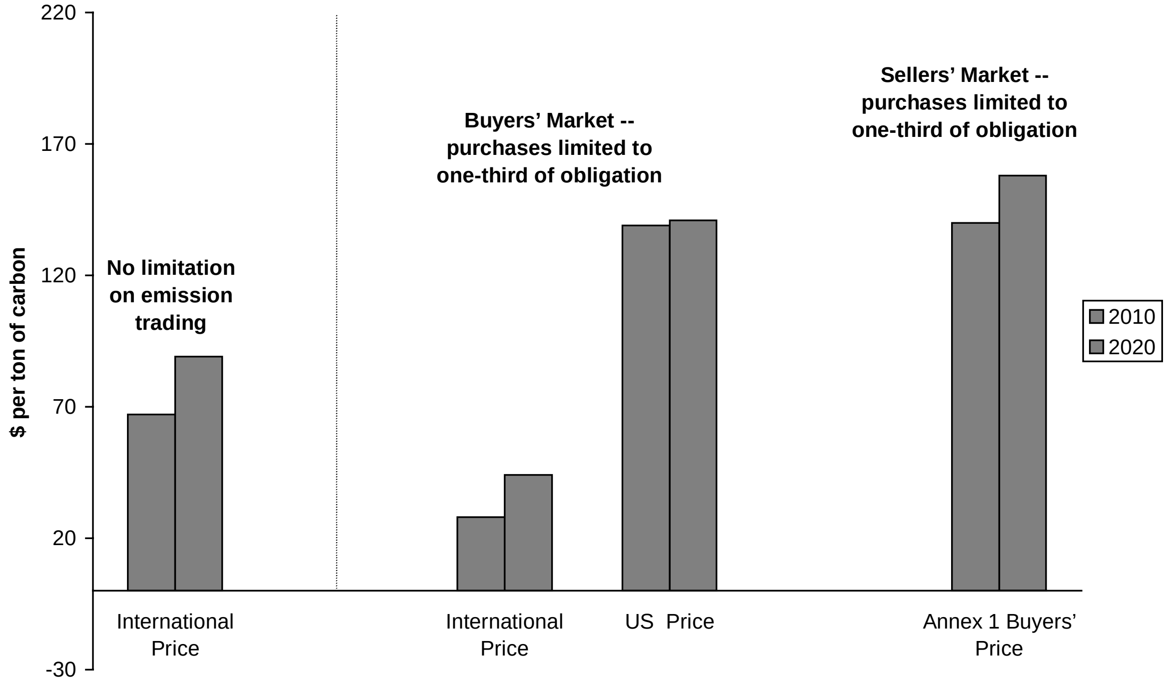

Figure 5.3 Annual US GDP Losses with Full Trading - Annex 1 May Satisfy Only One-Third of Obligation Through the Purchase of Emission Rights -- Kyoto Forever

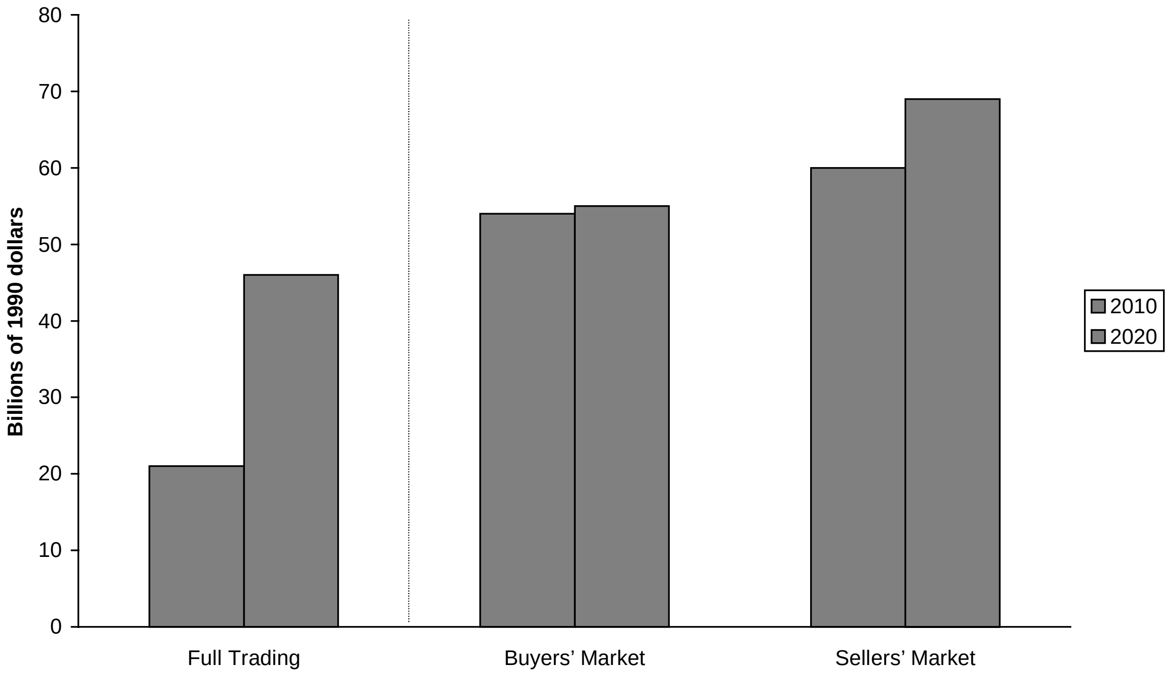

Figure 6.1 Carbon Emissions Outside Annex 1 -- Alternative Leakage Scenarios

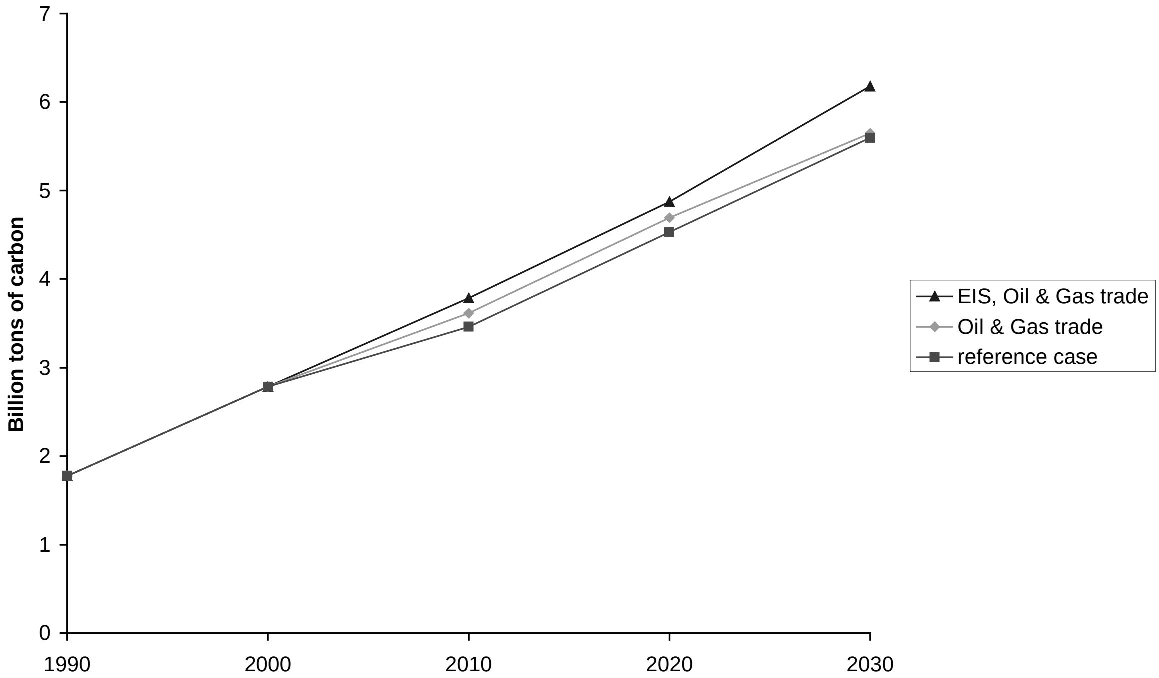

Figure 6.2 Ratios of Domestic EIS Supplies to Demands -- Kyoto with Leakage

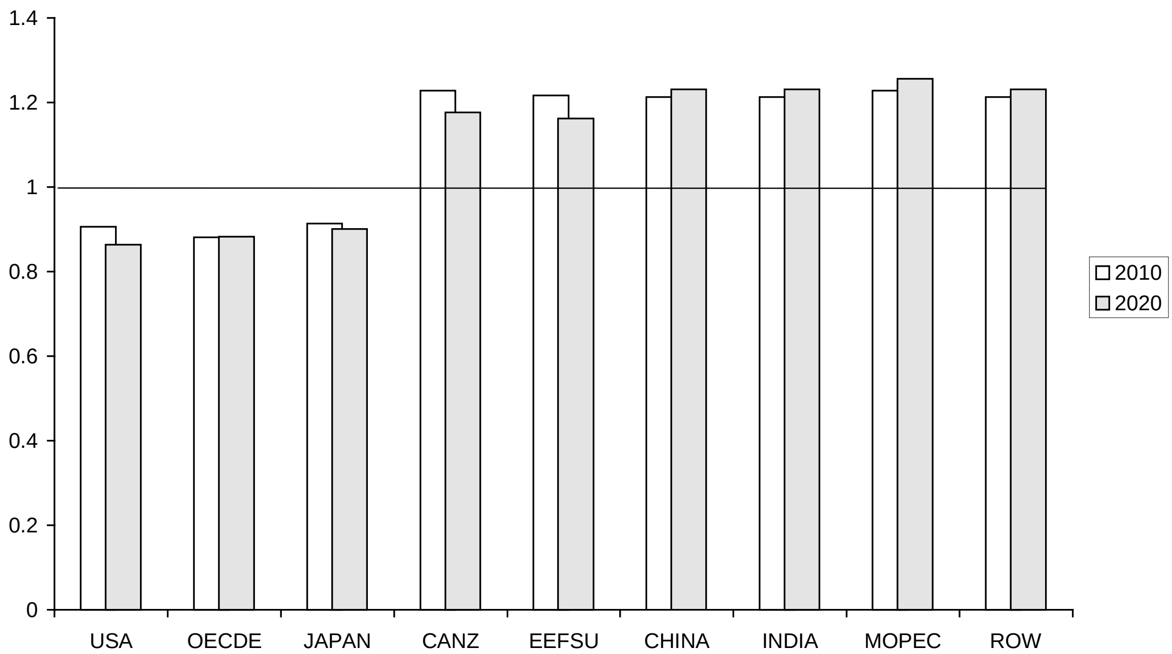

Figure 7.1 Global Carbon Emissions -- Reference Case and Three Alternative Emission Pathways for Stabilizing Concentrations at 550ppmv

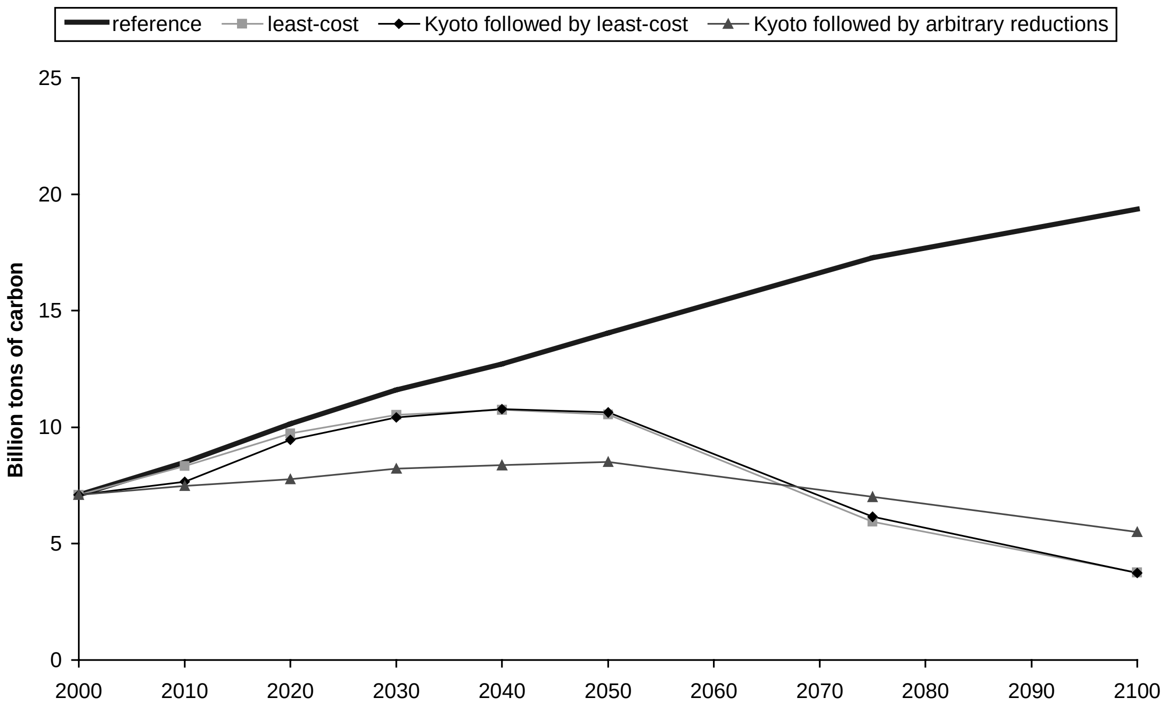

Figure 7.2 Incremental Value of Carbon Emission Rights under Three Alternative Emission Pathways for Stabilizing Concentrations at 550ppmv -- Global Trading

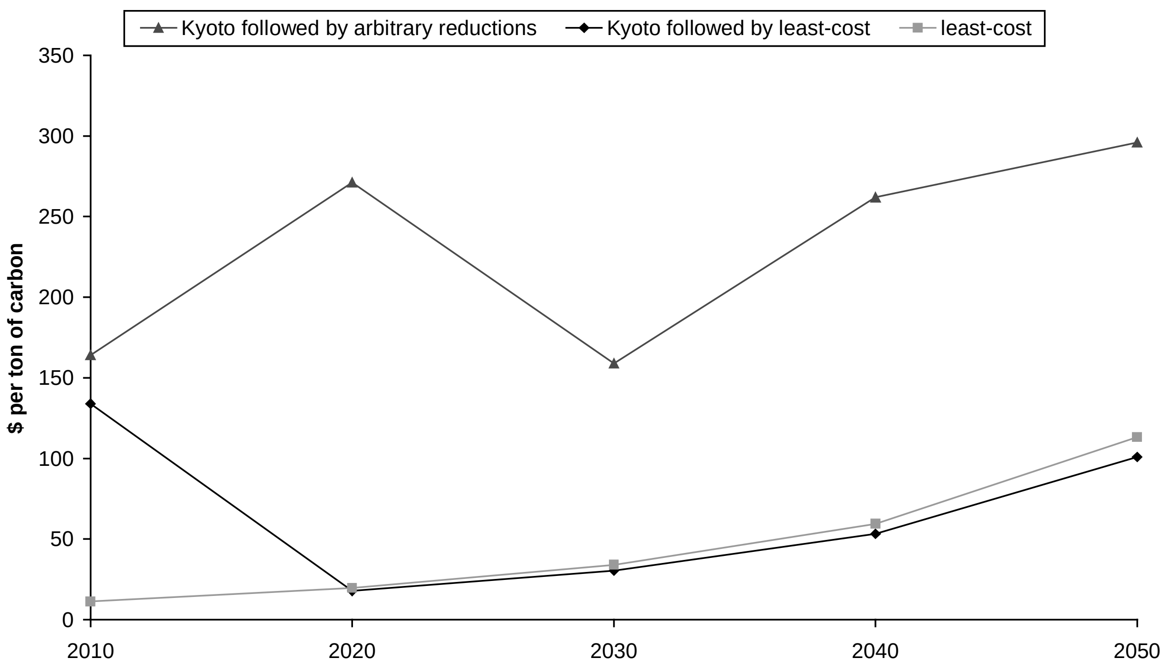

Figure 7.3 US GDP Losses Under Alternative 550ppmv Stabilization Scenarios

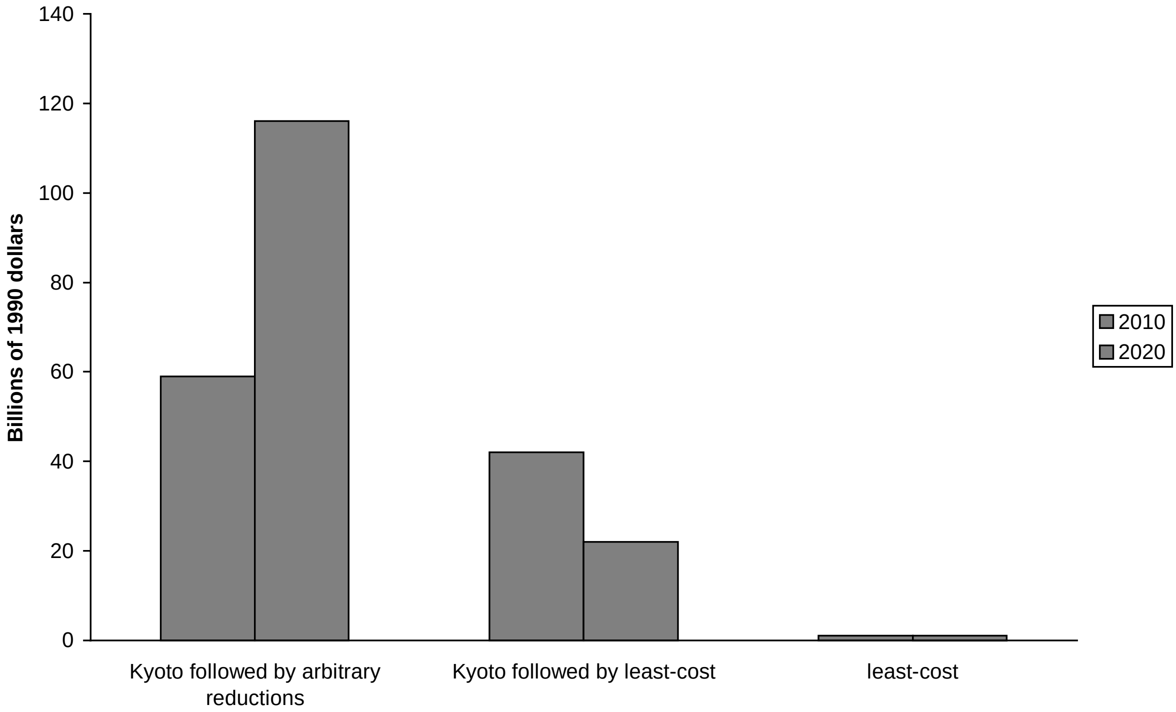

Figure 7.4 Global Consumption Losses through 2100 Discounted to 1990 at 5% -- Kyoto Forever vs. Three Scenarios for Stabilizing Concentrations at 550ppmv

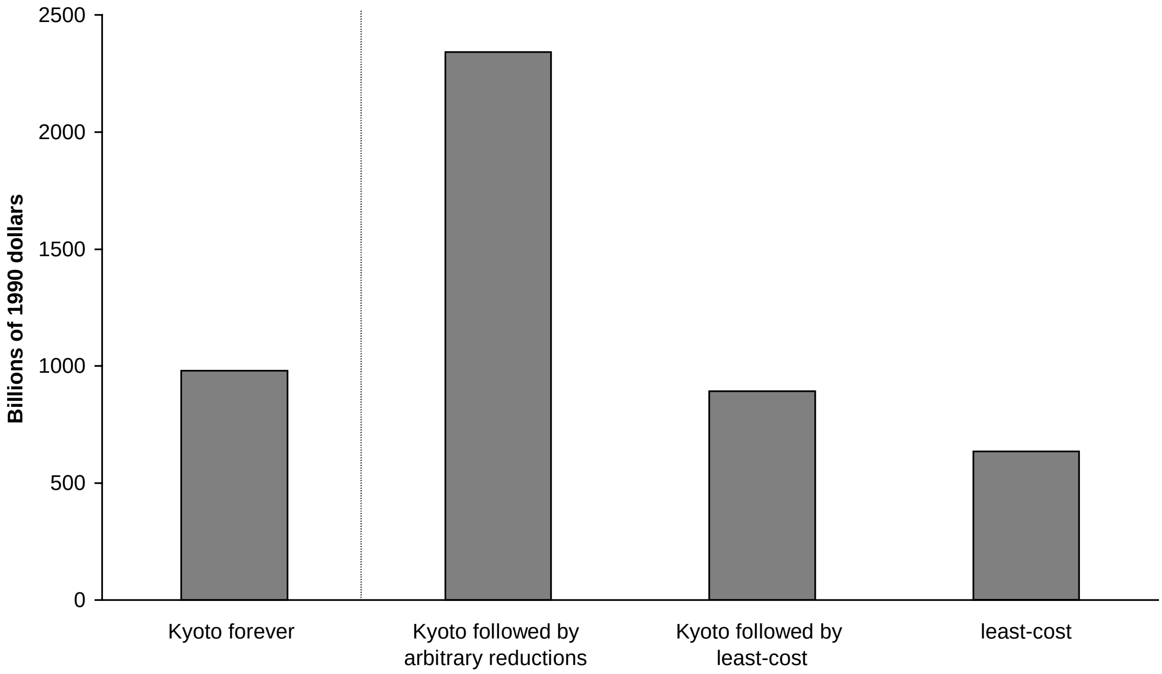

Figure A.1 EIS Supply Curves --
Marginal Cost of Non-Energy Inputs to EIS