

# Roll the DICE Again: Economic Models of Global Warming

## Chapter 8

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## **Chapter 8. Economic Analysis of the Kyoto Protocol**

The last chapter reviewed a wide range of alternative approaches for dealing with the threat of climate change. The present chapter focuses on the current approach which has been adopted under international agreements, the Kyoto Protocol. We begin with a description of the Protocol and then analyze its impact on economic and environmental outcomes.<sup>1</sup>

### **1. Climate-Change Policy and The Kyoto Protocol**

Governments have struggled to find policies that can at the same time satisfy the demands of electoral politics and meet the needs for responsible global stewardship. The initial response of nations to the threat of global warming was the Framework Convention on Climate Change (FCCC), which issued from the Rio Summit of 1992. Under the FCCC, Annex I countries (high-income nations plus the former Soviet Union and Eastern European countries) committed on a voluntary basis to limit their concentrations of GHGs to 1990 levels. This commitment left open almost all the important questions, such as the environmental, economic, and political components of such a commitment.<sup>2</sup>

It soon became apparent that the voluntary approach under the FCCC was producing next to nothing in actual policy measures. Moreover, some countries,

particularly the U.S., were experiencing rapid growth in CO<sub>2</sub> emissions. This led the advocates of strong policy measures to pursue binding commitments, which led to the Kyoto Protocol of December 1997. The key provision of the Kyoto Protocol is Article 3, which states that Annex I countries will on average reduce their emissions of GHGs by 5 percent relative to 1990 levels by the budget period 2008-2012, with each country facing an individual emissions limit.<sup>3</sup> (See Chapter 7, section 2, subsection D.)

Both economic theory and historical experience have shown that allowing economic agents to trade — in this case, to trade national emissions-reduction permits — can substantially reduce the cost of meeting an aggregate quantitative reduction target. The U.S. therefore proposed international emissions trading. The trading provision is contained in Article 6, which reads: “For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units ... provided that: ...the acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.” This provision gives Annex I nations the right to trade emissions units. However, it is haunted by the vague and troubling provision that the acquired permits shall be supplemental to domestic actions. In other words, nations can buy only part of their emissions reductions — although the allowable amounts are unspecified in the Protocol.

An additional provision introduces the possibility of offsets from developing countries. Article 12 defines a *clean development mechanism*, under which “(a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and (b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments... Emission reductions resulting from each project activity shall be certified ... on the basis of ...real, measurable, and long-term benefits related to the mitigation of climate change [and] reductions in emissions that are additional to any that would occur in the absence of the certified project activity.”<sup>4</sup> Some have interpreted this as a green light to include trading with developing countries, but the need to ensure additionality and to certify each transaction probably means it will lead to only a small fraction of potential trades.

A further complication involves GHG emissions other than those from energy use. The Kyoto Protocol has provisions for five other gases as well as for the potential for enhancing sinks. Specialists are working to understand the potential offsets that might come from these additional actions and to clarify the treatment of carbon sinks in the treaty.

In the various versions of the Kyoto Protocol considered below, we make a variety of assumptions about Annex I regions’ ability to reduce their own abatement costs by

buying emissions reductions elsewhere. We assume that other gases and sinks are neutral. More precisely, we assume that reductions in other GHGs and increased sequestration in carbon sinks for each region are such that the percentage reduction in industrial emissions required to meet Kyoto is below 1990 industrial emissions level by the same fraction as overall GHG target is below the 1990 level.

## **2. Economic Analysis of the Kyoto Protocol**

Earlier chapters discussed the details of the RICE-99 model. We now discuss the modifications of RICE-99 needed to analyze the Kyoto Protocol. We analyze in this chapter a number of different approaches to implementing the Kyoto Protocol and compare the different approaches with the optimal run described in the last chapter. Table 8-1 shows the major runs analyzed in this chapter. Most of them require no discussion, but a few details need elaboration.

The reference case (run 1) and the optimal case (run 2) were described in Chapter 7. The cases denoted “Kyoto emissions limitations” take the emissions permit allocations agreed upon in the 1997 Kyoto Protocol and extend them indefinitely for Annex I regions — this might be called “Kyoto forever.”<sup>5</sup> There are four variants of the Kyoto Protocol analyzed here. Under the “no-trade” run 3a, no trading of emissions permits is allowed among the four Annex I regions included in RICE-99, and there are no offsets with the

non-Annex I regions. Under the “OECD-trade” runs (run 3b), emissions trading is allowed only among the OECD regions.<sup>6</sup> The “Annex I-trade” case (run 3c) allows trading among all Annex I regions. This is the same as case 4 in the previous chapter. The global trading case (run 3d) extends the umbrella of trading to all regions. In this case, the non-Annex I regions receive emissions permits equal to their baseline emissions from run 1, but regions are then allowed to sell any emissions rights that exceed their actual emissions. Each of these runs has serious implementation issues, but these are ignored in this analysis.

While we refer to the Kyoto emissions limitation cases as types of trading regimes, each of these could be implemented as a fiscal regime in which carbon taxes are made uniform across a trading bloc and the tax revenues shared across regions in a bloc.

It should be emphasized that global trading in case 3d is actually a radical extension of the Kyoto Protocol and contains crucial and problematical assumptions about the behavior of non-Annex I countries. In principle, each non-Annex-I country will be better off by agreeing to this limit-and-trade procedure — it can do no worse than simply consuming its permits and can do better by reducing its low marginal-cost sources and selling the permits at the world price. This assumption is questionable in practice, however, because of the difficulty of estimating and assigning the appropriate baseline emissions, because of the need to ensure compliance among countries with weak

governance structures, and because of the potential for countries to repudiate their commitments in the future.

In addition to the Kyoto runs, we present two alternative cases which are useful for assessing the efficiency of different approaches. The emissions objectives of the Kyoto Protocol are not based on any ultimate environmental objective — they are instead the simple and easily understood guidelines of holding emissions constant. We can translate the emissions objectives into more meaningful environmental objectives by examining the consequences of the Kyoto Protocol for CO<sub>2</sub> concentrations and for global temperature. Run 4a finds a Pareto optimal carbon tax trajectory subject to the concentrations target implicit in the Kyoto emissions limitations; in this policy, concentrations are constrained to be at the same level implied by the Kyoto Protocol after 2050. Run 4b takes the same approach for global temperature, where temperature is constrained to be at the same level as that implicit in the Kyoto Protocol after 2100. (These dates are selected to take account of the lags between emissions and the two other objectives.) Runs 4a and 4b allow us to ask how cost-effective the different approaches are in attaining the environmental objectives embodied in the Kyoto Protocol. In both runs 4a and 4b, the entire world is treated as one trading bloc, and net permit revenue is held to zero by assigning to each region emissions permits equal to its emissions.

As we move from the no-trade case to the global-trading case, we improve the where-efficiency of the Kyoto Protocol. Each step from global trading to case 4a and from 4a to 4b improves on when-efficiency. But even case 4b is not why-efficient, as a comparison with the optimal run will demonstrate, since the temperature target chosen has no grounding in optimization (see discussion of types of efficiency in Chapter 7, section 1).

### **3. Major Results**

This section presents the results of the analysis of the Kyoto Protocol using RICE-99. We will highlight important conclusions in this summary – the ranking of policies, the optimal carbon price, and a revised view of the climate-change problem.

#### **A. Environmental variables**

The first set of results pertains to the major environmental variables — emissions, concentrations, and global temperature increases. Figure 8-1 and Table 8-2 show global industrial CO<sub>2</sub> emissions for the major cases. The overall level of abatement in the early years under the Kyoto Protocol is close to that of the optimal program – in 2015 global emissions under the Annex I variant are 7.50 GtC as compared to 7.45 GtC in the optimal case. However, the rate of emissions reduction falls over time because of the exclusion of

low-income countries from the Kyoto Protocol. By 2105, under the Kyoto Protocol, emissions are actually higher than under the optimal program. The fact that the initial level of global emissions reductions is close to the optimal in RICE-99 implies that the Kyoto Protocol with global trading would begin relatively efficiently, while other forms of implementation will prove inefficient because of where-inefficiency in allocation across different countries (particularly the omission of developing countries).

The buildup of CO<sub>2</sub> concentrations projected in different scenarios is shown in Figure 8-2. In the base run of RICE-99, concentrations in 2100 are 557 ppm (1187 GtC). In the optimal run, concentrations in 2100 are 538 ppm (1145 GtC), while those in the Annex I version of the Kyoto Protocol are 551 ppm (1174 GtC). The Kyoto Protocol has higher concentrations than the optimal run because it leaves uncontrolled the emissions in the low-income regions. The Kyoto Protocol makes little headway in reducing CO<sub>2</sub> concentrations under any trading scheme.

The impact of the Kyoto Protocol on global temperature is exceeding modest, especially for the first century. Table 8-3 shows that the reduction in global mean temperature in the Annex I case is 0.03 °C relative to the base case in 2100. This compares with a difference of 0.17 °C from the Kyoto Protocol calculated by Wigley [1998], which assumes the IPCC IS92a emissions scenario as a reference. The temperature reduction is so small in RICE-99 because of the flat base-case trajectory of

emissions (and consequently the small impact on emissions) of Annex I regions projected in the current study compared to the IPCC emissions scenario.

To summarize the key results:

First, emissions reductions under the Kyoto Protocol are extremely modest. Indeed, they are less than those projected under the optimal program. The reason is primarily that emissions in the high-income countries are projected to grow quite slowly, whereas the more rapidly growing emissions in developing countries are uncontrolled under the Kyoto Protocol.

Second, the Kyoto Protocol is projected to have a very modest impact on CO<sub>2</sub> concentrations and on global warming. Because the Kyoto Protocol policy is not designed to cap the emissions of non-Annex I countries, the long-run impact of the Kyoto Protocol on carbon emissions and global temperature is extremely small.

Third, in the short run, the global emissions, concentrations, and warming under the Kyoto Protocol are close to those in the optimal policy.

B. Economic Variables

### (1) Carbon taxes

One of the most useful measures of the strictness of climate-change policy is the carbon tax that would be generated by the policy. Table 8-4 and Figure 8-4 show the carbon taxes for the major cases. The optimal and global-trading cases have relatively low carbon taxes. The carbon tax in the global-trading case is \$11 per ton in 2015, then rises to about \$16 per ton in 2100; this compares with our estimate of the optimal carbon tax, which is \$13 per ton in 2015 and rises to \$63 per ton in 2100. The prices indicate that the Kyoto Protocol starts out with an efficient *global* rate of emissions reduction but then fails to make sufficient further reductions in the coming decades.

Policies which restrict trade have higher average carbon taxes, with the variation of prices among regions leading to an inefficient distribution of abatement. The Annex I-trading case has sharply rising carbon taxes in the Annex I regions, starting at \$35 per ton in 2015 and rising to around \$82 per ton at the end of the next century. These prices hold for Annex I regions; carbon taxes in non-Annex I regions are zero.

Russia and Eastern Europe play a crucial role in the Annex I version of the Kyoto Protocol. Baseline emissions in these countries are below their Kyoto Protocol limits; this provides an enormous pool of potential emissions reductions that keeps carbon taxes in the OECD region down in the Annex I case. As shown in Figure 8-4, the carbon taxes for

the no-trade version of the Kyoto Protocol are significantly higher than the Annex I case. For example, the U.S. 2015 carbon tax is \$153 per ton for the no-trading case, rising to about \$360 per ton by 2100. These numbers are so large that they cast a fairy-tale (or perhaps horror-story) quality to the analysis. For example, by the middle of the next century, annual U.S. carbon tax revenues are around \$300 billion dollars in the no-trade version. In the Annex I case, the U.S. is transferring about \$20 billion annually to other regions through purchases of carbon emissions permits in the next century.

## (2) Overall abatement costs

The next set of issues concerns the economic impact of alternative policies. The present value of total abatement costs is shown in Figure 8-5 and Table 8-5. The present value of abatement (which excludes damages) ranges from a low of \$59 billion in the global-trading case, to \$217 billion in the Annex I-trading case, to a high of \$884 billion in the no-trade case. Clearly, there are enormous stakes involved in policies to control global warming. (See Chapter 7, section 3, subsection A for definition of abatement costs.)

It is interesting to compare the costs of different regimes with the minimum global cost of meeting the Kyoto temperature trajectory. We estimate that the trajectory can be attained at a minimum cost of \$5 billion. The global trading scenario is relatively efficient

compared to the other Kyoto trading schemes, with a cost of 12 times the temperature-minimum path. The other Kyoto emissions limitations scenarios have costs of between 43 and 177 times the temperature-minimum path. Note that there is relatively little gain from trading within the OECD countries alone; most of the gain from Annex I trade arises from the inclusion of Russia and other Eastern European countries under the trading umbrella.

Figure 8-6 shows the impact of different strategies on the time path of world output. In the cases that allow large-scale trading, the overall impact of the Kyoto Protocol is relatively modest, between 0.1 and 0.2 percent of income per year.

Tables 8-6 and 8-7 and Figure 8-7 show the economic impacts on different regions. Abatement costs in Table 8-6 include net purchases of emissions permits. The net economic impact of a policy in Table 8-7 is the environmental benefits of the policy minus the abatement costs (see Chapter 7, section 3, subsection A for further description).

Table 8-6 indicates why the U.S. might be most unhappy about the Kyoto Protocol. Its cost is actually more than the global total for the Annex I version. The U.S. discounted cost is \$325 billion, while the rest of the world has a net benefit (primarily through permit sales) of \$108 billion. OECD Europe and OHI have very little net abatement costs in any versions of the protocol. The high cost of the Kyoto Protocol to the United States arises because CO<sub>2</sub> emissions are projected to grow much more rapidly in the U.S. than in other

regions, so containing emissions is likely to prove much more expensive. (For a comparison of the baseline emissions, see Figure 7-7.)

### (3) Trading and transfers

Permit sales and purchases are relatively small in the calculations in RICE-99, primarily because the impact of the Kyoto Protocol is relatively limited. In the global trade case, the only purchasers of permits are the high income regions, who buy \$6.3 billion worth of permits in 2015. In the Annex I trading case, the major trade takes place between the United States and R&EE; the transfer from the U.S. averages \$22 billion per year over the next century. This is far less than many other estimates of the impact of the Kyoto Protocol.<sup>7</sup>

By examining the flows of permit revenues, we see two major flaws in the design of the Kyoto Protocol. First, the Protocol caps the emissions of one group of countries at historical levels but does not do so for the non-Annex I countries. Bringing non-Annex I countries in under the additionality criterion assigns *reference* emissions to non-Annex I countries, thus giving them substantially different treatment from Annex I countries. A second and related major design flaw is assigning historical emissions. This gives a major windfall to those countries which had inefficient energy systems (particularly Russia, Eastern Europe, and Germany after its purchase of East Germany). A better procedure

would be a rolling emissions base, which would remove the advantages of inefficiency and also remove the difference of treatment of non-Annex I and Annex I countries.

#### (4) Summary of economic impacts

The overall impacts of the Kyoto Protocol and variants are complex, but the major points to emphasize are the following:

First, here are big impacts of virtually all variants of the Kyoto Protocol on the United States. As shown in Table 8-6, the discounted value of production costs (exclusive of climate damages) range from \$325 billion in the Annex-I trading case to \$852 billion in the no-trading case. Introducing global trading reduces abatement costs by about two-thirds, but it is probably unrealistic as a policy at present.

Second, if damages are excluded, the major beneficiaries of the Kyoto Protocol are the regions with permits to sell. In the Annex I trading case, Russia and Eastern Europe gain \$112 billion more in present value from permit sales than they incur in abatement costs. In the OECD trading case, OECD Europe is the major beneficiary.

Third, the major beneficiary of the environmental effects of reducing emissions is Europe. The net economic impact on OECD Europe is positive in all experiments

considered in this chapter, with the environmental benefits ranging from \$35 to \$127 billion.

Fourth, trading significantly reduces the aggregate cost of abatement – particularly trading with Russia and low-income countries like China. But the counterpart of these efficiency gains is transfers – mainly from the United States – although they are not as large as indicated in other models.

### C. Costs and damages

We have focused primarily on the abatement costs, but it is always important to keep in mind that the point of reducing emissions is to reduce future damages. Our estimates indicate that there are likely to be substantial costs of global warming in any of the cases examined here; the discounted value of damages in the base case are approximately \$4 trillion in present value.

The impact of different policies on both costs and damages is shown in Figure 8-8 and Table 8-8. The second set of bars shows the discounted value of the reduced damages. This figure shows that the policies reduce (discounted) damages by only a modest amount – between \$100 and \$300 billion out of a total damages of \$4 trillion. The maximum damage reduction from the Kyoto Protocol is \$160 billion.

Many readers have expressed surprise about the small impact of the Kyoto Protocol on the damages from global warming. The reasons are that, because there is so much inertia in the climate system and because the Protocol does not limit the emissions of developing countries, the Kyoto Protocol reduces the global temperature increase by only a fraction of a degree over the next century. The other point shown in Figure 8-8 and Table 8-8 is that where- and when-inefficiency raise the costs of abatement substantially with little or no improvement in benefits. For example, moving from no controls to the Kyoto Protocol plan with Annex I trading incurs discounted abatement cost of \$217 billion; however, the discounted value of damages decreases by only \$96 billion. Moving from the Annex I version to the no-trade version increases benefits by \$65 billion while increasing costs by \$667 billion.

Finally, Figure 8-9 shows the distribution of net impacts (including transfers and climate damages) of the seven major policies considered here.

The main conclusions that come from an examination of damages are that there are likely to be substantial damages from climate change, but that the Kyoto Protocol does virtually nothing to mitigate the damages.

#### D. Gains from trade

Much has been made about the gains from trade. Table 8-5 indicates that the cost-effectiveness differs greatly across different options. We estimate that the minimum costs of attaining the environmental objectives of the Annex I version of the Kyoto Protocol are approximately \$12 billion for the concentration objective and \$5 billion for the temperature objective. By this standard, the Annex I protocol has costs that are 18 to 43 times the cost-effective amount, while the no-trade version has costs that are 74 to 177 times the cost-effective standard.

The cost savings from the minimum-cost variants over the versions of the Kyoto Protocol derive from when-efficiency and where-efficiency. Like the global trade run, the Kyoto temperature run allows emissions reductions to occur where they are least costly; but the Kyoto temperature run also has the additional flexibility of allowing the emissions reductions to take place when they are cost-effective, whereas all the Kyoto cases arbitrarily specify the time path of emissions reductions. When-efficiency accounts for about 6 percent of the difference in abatement costs between the minimum cost and the no trade variant; the remaining 94 percent, captured by the global trading case, is due to gains from trade, or where-efficiency. Eight percent of the gains from trade can be captured through Annex I trading.

One major surprise is that trading within the OECD only attains relatively little — 33 percent — of the potential gains from trade. This low fraction comes because the energy efficiencies are relatively similar within the large OECD blocs.

While targeting temperature directly produces the minimum-cost way of achieving the environmental objective in RICE, targeting concentrations is nearly as good; this policy captures 99 percent of the gains from when- and where-efficiency.

#### **4. Findings and Conclusions**

The present chapter examines the implications of the Kyoto Protocol and variants of that policy in a new integrated-assessment model of climate change and the world economy. Before moving to the major conclusions, it must be emphasized that these results should be taken with suitable reservations reflecting the difficulties inherent in the subject and the fact that this is but one of many models that can be used to estimate the impacts of the Kyoto Protocol. For instance, analysis of the Kyoto Protocol is inherently highly uncertain because of the nature of the protocol. The outcomes for countries depend upon the difference between emissions and a fixed historical benchmark. Small changes in growth rates can make big differences in the outcomes. A modest change in the projected growth rate of output, with carbon intensity constant, can make a substantial difference in the projected costs and benefits over the next few decades. This uncertainty

is reflected in the differences across models or even across different versions of the same model.

We conclude our analysis with three observations. First, we find that the strategy behind the Kyoto Protocol has no grounding in economics or environmental policy. The approach of freezing emissions at a given level for a group of countries is not related to a particular goal for concentrations, temperature, or damages. Nor does it bear any relation to an economically oriented strategy that would balance the costs and benefits of greenhouse-gas reductions. The emissions and concentrations implicit in the Kyoto Protocol are close to those in the optimal policy for the first few decades, but they are too low relative to the efficient policy over the next century. The basic difficulty is that the Kyoto Protocol targets only the emissions of high-income countries, which are likely to be a dwindling fraction of global emissions.

Second, while the environmental damages from climate change do not differ markedly among the different Kyoto Protocol variants, the costs of implementation vary enormously. The cost of the no-trade variant of the Kyoto Protocol is about 15 times the cost of the global-trade variant. Most of the gains from trade come from including non-OECD countries such as Russia, China, and India. The costs of an efficiently designed Kyoto Protocol with global trading are \$59 billion, while the benefits of the emissions reduction from the Kyoto Protocol are around \$108 billion, for a benefit-cost ratio of 1.8.

However, the benefit-cost ratio of the Annex I version is 0.44, while the ratio for the no-trade version is 0.18. Moreover, these estimates are based on the optimistic assumption that policies are efficiently implemented. The differences among implementation strategies emphasize the point that efficient design of the policy should be a major concern of policymakers.

Finally, the Kyoto Protocol has significant distributional consequences. Annex I countries pay the costs of Protocol. These costs will come either through abatement activities or through purchase of permits. The lion's share of these costs are borne by the United States — indeed, the U.S. is a net loser while the rest of the world on balances benefits from the Kyoto Protocol.

1. *Reference*: no controls
2. *Optimal*: sets emissions by region and period to balance the costs and benefits of emissions reductions
3. *Kyoto emissions limitations*:
  - a. No trade: no trade among 6 major Annex I blocs
  - b. OECD trade: emissions trading limited to OECD countries
  - c. Annex I trade: emissions trading limited to Annex I countries
  - d. Global trade: emissions trade among all regions
4. *Cost effectiveness benchmarks*:
  - a. Limit atmospheric concentrations to those resulting from the Kyoto Protocol case 3c (for the period after 2050)
  - b. Limit global mean temperature to that resulting from the Kyoto Protocol case 3c (for the period after 2100)

**Table 8-1. Runs for Analysis of Kyoto Protocol**

This list shows the runs examined in the analysis of the Kyoto Protocol.

**Industrial carbon emissions, 2015 (GtC)**

	<b>Base</b>	<b>Optimal</b>	<b>Kyoto conc</b>	<b>Kyoto temp</b>	<b>Global</b>	<b>AI Trade</b>	<b>OECD</b>	<b>No Trade</b>
<b>USA</b>	1.73	1.68	1.72	1.72	1.69	1.61	1.36	1.29
<b>OHI</b>	0.62	0.61	0.62	0.62	0.61	0.59	0.51	0.52
<b>Europe</b>	0.91	0.89	0.90	0.90	0.89	0.85	0.75	0.81
<b>R&amp;EE</b>	0.82	0.74	0.80	0.81	0.75	0.63	0.82	0.82
<b>MI</b>	0.64	0.62	0.63	0.63	0.62	0.64	0.64	0.64
<b>LMI</b>	0.94	0.87	0.92	0.93	0.88	0.95	0.95	0.95
<b>China</b>	1.08	0.97	1.05	1.07	0.98	1.08	1.08	1.08
<b>LI</b>	1.15	1.08	1.13	1.14	1.08	1.15	1.15	1.15
<b>Annex I</b>	4.07	3.92	4.03	4.05	3.93	3.68	3.44	3.44
<b>ROW</b>	3.82	3.54	3.74	3.78	3.57	3.82	3.82	3.82
<b>World</b>	7.89	7.45	7.77	7.83	7.50	7.50	7.26	7.26

**Industrial carbon emissions, 2105 (GtC)**

	<b>Base</b>	<b>Optimal</b>	<b>Kyoto conc</b>	<b>Kyoto temp</b>	<b>Global</b>	<b>AI Trade</b>	<b>OECD</b>	<b>No Trade</b>
<b>USA</b>	1.87	1.75	1.83	1.83	1.84	1.71	1.54	1.29
<b>OHI</b>	0.51	0.49	0.50	0.50	0.50	0.48	0.44	0.51
<b>Europe</b>	0.75	0.71	0.74	0.73	0.74	0.70	0.64	0.75
<b>R&amp;EE</b>	0.94	0.83	0.91	0.90	0.91	0.79	0.95	0.95
<b>MI</b>	1.33	1.24	1.30	1.30	1.31	1.34	1.34	1.34
<b>LMI</b>	2.05	1.76	1.97	1.96	1.97	2.07	2.08	2.08
<b>China</b>	2.02	1.77	1.94	1.94	1.95	2.03	2.04	2.04
<b>LI</b>	3.77	3.26	3.62	3.60	3.63	3.80	3.80	3.80
<b>Annex I</b>	4.07	3.77	3.98	3.98	4.00	3.68	3.57	3.50
<b>ROW</b>	9.17	8.03	8.82	8.80	8.86	9.23	9.25	9.26
<b>World</b>	13.25	11.80	12.80	12.77	12.86	12.91	12.83	12.76

**Table 8-2. Industrial Carbon Emissions in Kyoto Runs**

**Atmospheric Temperature**  
(degrees C increase from 1900)

	<b>1995</b>	<b>2055</b>	<b>2105</b>
<b>Base</b>	0.43	1.46	2.53
<b>Optimal</b>	0.43	1.43	2.44
<b>Kyoto conc</b>	0.43	1.45	2.49
<b>Kyoto temp</b>	0.43	1.46	2.50
<b>Global</b>	0.43	1.45	2.50
<b>AI Trade</b>	0.43	1.45	2.50
<b>OECD</b>	0.43	1.43	2.47
<b>No Trade</b>	0.43	1.43	2.47

**Table 8-3. Comparison of Global Mean Temperature Increase in Different Runs**

**Carbon tax, 2015 [1990 \$ per metric ton carbon]**

	Base	Optimal	Kyoto Concentrations	Kyoto Temperature	Global Trade	Annex I Trade	OECD Trade	No Trade
<b>USA</b>	0.00	12.71	4.99	1.65	11.17	34.52	121.31	152.75
<b>OHI</b>	0.00	12.71	4.99	1.65	11.17	34.52	121.31	108.42
<b>Europe</b>	0.00	12.71	4.99	1.65	11.17	34.52	121.31	69.31
<b>R&amp;EE</b>	0.00	12.71	4.99	1.65	11.17	34.52	0.00	0.00
<b>MI</b>	0.00	12.71	4.99	1.65	11.17	0.00	0.00	0.00
<b>LMI</b>	0.00	12.71	4.99	1.65	11.17	0.00	0.00	0.00
<b>China</b>	0.00	12.71	4.99	1.65	11.17	0.00	0.00	0.00
<b>LI</b>	0.00	12.71	4.99	1.65	11.17	0.00	0.00	0.00
<b>Annex I</b>	0.00	12.71	4.99	1.65	11.17	34.52	--	--
<b>ROW</b>	0.00	12.71	4.99	1.65	11.17	0.00	0.00	0.00
<b>World</b>	0.00	12.71	4.99	1.65	11.17	34.52	121.31	152.75

**Carbon tax, 2105 [1990 \$ per metric ton carbon]**

	Base	Optimal	Kyoto Concentrations	Kyoto Temperature	Global Trade	Annex I Trade	OECD Trade	No Trade
<b>USA</b>	0.00	67.39	24.57	20.53	17.63	81.61	184.33	378.01
<b>OHI</b>	0.00	67.39	24.57	20.53	17.63	81.61	184.33	0.00
<b>Europe</b>	0.00	67.39	24.57	20.53	17.63	81.61	184.33	0.00
<b>R&amp;EE</b>	0.00	67.39	24.57	20.53	17.63	81.61	0.00	0.00
<b>MI</b>	0.00	67.39	24.57	20.53	17.63	0.00	0.00	0.00
<b>LMI</b>	0.00	67.39	24.57	20.53	17.63	0.00	0.00	0.00
<b>China</b>	0.00	67.39	24.57	20.53	17.63	0.00	0.00	0.00
<b>LI</b>	0.00	67.39	24.57	20.53	17.63	0.00	0.00	0.00
<b>Annex I</b>	0.00	67.39	24.57	20.53	17.63	81.61	--	--
<b>ROW</b>	0.00	67.39	24.57	20.53	17.63	0.00	0.00	0.00
<b>World</b>	0.00	67.39	24.57	20.53	17.63	81.61	184.33	378.01

**Table 8-4. Comparison of Carbon Taxes, 2015 and 2105, in Different Approaches to Kyoto Protocol**

<b>Strategy</b>	<b>Discounted Costs</b> [billions of 1990 dollars]
Base	0
Optimal	98
Kyoto Protocol:	
Global	59
AI Trade	217
OECD	611
No trade	884
Kyoto concentration limit	12
Kyoto temperature limit	5

### **Table 8-5. Discounted Abatement Costs in Different Strategies**

Table shows the discounted global costs of different targets or control strategies. The estimates are the discounted consumption in the base case minus the discounted consumption in the case in question, where these have been calculated excluding the environmental benefits of controls.

**Abatement Costs**  
[billions of 1990 U.S. \$]

	<b>Base</b>	<b>Optimal</b>	<b>Kyoto conc</b>	<b>Kyoto temp</b>	<b>Global</b>	<b>AI Trade</b>	<b>OECD</b>	<b>No Trade</b>
<b>USA</b>	0	15	1	0	91	325	710	852
<b>OHI</b>	0	1	-1	-1	7	24	16	39
<b>Europe</b>	0	1	-1	-1	0	-5	-93	15
<b>EE</b>	0	12	2	1	-28	-112	-2	-2
<b>MI</b>	0	5	0	0	-2	-3	-4	-4
<b>LMI</b>	0	23	4	3	-2	-4	-5	-5
<b>China</b>	0	14	2	0	-4	-3	-4	-4
<b>LI</b>	0	27	5	3	-2	-5	-7	-8
<b>Annex I</b>	0	29	1	-1	70	232	630	905
<b>ROW</b>	0	69	11	7	-11	-15	-20	-21
<b>World</b>	0	98	12	5	59	217	611	884

**Table 8-6. Abatement Costs in Different Regions for Different Policies**

Table shows the discounted global costs of different targets or control strategies. The estimates are the discounted consumption in the base case minus the discounted consumption in the case in question, where these have been calculated excluding the environmental benefits of controls. Revenues from permit trading are implicit in the calculations.

**Net Economic Impact**

[billions of 1990 U.S. \$]

	<b>Base</b>	<b>Optimal</b>	<b>Kyoto conc</b>	<b>Kyoto temp</b>	<b>Global</b>	<b>AI Trade</b>	<b>OECD</b>	<b>No Trade</b>
<b>USA</b>	0	22	12	10	-78	-313	-692	-833
<b>OHI</b>	0	26	10	9	3	-15	-2	-26
<b>Europe</b>	0	126	47	36	47	46	161	54
<b>EE</b>	0	-9	-1	0	29	113	3	3
<b>MI</b>	0	19	8	7	11	11	17	18
<b>LMI</b>	0	5	6	5	13	13	20	21
<b>China</b>	0	-10	0	1	5	4	6	6
<b>LI</b>	0	20	12	9	19	21	32	34
<b>Annex I</b>	0	164	69	56	0	-170	-530	-801
<b>ROW</b>	0	34	26	21	48	49	75	78
<b>World</b>	0	198	95	77	49	-121	-455	-723

**Table 8-7. Net Economic Impacts in Different Regions for Different Policies**

Table shows the total impacts of different targets or control strategies for different regions, including environmental benefits and net sales of emissions permits. The estimates are the difference between the present value of consumption in the case in question and the present value of consumption in the base. Positive values reflect net benefits while negative ones reflect net costs.

**Costs, Benefits, and Benefit-Cost Ratios**

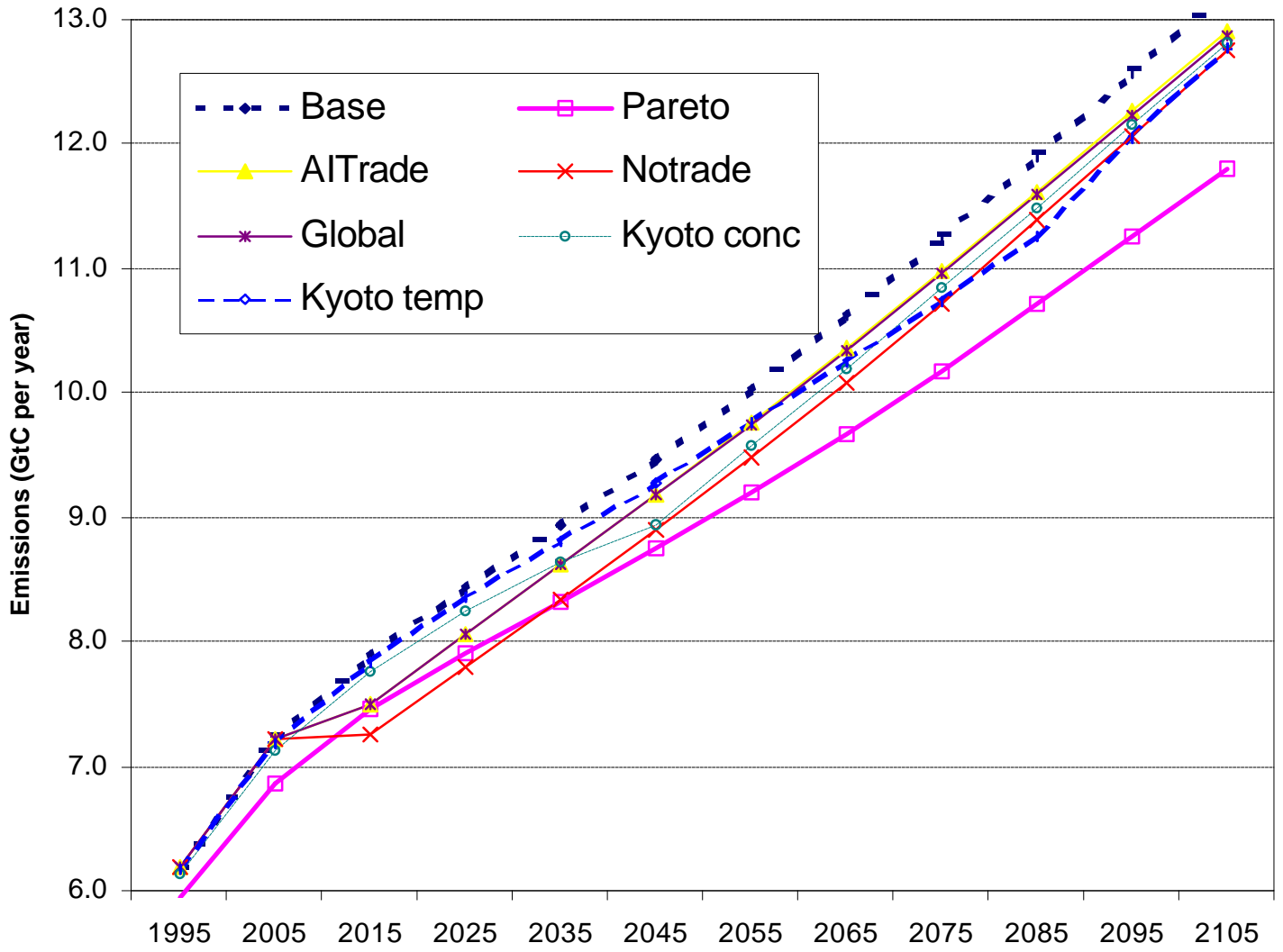
[Costs and damages in billions of 1990 U.S. dollars]

	Base	Optimal	Kyoto conc	Kyoto temp	Global	AI Trade	OECD	No trade
Abatement costs	0	98	12	5	59	217	611	884
Reduction in damages	0	296	107	83	108	96	155	161
Benefit-cost ratio	na	3.02	9.07	15.22	1.82	0.44	0.25	0.18

**Table 8-8. Benefits, Costs, and Benefit-Cost Ratio of Different Approaches**

Calculations show the abatement costs and reduction of climate damages from alternative policies. Costs and damages are in billions of dollars discounted to 1995 in 1990 dollars.

Fig 8-1. Global CO2 Emissions



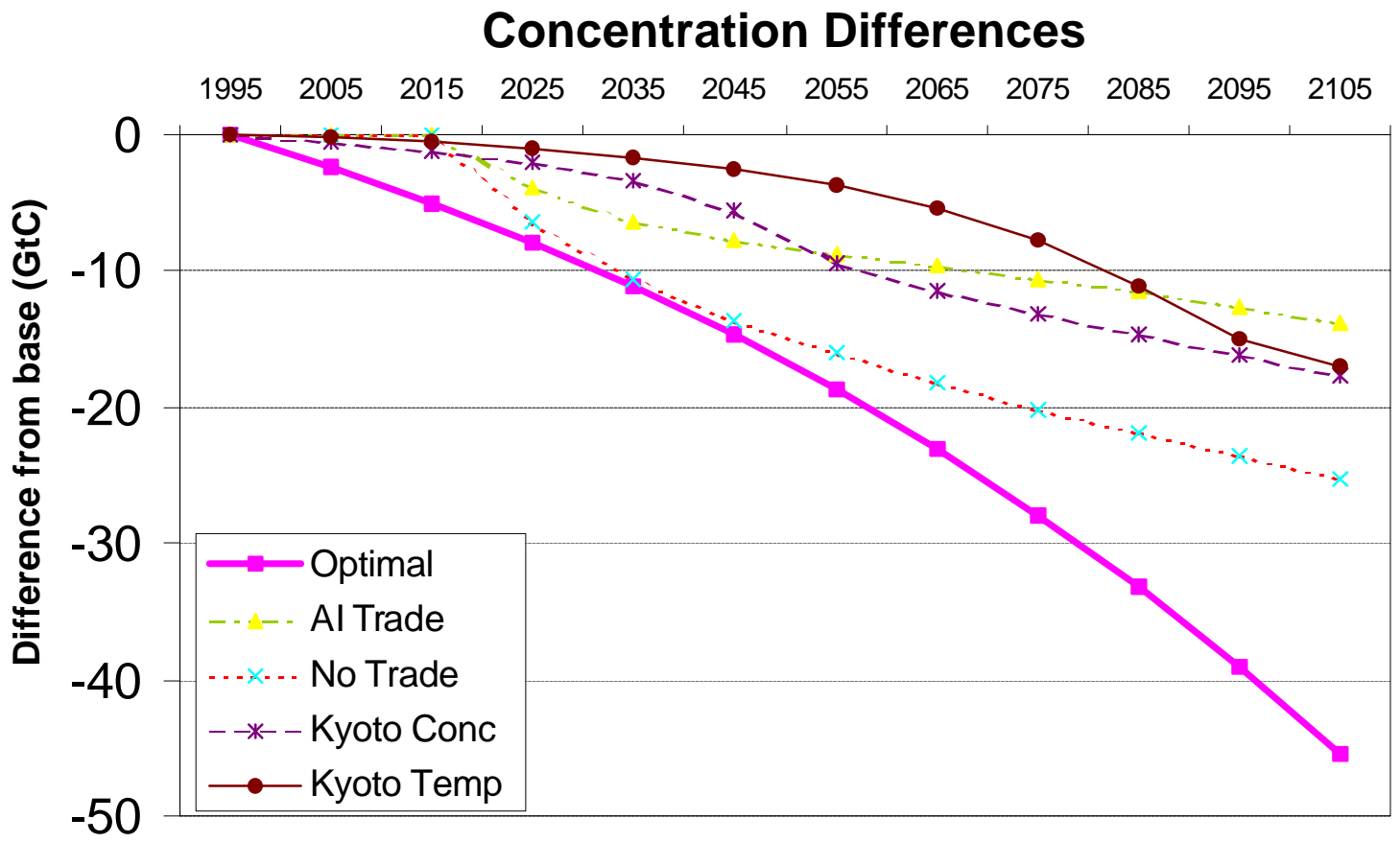


Figure 8-2

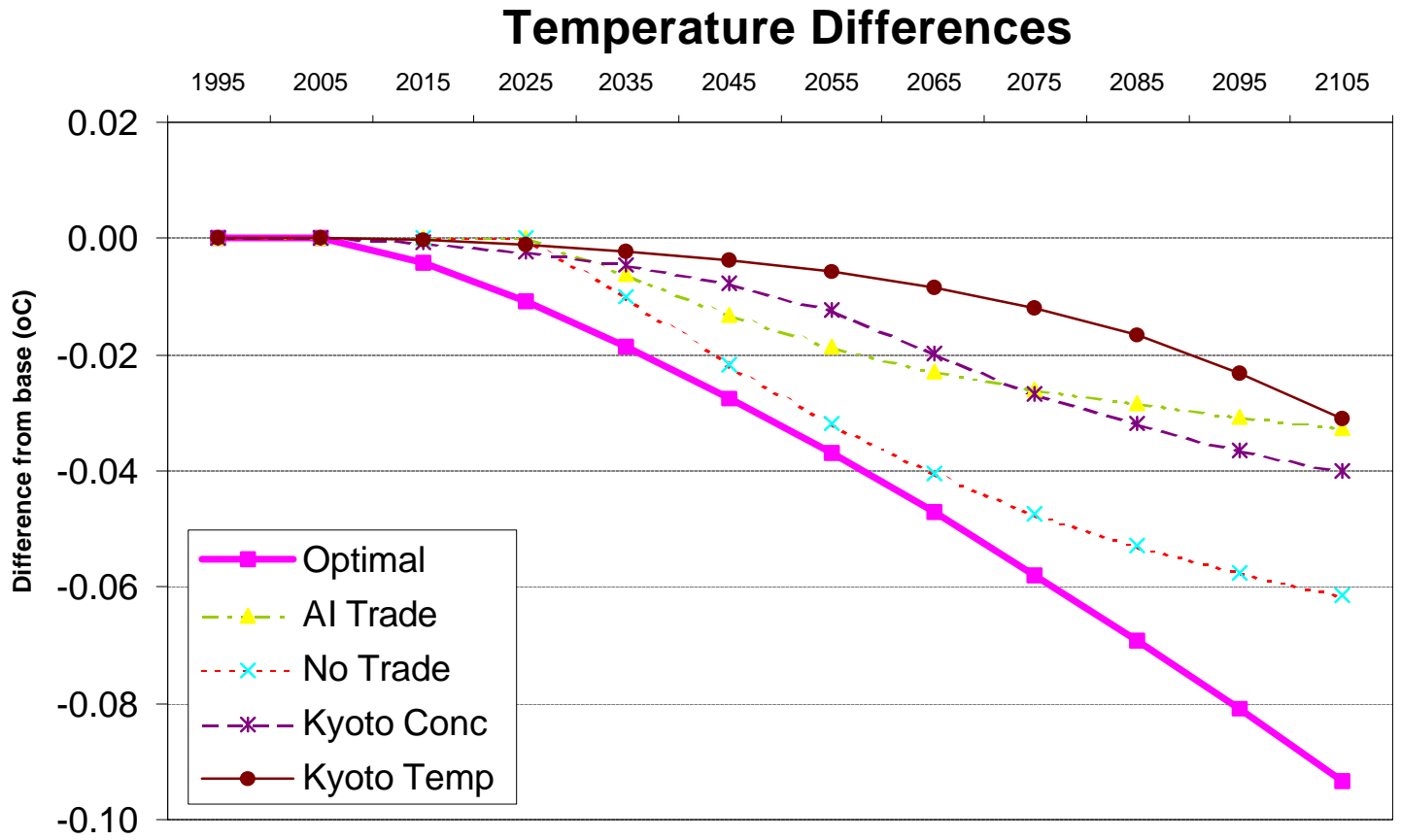
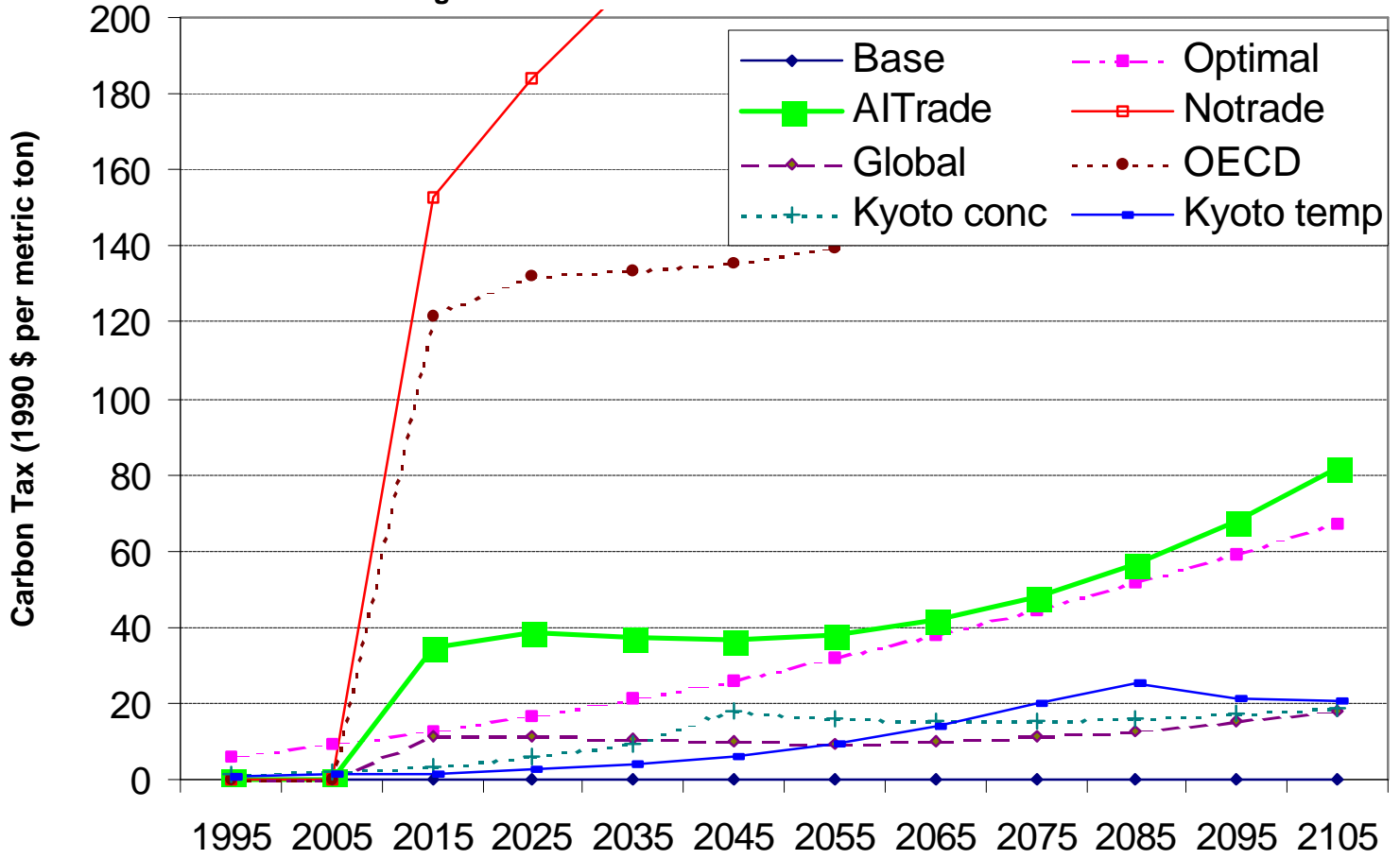
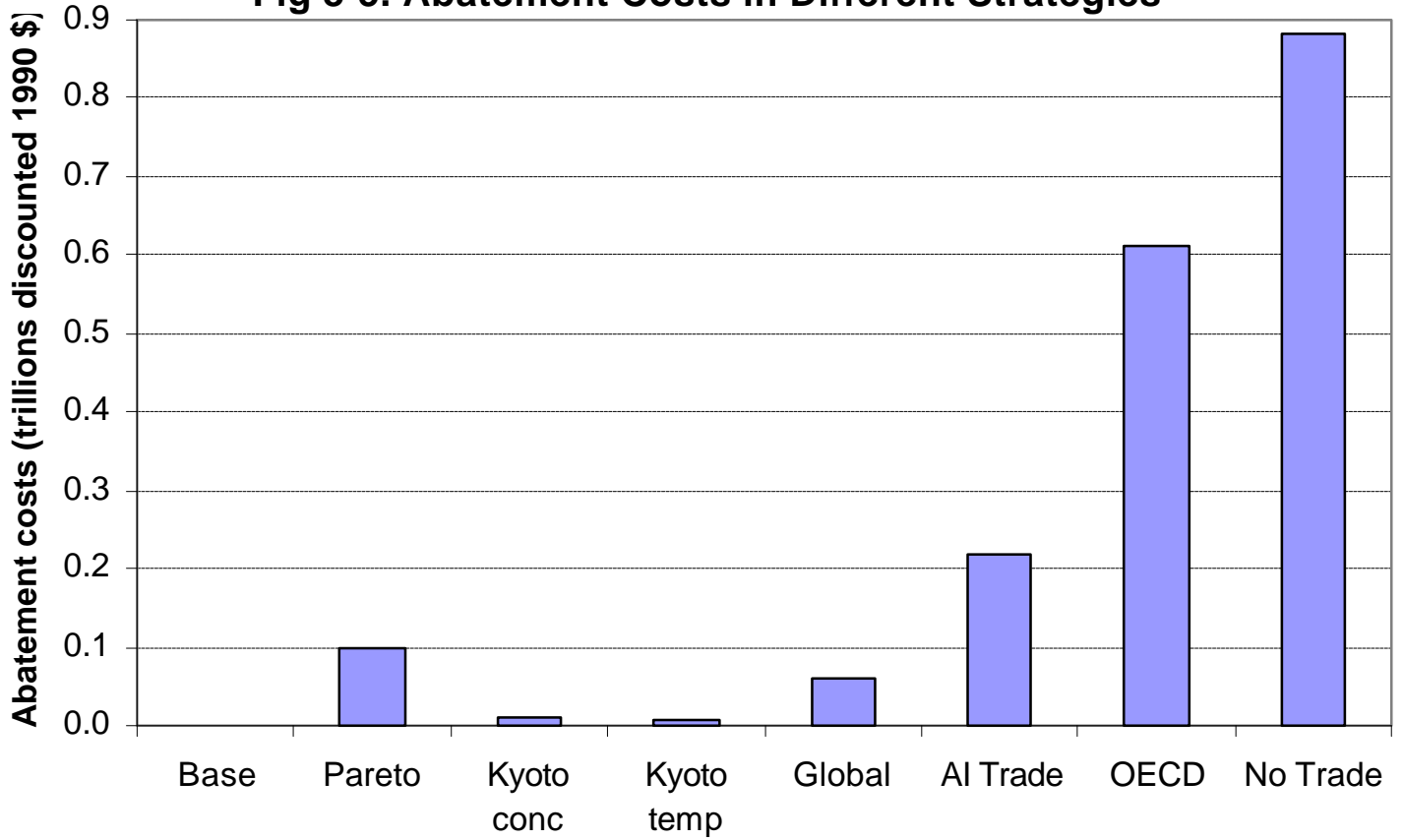


Figure 8-3

Fig 8-4. Carbon Taxes in Different Policies



**Fig 8-5. Abatement Costs in Different Strategies**





**Fig 8-7. Regional Impacts of Alternative Strategies**

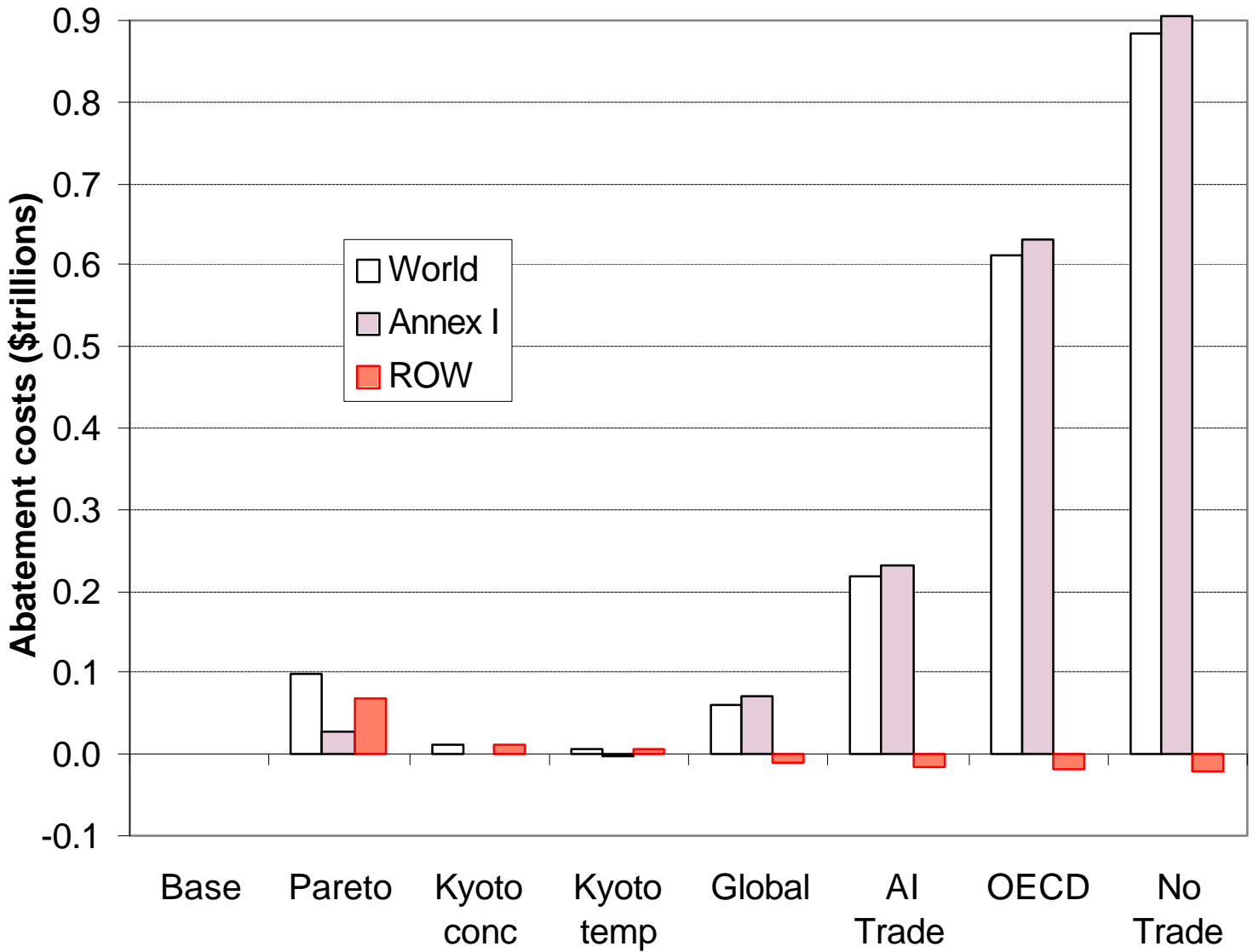


Fig 8-8. Overall Impacts of Alternative Strategies

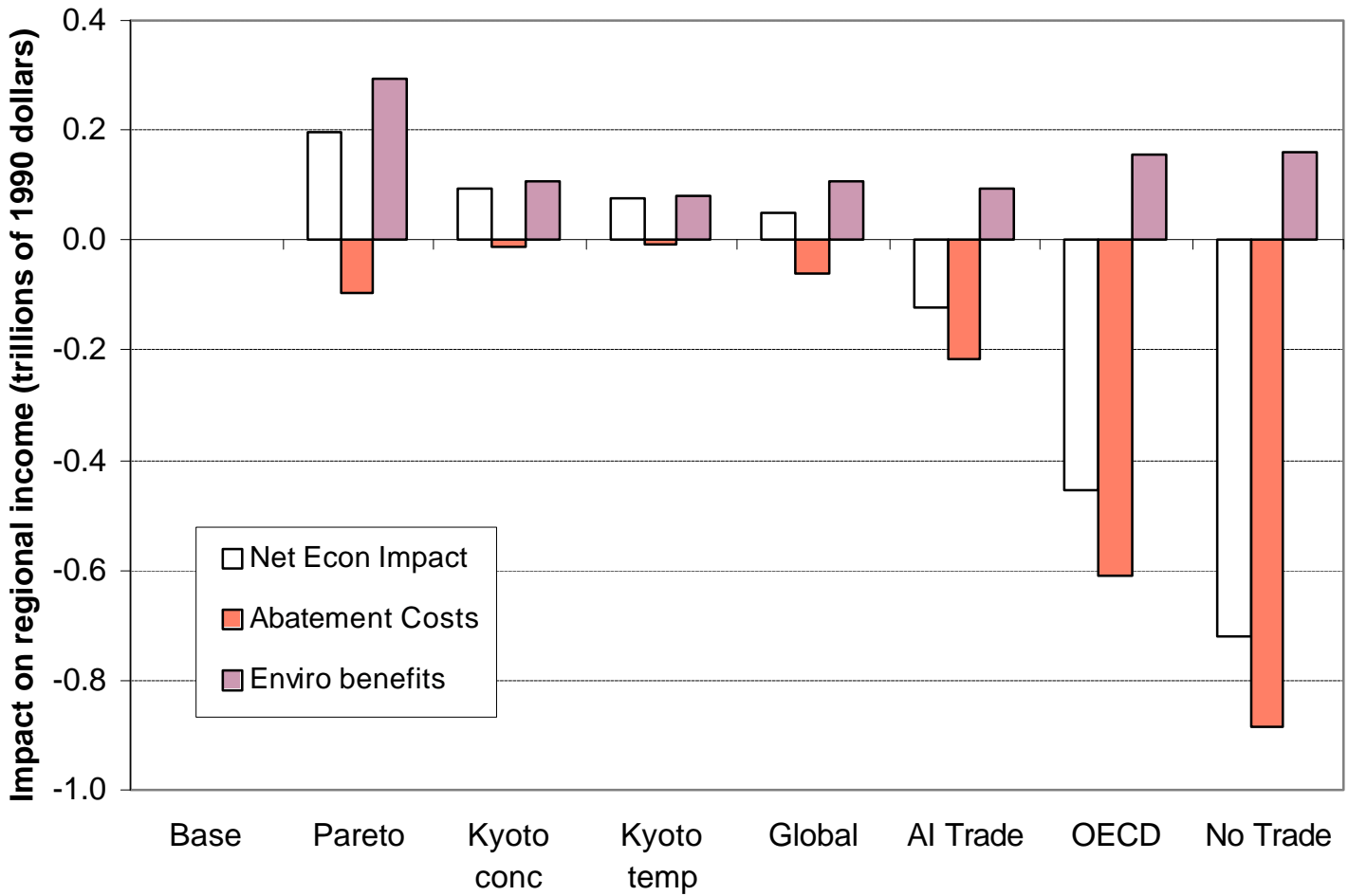
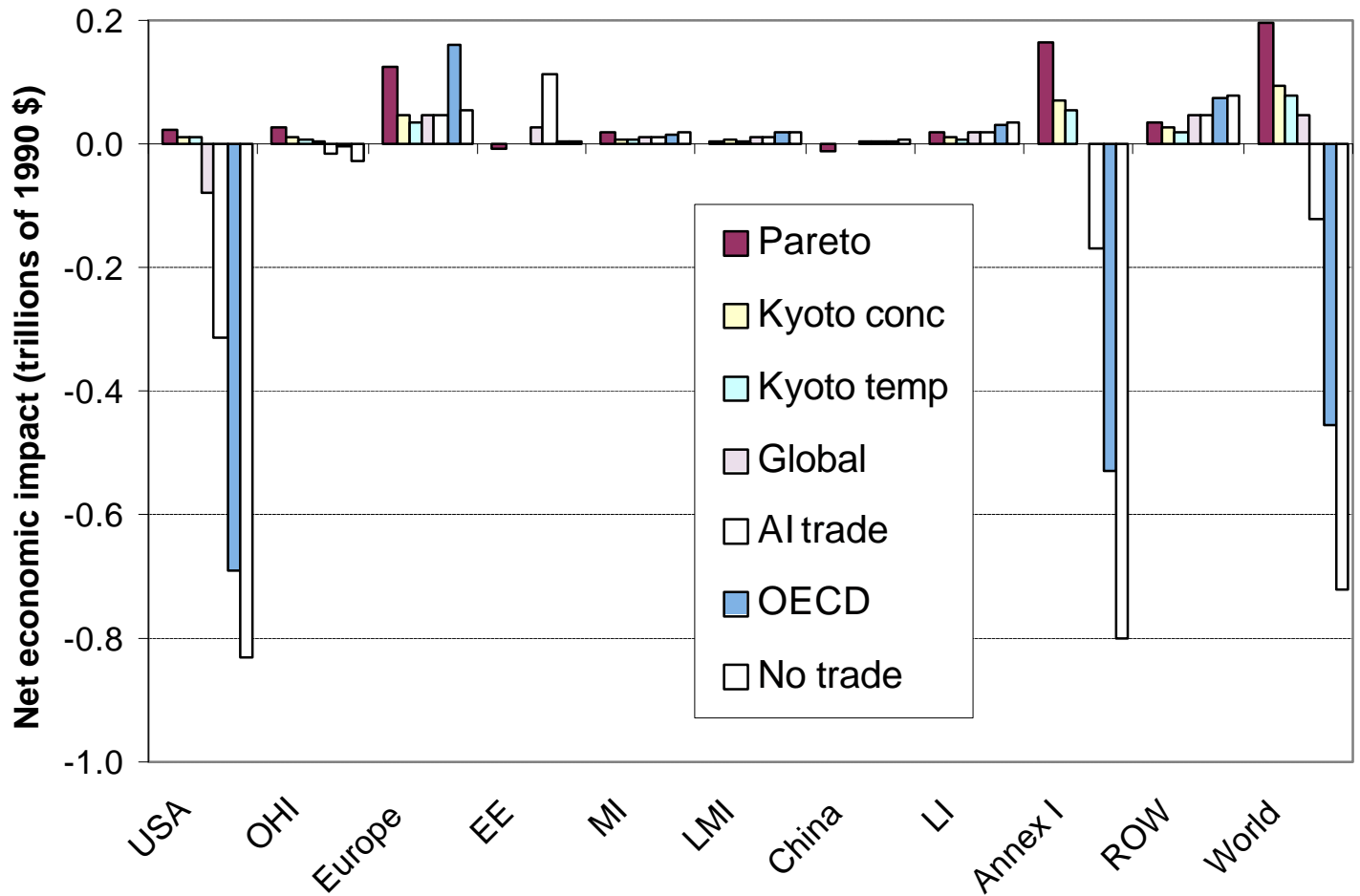


Fig 8-9. Net Economic Impact by Region



Endnotes:

1. An earlier version of this chapter, using the RICE-98 model, appeared in Nordhaus and Boyer [1999].

2. A full discussion of the FCCC can be found at the website [http:// www.unfccc.de/](http://www.unfccc.de/). The text and discussion of the Kyoto Protocol can also be found at that site.

3. As discussed below, the Protocol opens the door for possible emissions trading and other cooperative schemes, so it might be possible for a country to meet its emissions limit even if its actual emissions exceed that limit.

4. All citations of the Protocol have omitted provisions that are not relevant to the present analysis, such as the need for consent and the monitoring by international bodies.

5. See Chapter 7, section 2, part D for description of Annex I in RICE-99.

6. Strictly speaking, the “OECD” here consists of the US, OHI, and OECD Europe regions, the high-income regions. This includes the actual OECD less Mexico, South Korea, Poland, Hungary, and the Czech Republic plus Singapore, Israel, Hong Kong, and a handful of small island nations.

7. See the different estimates collated in Weyant [1999].

