Roll the DICE Again:
Economic Models of Global Warming

Chapter 7

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Part II. Policy Applications of the RICE Model

Chapter 7. Efficient Climate-Change Policies

In the first part of this volume we laid out the DICE-99 and RICE-99 models. In the balance of the study we apply the model to major issues of climate-change policy. The present chapter identifies a number of alternative approaches to climate change policy and investigates the relative efficiency of these alternatives. The next chapter then analyzes the current approach to climate-change policy – the Kyoto Protocol.

1. Alternative Approaches to Climate-Change Policy

The present study uses “integrated assessment” (IA) modeling to assess the economic and environmental impacts of alternative approaches to climate-change policy. The advantage of using IA models is that the entire system can be analyzed simultaneously – that is, the impact of alternative policies on the environment and the economy can be analyzed as a package. This allows us to understand the tradeoffs involved in a more precise fashion.

While there is a bewildering array of potential approaches to greenhouse warming, we have organized these into eight major polices shown in Table 7-1. These can be grouped into four general categories: do nothing (policy 1); variants on an optimal policy (policies 2 and 3); arbitrary limitations on environmental variables (policies 4 through 7); and a major technological breakthrough (policy 8). We will want to determine what are the relative advantages and disadvantages of different approaches.

It is desirable to design policies that are economically efficient so that the environmental objectives can be attained in a least cost manner. There are four kinds of efficiency standards that we can examine — how-efficiency, where-efficiency, when-efficiency, and why-efficiency.

- *How-efficiency* denotes the use of efficient ways of achieving the actual emissions reductions in a given year and region. The current study assumes that individual regions attain how-efficiency by domestic auctioning of emissions permits (or equivalently, via uniform carbon taxes).

- *Where-efficiency* denotes allocating emissions reductions across regions to minimize the costs of attaining the global emissions target for a given year. A policy where the only trading bloc is the entire world, which is true for all the policies in Table 7 except number 4, will be where-efficient,[1] whereas a policy such as the Kyoto Protocol, in which there is more than one trading bloc with limited trading, will forfeit some of the gains from trade.

- *When-efficiency* refers to an efficient allocation of emissions over time. A when-efficient policy seeks an emissions path which minimizes the present value of the cost of emissions reductions subject to the policy's environmental goal and the allocation of emissions reductions across regions. Policies 2, 6, and 7 seek efficient timing of emissions reductions. Policies 4 and 5 specify an arbitrary time path of global emissions; since they do not attempt to optimize on timing, they are not when-efficient.

- Finally, *why-efficiency* refers to attaining the ultimate objective of a program, which is here taken to be a set of policies which balance the costs of abatement and benefits of damage reduction. The optimal program in run 2 satisfies why-efficiency and can therefore be used as a benchmark for why-efficiency comparisons with other proposals. The environmental goals of policies 4, 5, 6, and 7 are chosen arbitrarily, so these policies are not why-efficient.

Table 7-1

Alternative Policies Analyzed in RICE-99 and DICE-99 Models

1. *No controls ("baseline").* No policies taken to slow greenhouse warming.

2. *Optimal policy*. Emissions and carbon prices set at Pareto optimal levels.

3. *Ten-year delay of optimal policy*. Delays optimal policy for 10 years.

4. *Stabilize emissions of high-income regions (Kyoto Protocol).* Annex I regions reduce their emissions 5 percent below 1990 levels forever, with trading allowed among Annex I regions.

5. *Stabilizing global emissions.* Stabilizes global emissions at 1990 levels.

6. *Concentrations stabilization.* Stabilizes concentrations at two times pre-industrial levels.

7. *Climate stabilization.* Sets policies to limit temperature rise to (a) 2.5 ºC or (b) 1.5 ºC

8. *Geoengineering.* Implements a geoengineering option that offsets greenhouse warming at no cost.

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2. Detailed Description of Different Policies

A. No controls ("baseline")

The first run is one in which no policies are taken to slow or reverse greenhouse warming. Individuals and firms would adapt to the changing climate, but governments are assumed to take no steps to curb greenhouse-gas emissions or to internalize the greenhouse externality. This policy is one which has been followed for the most part by nations through 1999.

B. Optimal policy

The second case solves for an economically efficient or “optimal” policy to slow climate change. More precisely, this run finds a Pareto optimal trajectory for the world carbon tax (and thus for global industrial emissions), one that balances current abatement costs against future environmental benefits of carbon abatement. Permits are allocated in a revenue-neutral way across countries (Recall that a revenue-neutral permit allocation grants each region permits equal to its emissions at the equilibrium carbon tax.)

The optimal case is where-efficient, when-efficient, and why-efficient. Where-efficiency is guaranteed by the fact that the entire world is one trading bloc. The when- and why-efficient carbon tax is found by setting it equal to the environmental shadow price of carbon.

It will be useful to provide a word of interpretation of the optimal case. This is not presented in the belief that an environmental pope will suddenly appear to provide infallible canons of policy that will be scrupulously followed by all. Rather, the optimal policy is provided as a benchmark for policies to determine how efficient or inefficient alternative approaches may be.

C. Ten-year delay of optimal policy

This case is one which delays implementing the optimal policy for ten years. This policy might be rationalized as one that allows nations to calculate the costs and benefits of delaying implementing policies until knowledge about global warming is more secure. In this scenario, we assume that sufficient information is in hand so that nations begin to act optimally starting in the period 2000-09.

D. Kyoto Protocol

Many current policy proposals deal with intermediate objectives like stabilizing emissions. For example, the Kyoto Protocol of December 1997 is designed to limit the emissions of Annex I countries (essentially, OECD countries plus Eastern Europe and most of the former Soviet Union). The Protocol states: “The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases ... do not exceed their assigned amounts, ... with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.” In other words, Annex I countries will during the period 2008-2012 reduce their combined emissions of greenhouse gases on average by 5 percent relative to 1990 levels.

There are a number of ways of implementing the Kyoto Protocol. While the next chapter analyzes the Kyoto Protocol in detail, the present chapter looks only at the basic Kyoto Protocol design; the basic framework assumes that the Annex I emissions limit is constant indefinitely (“Kyoto forever”) and allows trading of emissions rights among Annex I regions (“Annex I trading”). Annex I regions are allocated emissions permits as specified in the Protocol. In RICE-99, Annex I is made up of USA, OHI, OECD Europe, and R&EE.[2]

Non-Annex I regions have unconstrained emissions in this case (non-Annex I carbon tax=0).

E. Stabilizing global emissions

The Kyoto Protocol targets the emissions only of high-income countries. A broadened Kyoto Protocol would include all countries. For this policy, we assume that global industrial emissions are limited to 1990 levels starting in 2005, and abatement is efficiently distributed around the world (i.e., the carbon tax is the same in all regions). As in cases 2 and 3, permits are allocated so that net permit revenue is zero in all regions. In RICE-99, global reference industrial CO_2 emissions are estimated to be 6.19 GtC per year on average for 1990-99. We estimate that 1990 emissions were 0.916 times first-period emissions. Therefore, under this policy, global CO_2 industrial emissions are limited to 5.67 GtC per year. (These emissions exclude emissions from land-use changes, estimated to total 1.13 GtC per year in the 1990-1999 period.) Note that this policy is more stringent that the Kyoto Protocol, which limits emissions only of high-income countries but does not limit developing-country emissions.

F. Concentrations stabilization

One of the new approaches that has received considerable attention is to stabilize the concentrations of CO_2 in the atmosphere. This policy is motivated by two ideas. First, it is concentrations rather than emissions which will produce harmful and dangerous climate change. Second, CO_2 concentrations are closely related to CO_2 emissions, which are in principle under the control of policy. Concentrations were specifically identified under the U.N. Framework Convention on Climate Change, which states, “The ultimate objective of this Convention ... is to achieve ... stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[3] Although no dangerous level has been established, some scientists believe that a prudent policy would be to limit CO_2 concentrations to two times their pre-industrial levels. This policy is usually taken to be a threshold of 560 parts per million of CO_2, or about 1190 GtC carbon in the atmosphere.

In case 6 we limit atmospheric concentrations to 1190 GtC or less and solve for a Pareto optimal carbon tax trajectory subject to this constraint. As in cases 2, 3, and 5, the entire world is one trading bloc with revenue-neutral allocation of permits.

G. Climate stabilization

A more ambitious approach involves taking steps to slow or stabilize the increase in global temperature so as to prevent major ecological impacts and other damage. This approach is particularly interesting because it focuses on an objective that is closer to the area of actual concern — climate change — as opposed to most other policies, such as emissions or concentrations limits, which focus on intermediate variables of no intrinsic concern.

There have been a number of proposals for setting "tolerable windows" on climate change.[4] In case 7a we limit the global mean temperature rise to 2.5 ºC. This is the IPCC's central estimate for the equilibrium temperature increase associated with a doubling of atmospheric carbon dioxide (IPCC [1996a]). In the RICE-99 base case, this increase is reached in the first decade of the 22nd century. In case 7b we limit the temperature increase to 1.5 ºC. In both cases, we solve for cost-minimizing emissions trajectory subject to temperature remaining below the limit, and again we assume that the plan is implemented through harmonized carbon taxes or a revenue-neutral permit allocation. There have been in addition proposals to limit the rate of change of temperature. In practice, the proposed rate of change constraints do not bind for the two limits investigated here, so the rate of change constraints have been omitted.

Policies 2, 3, 5, 6, and 7 allocate emissions permits so that each region receives its own permit payments as revenues. As explained in Chapter 2, section 5, these policies can be thought of as uniform and harmonized carbon taxation with lump-sum recycling of revenues within regions.

H. Geoengineering

A radical technological option would be geoengineering, which involves large-scale engineering to offset the warming effect of greenhouse gases. Such options include injecting particles into the atmosphere to increase the backscattering of sunlight and stimulating absorption of carbon in the oceans. The most careful survey of this approach by the 1992 report of the U.S. National Academy concluded, “Perhaps one of the surprises of this analysis is the relatively low costs at which some of the geoengineering options might be implemented."[5]

For our calculations, we assume that geoengineering is costless. This is based on current findings which indicate that several geoengineering options are available that would cost less than $10 per ton carbon or have the globally averaged radiative effect of reducing emissions by one ton of carbon. It should be emphasized that many ecologists and environmentalists have grave reservations about the environmental impacts of the geoengineering options. Moreover, the climatic impacts have been insufficiently studied. Nonetheless, because of the high cost of other mitigation strategies, this scenario is useful as a benchmark to determine the overall economic impact of greenhouse warming and of policies to combat warming.

3. Major Results

The results for the DICE-99 and RICE-99 models in this section have been obtained using the EXCEL versions.

A. Overall results

We first summarize the overall results for the scenarios described above. Table 7-2 and Figure 7-1 show the results for the different runs in RICE-99 and DICE-99 as well as the original DICE model. The definition of net economic impact used here is the following:

> The *net economic impact* of a policy is the sum across regions of the present value of consumption under that policy minus the present value of consumption in the base case. The present values are computed using the base case discount factors.

The RICE-99 model finds that the optimal policy produces a net economic gain of $198 billion. This is the present value of the gain to all regions, discounted back to 1995. Concentrating on the RICE-99 model results in Table 7-2, we see that a delay of ten years leads to a trivially small net loss — $6 billion. This important result indicates that the loss from waiting and gathering more information is relatively small, assuming that action is appropriately taken in the future.

The next set of policies concerns emissions limitations. On theoretical grounds, we would expect these policies to be relatively inefficient because they target an inappropriate variable. Emissions are an inappropriate policy instrument because they are not of any intrinsic concern; they are intermediate variables connecting economic activity and the ultimate variable of concern, which is damages from climate change. A policy that limits global emissions to 1990 levels has a discounted loss of $3 trillion in RICE-99. The Kyoto Protocol with Annex I trading has relatively small impact (a small loss) because RICE-99 projects relatively low emissions of Annex I regions; this also implies that the environmental gains from the Kyoto Protocol are small. (This point will be discussed below.) Emissions, concentrations, and temperature increases under the Kyoto Protocol are very close to the base case because it has little impact on global emissions.

A policy of limiting CO_2 concentrations to double pre-industrial levels has unfavorable net economic impacts, with a net loss of $0.7 trillion. A policy to limit temperature to 2½ ºC is also quite costly. The present value of the net economic impact is about $2½ trillion.

Finally, as is intuitively clear, geoengineering options that in effect remove atmospheric carbon at zero cost or neutralize the damages from climate change have highly positive net value. Estimates from RICE-99 indicate that the value is almost $4 trillion. This gives us a measure of the damages from climate change in the base case.[6]

Table 7-3 shows the breakdown of costs, damages, and net benefits for the different policies in RICE-99. “Abatement costs” are defined as the difference between the present value of consumption in the base case and the present value of consumption under the current policy assuming that the policy does not have any effect on the path of global mean temperature. The “environmental benefits” of the policy are then the sum of the abatement costs and the net economic impact. It is apparent that there are modest potential benefits from a successful climate change policy. The reduced damages from slowing climate change range from about $300 billion in present value in the optimal policy to $1.5 billion in the more ambitious emissions-limitation plan. Increases in production costs are also substantial, however. The optimal abatement policy incurs $98 billion in abatement costs, while inefficient plans such as stabilizing global emissions or limiting temperature increases to 2½ ºC impose present value costs in the range of $3.5 to $4.5 trillion.

The benefit-cost ratios of different policies are shown in the last column of Table 7-3. The optimal policy passes a cost-benefit test – the optimal program has a benefit-cost ratio of 3.0. The inefficient plans, by contrast, have benefit-cost ratios of 0.08 to 0.5. In judging these ratios, it must be recalled that we assume that policies are efficiently implemented. If inefficient implementation occurs (say through allocation of permits, exclusions, inefficient taxation, or regional exemptions), then the costs will rise and the benefit-cost ratio of even the optimal policy will quickly pass below 1.

Table 7-4 shows the regional breakdown of the net economic impact for different policies. In analyzing the regional impacts, we assume a revenue-neutral allocation of emissions permits or zero net permit revenue in each of the cases except the Kyoto Protocol, as explained in section 2. This assumption is important for the regional allocation of the costs and benefits of climate change policies.

To the extent that regions have relatively high emissions reductions under a policy or benefit from modest climate change (both of which occur in the case of the “Russia and Eastern Europe” region), the policy may lead to economic losses.

The major gainer from climate policies is OECD Europe, which gains from all policies, even the ones that have high global costs. In the optimal case, OECD Europe has over three-fifths of the net gain. These gains arise primarily because the region is highly sensitive to climate change, has a low discount rate, and pays little of the abatement costs under the policy of zero net permit revenue. Regions with high carbon intensities, high discount rates, and low vulnerability to global warming (such as Eastern Europe and China) have negative net impacts in the optimal case. Note that if there is trading of emissions permits, virtually any regional redistribution of the costs and benefits would be possible through the initial allocation of permits. This is not done in the current version for simplicity of presentation and calculation.

The final column in Table 7-4 shows the net impacts of geoengineering; this is also approximately the net climate damages in the base case. The interesting result is that the major gains from geoengineering accrue to OECD Europe. As was shown in Chapter 4, Russia, China, and Canada are likely to benefit from modest climate change of the kind found in the base case and have negative benefits from geoengineering.

The difference between the geoengineering results and the results for the other strategies is so dramatic that it suggests that geoengineering should be more carefully analyzed. Table 7-3 indicates that a technological solution that would offset the climatic impacts of increasing greenhouse-gas concentrations would have a benefit of around $4 trillion in present value. In addition to its significant economic benefits, geoengineering also has important political advantages over the current approach of emissions reductions. Geoengineering does not require near-unanimous agreement among all major countries to have an effective policy; indeed, the United States could easily undertake geoengineering by itself if other countries would give their assent. Given its clear economic and political advantages, we believe that geoengineering should be much more carefully analyzed.

B. Emissions controls and carbon taxes

Table 7-5 and Figures 7-2 and 7-3 show the carbon taxes or permit prices in the different policies. In the runs analyzed here, the prices are internationally harmonized; this could occur in practice either through harmonized taxes or a system of tradable emissions permits. The optimal policy has a carbon tax beginning at $6 per metric ton carbon for the first period (1990-99). The optimal tax rises in future years, reaching $13 per ton in 2015, $29 per ton in 2050, and $63 per ton carbon in 2100. For reference, a $10 per ton carbon tax will raise coal prices by $5.50 per short ton — about 30 percent of the current U.S. minemouth coal price. Further, a $10 per ton carbon tax would raise gasoline prices by about 2 U.S. cents per gallon.

The 10-year delay (not shown) has a zero carbon tax in the first period, but then is virtually indistinguishable from the optimal policy. The policy of no controls obviously has a zero carbon tax. The global-emissions-stabilization policy has steeply rising carbon taxes, hitting $200 per ton in the middle of the next century. Policies which stabilize CO_2 concentrations and temperature have initial carbon taxes close to those in the optimal policy, but they then rise sharply in the coming years. The optimal policy to meet these targets delays high carbon taxes to the future; reducing future emissions is a more cost-effective way to meet such targets both because it is less expensive in a present value sense and because much of a current emission has been removed from the atmosphere when the target becomes a binding constraint.

Table 7-6 and Figure 7-4 show the control rate for CO_2 for the different policies. These show the extent to which GHG emissions are reduced below their reference levels. In the optimal path, the rate of emissions reduction begins at a low rate of about 4 percent of emissions and climbs slowly over the next century, reaching about 11 percent of baseline emissions by 2100. The three environmental paths (limiting emissions, concentrations, and temperature) start with relatively low emissions controls but then climb sharply to emissions-control rates between 33 and 59 percent by the end of the next century.

Figure 7-5 shows the regional control rates in the optimal policy. One interesting feature is that the control rates fall into two general groups – those for high income regions and those for low-income economies and economies in transition. The control rates for the latter regions are generally more than twice those of the high-income regions. The reason for the difference is that energy is generally much more highly taxed in high-income countries, while it is often subsidized in low-income countries, so that it is less expensive to reduce emissions in the low-taxed regions. It is interesting to note that this pattern is exactly the *opposite* of the prescription in the Kyoto Protocol, which has the initial emissions reductions in the high-income Annex I countries.

C. Emissions, concentrations, and climate change

We next show some of the climatic details of the model runs. Table 7-7 and Figure 7-6 show the aggregate industrial CO_2 emissions, while Figure 7-7 shows the reference emissions for different regions. Baseline industrial CO_2 emissions in RICE-99 project steady growth to about 13 GtC annually in 2100. In the optimal case, emissions are limited to 11.5 GtC in 2100. By comparison, emissions are only 9 GtC in 2100 for limiting concentrations, and 5.8 GtC in 2100 for limiting temperature to 2½ ºC.

Atmospheric concentrations of CO_2 are shown in Figure 7-8. Beginning at an atmospheric concentration of 735 GtC (345 ppm) in 1995, baseline concentrations rise to 1187 GtC (557 ppm) in 2100. In the optimal control case, concentrations are limited to 1145 GtC (538 ppm) in 2100. The Kyoto concentration shown in Figure 7-8 and discussed in the next chapter is very close to the base case.

It is interesting to note that the emissions and concentrations projections in RICE-99 are well below those in many current projections. For comparison, of the 90 scenarios examined in IPCC [1995], the median projection for 2100 was around 22 GtC.[7] In the often-cited IPCC IS92a scenario, the 2100 carbon dioxide concentration is 710 ppmv (1500 GtC). On the other hand, many of these scenarios were prepared before the breakup of the Soviet Union and contained high rates of economic growth and low rates of decarbonization. It will be necessary to wait for the next generation of studies to determine whether the relatively low emissions projections in RICE-99 are an aberration or a harbinger.

However, the temperature trend in the base RICE-99 run is close to the IPCC projections developed in the early 1990s. The baseline temperature increase relative to 1900 in RICE-99 is 0.43 ºC in 1995 and rises to 2.42 ºC by 2100, for an increase of 2.0 ºC. This increase compares with a baseline warming used in IPCC [1996a] of 2.0 ºC in 2100 relative to 1990 with a climate sensitivity of 2.5 ºC. RICE-99 projects higher global temperatures despite lower projected emissions than the IPCC because RICE-99 uses a higher equilibrium temperature sensitivity of 2.9 ºC for a doubling of CO_2.

The effect of alternative policies on the projected global mean temperature is shown in Table 7-8 and Figure 7-9. All runs have very similar temperature trajectories through the middle of the next century. After 2050, the emissions-limitation scenario begins to head down relative to the other paths. One of the surprising results of virtually all policies is how little they affect the temperature trajectory in the next century. The optimal path reduces global mean temperature by 0.09 ºC relative to the baseline in 2100. However, the policies have a more substantial impact in the next century. The temperature reduction in 2200 relative to the baseline of the optimal, concentration target, and temperature target are 0.20, 0.88, and 1.37 ºC, respectively.

One puzzling feature of these results is the modest impact that the optimal policy or even more ambitious policies make upon the concentration and temperature trajectories. The first reason for the modest effect is straightforward. According to our estimates, the impact of warming upon the global economy is relatively small, amounting to around 2 percent of global output for a 2½ ºC average warming. By contrast, the abatement costs of significant reductions in GHGs are high. The interaction of small benefits and large costs is that an optimal policy has little effect on the near-term temperature increase.

Two other factors lead to the small decrease in the extent of warming in the optimal path. First, there is a great deal of momentum of climate change given the existing degree of buildup of GHGs and the lags in the response of the climate to GHG increases. For example, consider the policy of stabilizing global emissions at 1990 rates — an extremely ambitious target requiring reducing CO_2 emissions by over 40 percent below the baseline by the middle of the next century and costing $4.5 trillion in discounted abatement expenditures. Even with all this cost, global temperatures would still rise by slightly more than 2 ºC above 1900 by 2100.

Second, the relationship between GHG concentrations and warming is non-linear. According to scientific studies, the relationship between equilibrium warming and CO_2 concentrations is approximately logarithmic. This implies that moving from 300 to 315 ppm of CO_2 increases equilibrium temperature by 0.205 ºC while moving from 600 to 615 ppm of CO_2 increases equilibrium temperature by only 0.104 ºC. The implication of this nonlinear relationship is that policies that produce a small decrease in CO_2 concentrations have a relatively small impact upon the path of temperature. This result is the opposite of the usual diminishing returns seen almost everywhere in economic systems.

D. Other economic variables

The model has a wide variety of other projections that are necessary for a full analysis. They include both physical output (such as CO_2 emissions) as well as economic values (such as the values of output and consumption). Figure 7-10 shows per capita output for the eight regions, while the trends in regional carbon intensities are shown in Figure 7-11. We also showed regional emissions in Figure 7-7.

Two points about the trends should be noted. First, the model assumes continued rapid economic growth in the years ahead. This growth will lead to increased emissions, but it will also improve living standards and provide resources for coping with greenhouse warming. A second important feature of the RICE-99 model projections is that CO_2 emissions in the high-income regions are projected to be relatively flat over the next century. This is the result of continuing decarbonization plus slower population growth in high-income countries. This trend has important implications for the Kyoto Protocol, because the Kyoto Protocol constrains only high-income countries.

E. Comparison of DICE-99 and DICE-92

Finally, we can examine the extent to which projections and policies differ among the current RICE/DICE-99 models and compare those with the original DICE model (developed in the 1990-92 period). Although DICE-99 tracks RICE-99 closely as far as important variables are concerned over the next century (see Tables 5-1 and 5-2), Table 7-2 shows that in some cases the net economic impact of a policy differs substantially between the two models. However, the policy ranking that comes from the two models is the same.

Another interesting comparison is between the original and current versions of DICE. The net economic impact of policies has changed surprisingly little across model versions, except for cases that take us very far away from the baseline.

The carbon taxes for the first period are quite close in all three models, with the optimal carbon tax being $5.53 per ton in the original DICE model and $5.90 in RICE-99 and DICE-99. The optimal carbon tax turns out to be one of the most robust numbers through the evolving family of DICE and RICE models.

Table 7-2

Net Economic Impact

Billions of 1990 U. S. $

	RICE-99	DICE-99	Old Dice
Base	0	0	0
Optimal			
Policy in 1995	198	254	283
Policy in 2005	192	246	254
Limit Emissions			
Global stabilization	-3,021	-5,705	-7,394
Kyoto Protocol (a)	-120	na	na
Limit concentrations			
Double CO2	-684	-1,890	na
Limit temperature			
2.5 degree increase	-2,414	-4,396	na
1.5 degree increase	-26,555	-20,931	-42,867
Geoengineering (b)	3,901	2,775	5,859

[a] Annex I trading.
(b) Implemented by assuming that the damages from climate change are zero.
Source for Old Dice is Nordhaus [1994b], Chapter 5, Table 5.1.

Table 7-3

Abatement Costs and Environmental Benefits of Different Policies

[Billions of 1990 U.S. $]

	Abatement Cost	***Environ-mental Benefit***	***Net Economic Impact***	***Benefit/cost Ratio***
Base	0	0	0	na
Optimal				
Policy in 1995	-98	296	198	3.02
Policy in 2005	-92	283	192	3.08
Limit Emissions				
Global stabilization	-4,533	1,512	-3,021	0.33
Kyoto Protocol	-217	96	-120	0.44
Limit concentrations				
Double CO2	-1,365	681	-684	0.50
Limit temperature				
2.5 degree increase	-3,553	1,139	-2,414	0.32
1.5 degree increase	-28,939	2,383	-26,556	0.08
Geoengineering	0	3,901	3,901	na

Table 7-4

Net Economic Impact of Policies

[Difference from base, billions of 1990 U.S. $]

	Optimal	***Limit to 1990 Emissions***	***Limit to 2 x CO2 Concentrations***	**Limit** ***Temperature Rise to 2.5 deg C***	***Geoen-gineering***
USA	22	-946	-305	-885	82
OHI	26	-139	-6	-131	-391
Europe	126	258	162	121	1,943
R&EE	-9	-359	-64	-191	-110
MI	19	-300	-103	-304	620
LMI	5	-512	-122	-341	549
China	-10	-425	-74	-226	-21
LI	20	-597	-174	-458	1,228
Annex I	164	-1187	-212	-1,085	1,524
ROW	34	-1834	-472	-1,329	2,377
World	198	-3,021	-684	-2,414	3,901

Table 7-5

Carbon Taxes in Alternative Policies

[1990 US dollars per ton carbon]

	1995	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095	2105
Optimal	5.90	9.13	12.71	16.72	21.16	26.12	31.64	37.73	44.38	51.55	59.20	67.39
Delayed optimal	0.00	9.15	12.73	16.73	21.17	26.12	31.64	37.72	44.37	51.54	59.18	67.37
Limit to 1990 Emissions	0.00	52.48	89.69	128.03	169.62	217.89	273.65	337.45	409.67	490.60	580.45	679.32
Limit to 2 times CO2 concentrations	2.15	3.81	6.28	9.98	15.54	23.87	36.32	54.76	81.92	121.75	180.31	267.69
Limit Temperature	6.73	11.79	19.20	30.27	46.71	71.19	107.44	160.74	238.35	350.28	509.65	732.03

Table 7-6

Emissions Control Rates in Alternative Policies

[Reduction in emissions as percent of baseline emissions]

	1995	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095	2105
Optimal	3.9	4.8	5.6	6.2	6.9	7.5	8.2	8.8	9.4	10.0	10.5	10.9
Limit to 1990 Emissions	0.0	21.6	28.2	32.8	36.5	40.1	43.4	46.6	49.6	52.3	54.9	57.2
Limit to 2 times CO2 concentrations	1.3	1.9	2.5	3.5	4.7	6.4	8.7	11.7	15.5	20.4	26.3	33.3
Limit Temperature rise to 2.5 deg C	4.2	6.0	8.0	10.5	13.8	18.0	23.1	29.2	36.1	43.7	51.5	59.0

Table 7-7

Industrial CO2 Emissions in Alternative Policies

[GtC per year]

	1995	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095	2105
Base	6.2	7.2	7.9	8.4	8.9	9.5	10.0	10.6	11.2	11.9	12.6	13.3
Optimal	5.9	6.9	7.5	7.9	8.3	8.7	9.2	9.7	10.2	10.7	11.3	11.8
Limit to 1990 Emissions	6.2	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Limit to 2 times CO2 concentrations	6.1	7.1	7.7	8.1	8.5	8.9	9.1	9.4	9.5	9.5	9.3	8.8
Limit Temperature	5.9	6.8	7.3	7.6	7.7	7.8	7.7	7.5	7.2	6.7	6.1	5.4

Table 7-8

Temperature in Alternative Policies

[Difference in global mean atmospheric temperature from 1900]

	1995	2005	2015	2025	2035	2045	2055	2065	2075	2085	2095	2105
Base	0.43	0.49	0.63	0.82	1.03	1.25	1.46	1.68	1.89	2.11	2.32	2.53
Optimal	0.43	0.49	0.63	0.81	1.01	1.22	1.43	1.63	1.84	2.04	2.24	2.44
Limit to 1990 Emissions	0.43	0.49	0.63	0.80	0.96	1.13	1.29	1.45	1.60	1.75	1.89	2.02
Limit to 2 times CO2 concentrations	0.43	0.49	0.63	0.82	1.02	1.23	1.45	1.65	1.85	2.05	2.24	2.42
Limit Temperature rise to 2.5 deg C	0.43	0.49	0.63	0.81	1.01	1.21	1.41	1.60	1.78	1.95	2.11	2.25

Figure 7-1. Impacts of Alternative Policies

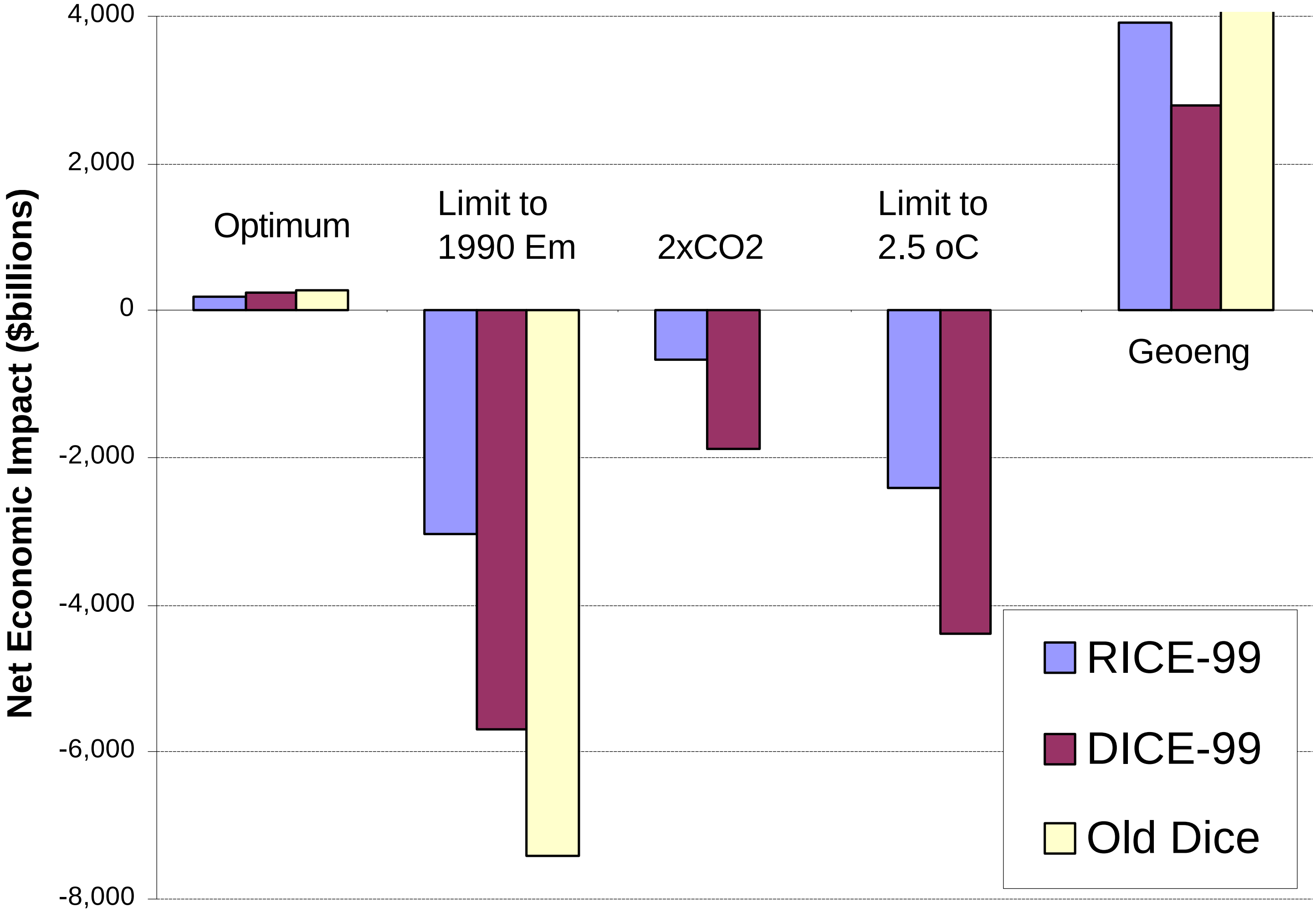


Figure 7-2. Carbon Taxes: Alternative Policies

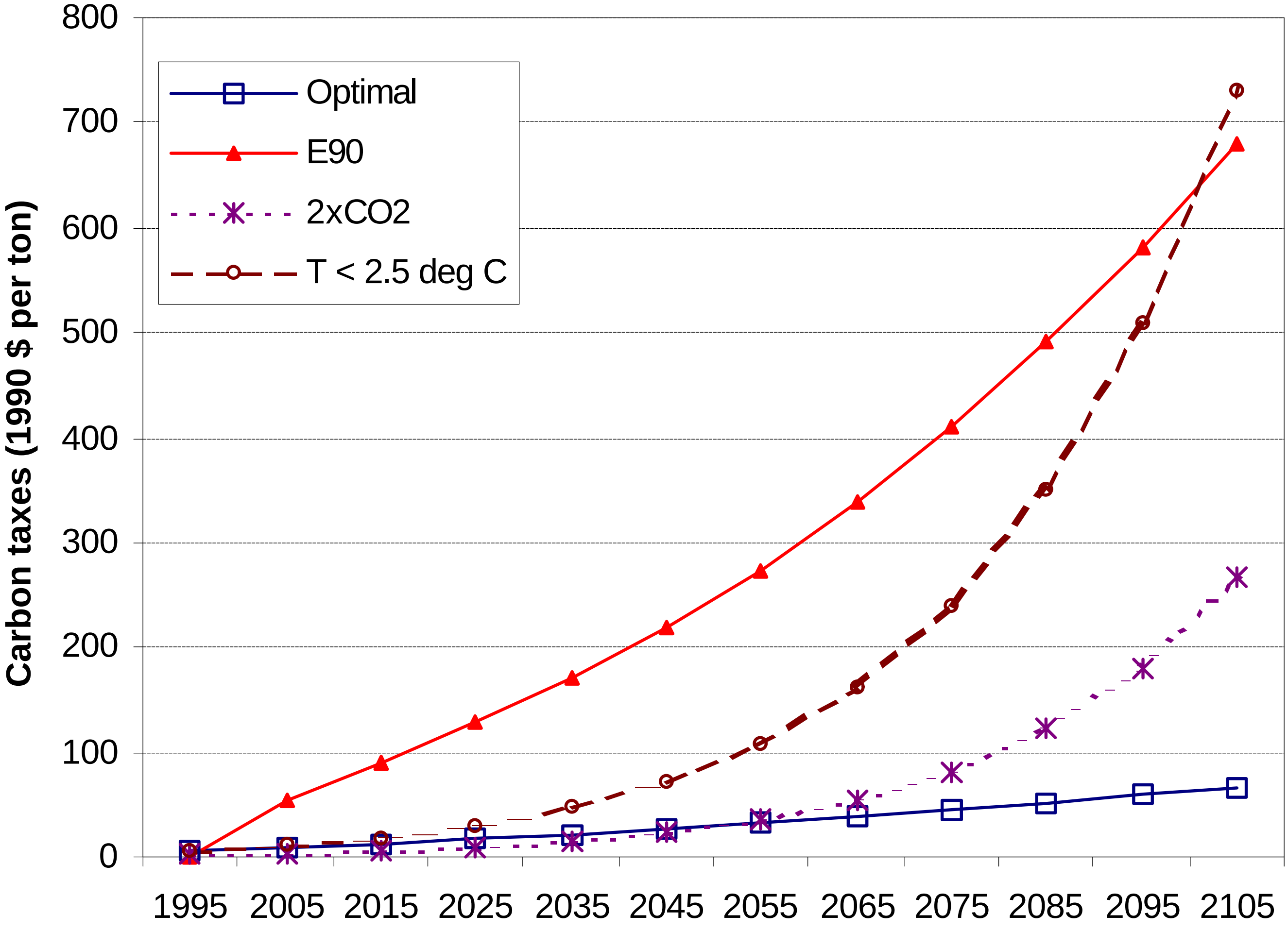


Figure 7-3. Carbon Taxes: Alternative Policies

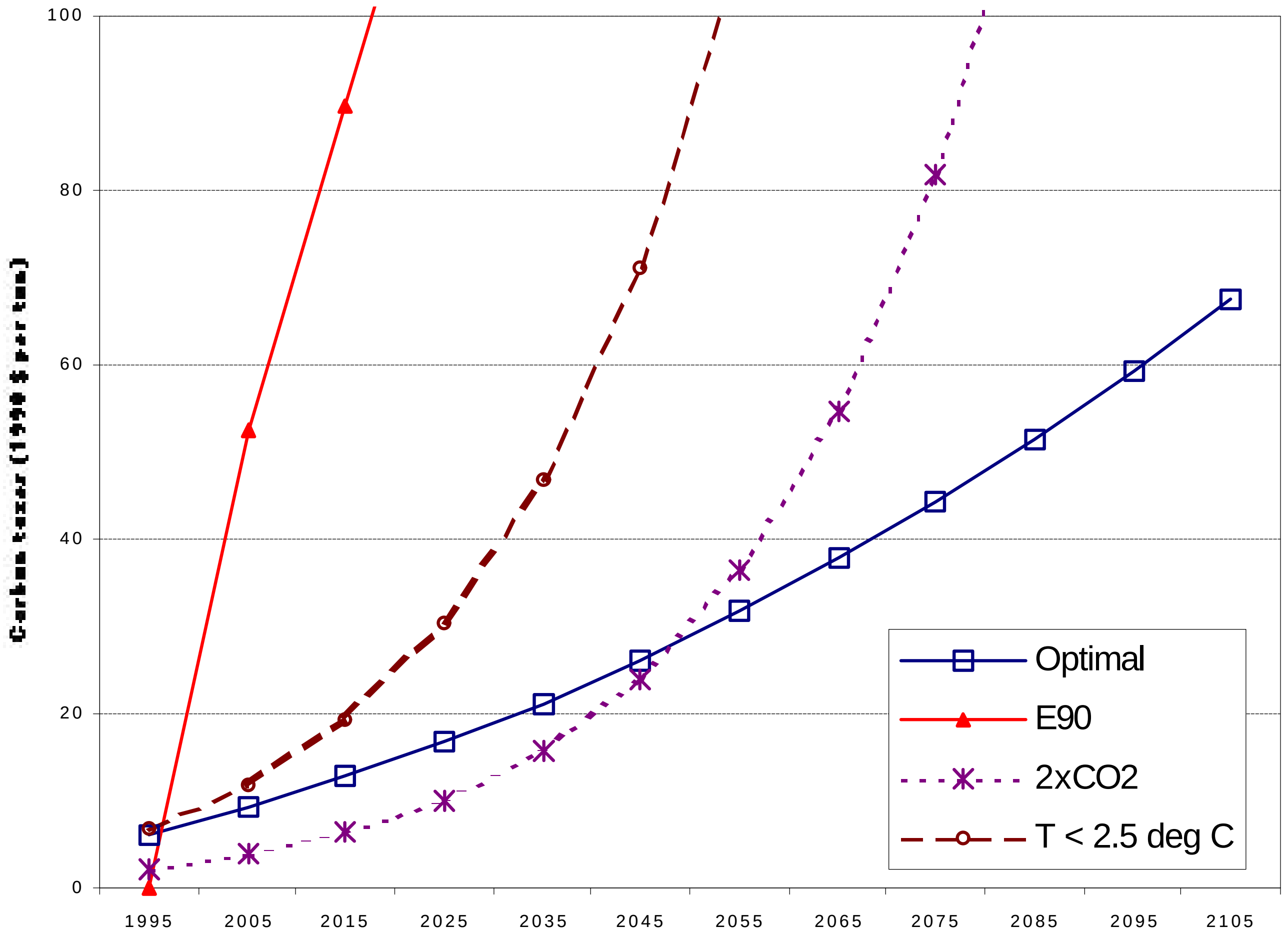


Fig 7-4. Emission Control Rates: Alternative Policies

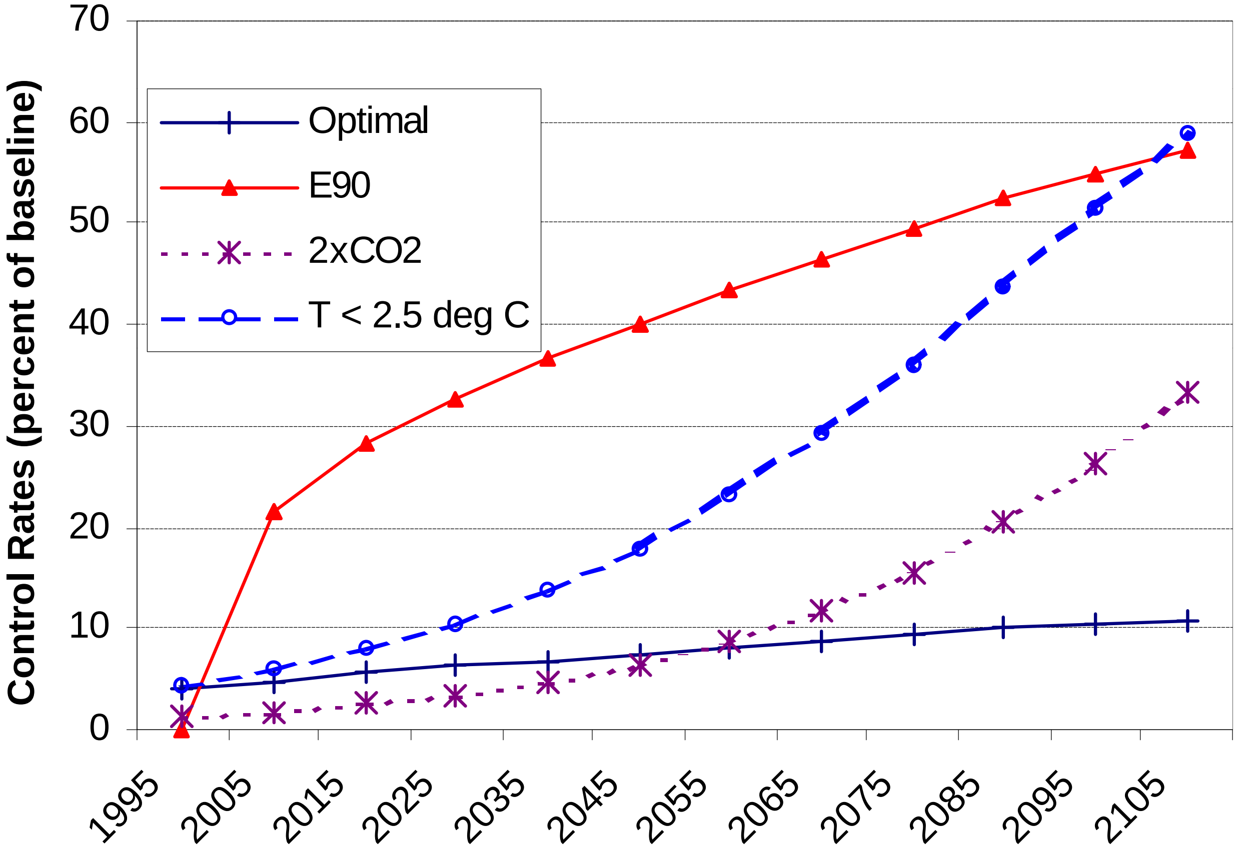


Fig 7-5. Optimal Emissions Control Rate by Region

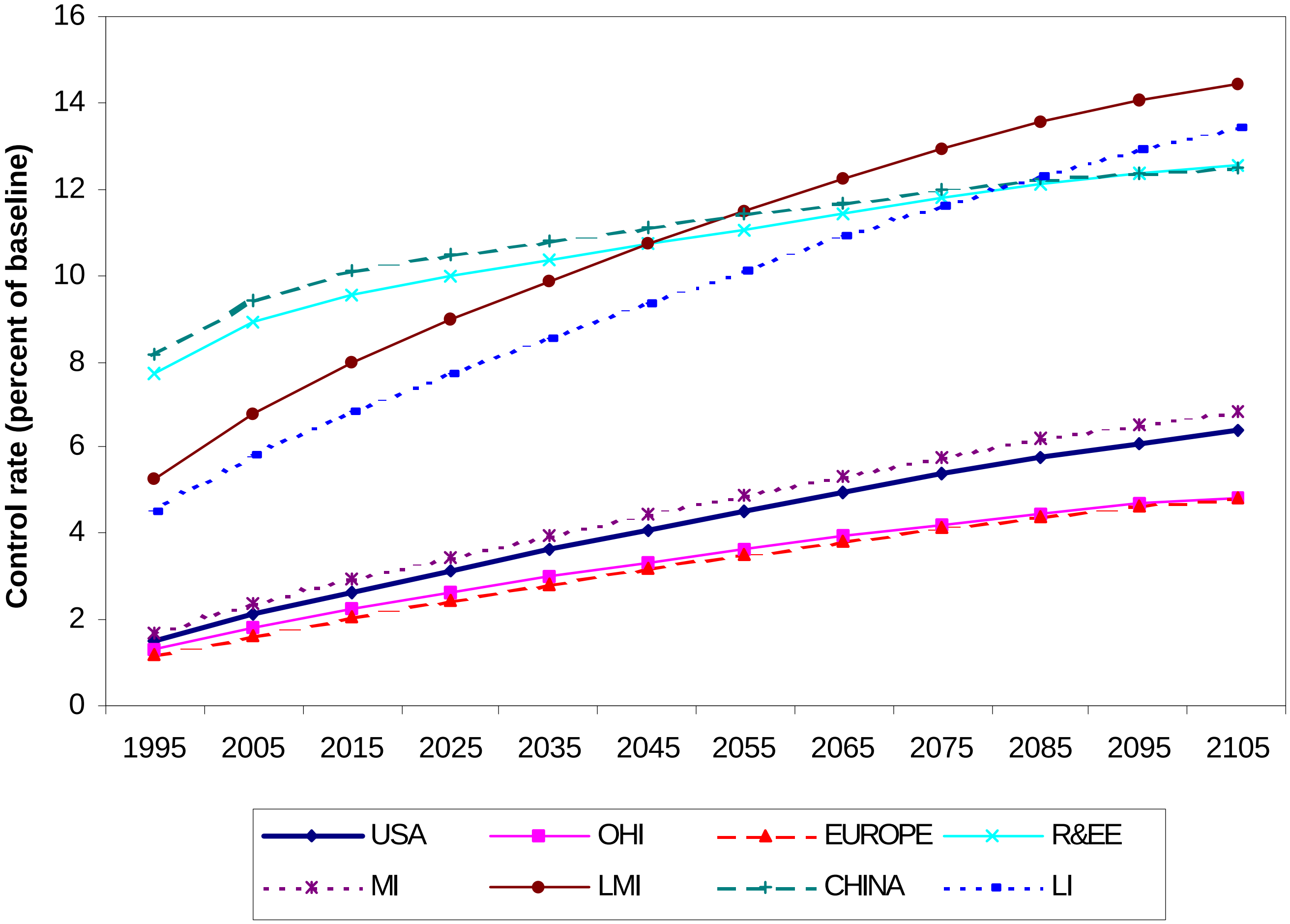


Fig 7-6. CO2 Emissions: Alternative Policies

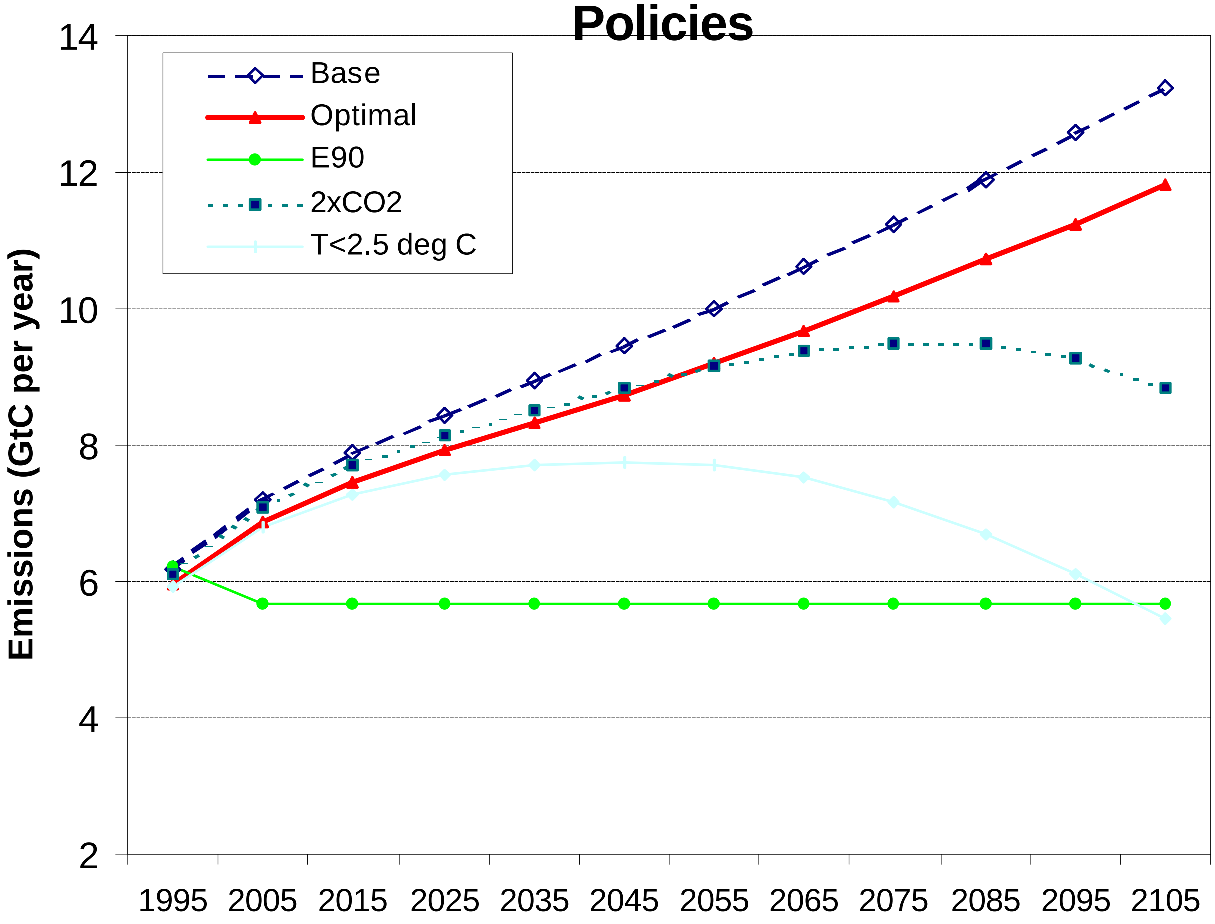
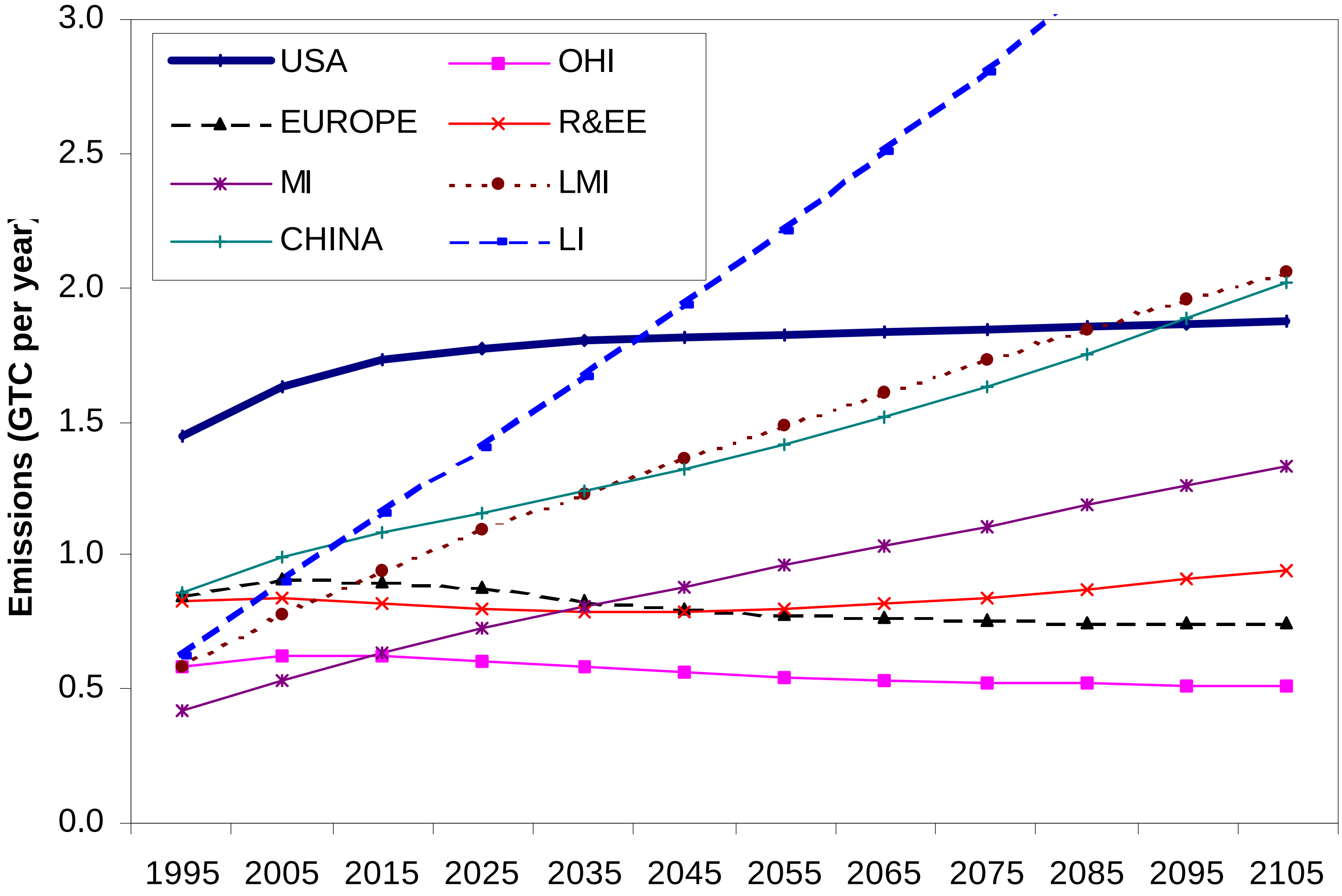


Fig 7-7. Regional Industrial CO2 Emissions in Base Case



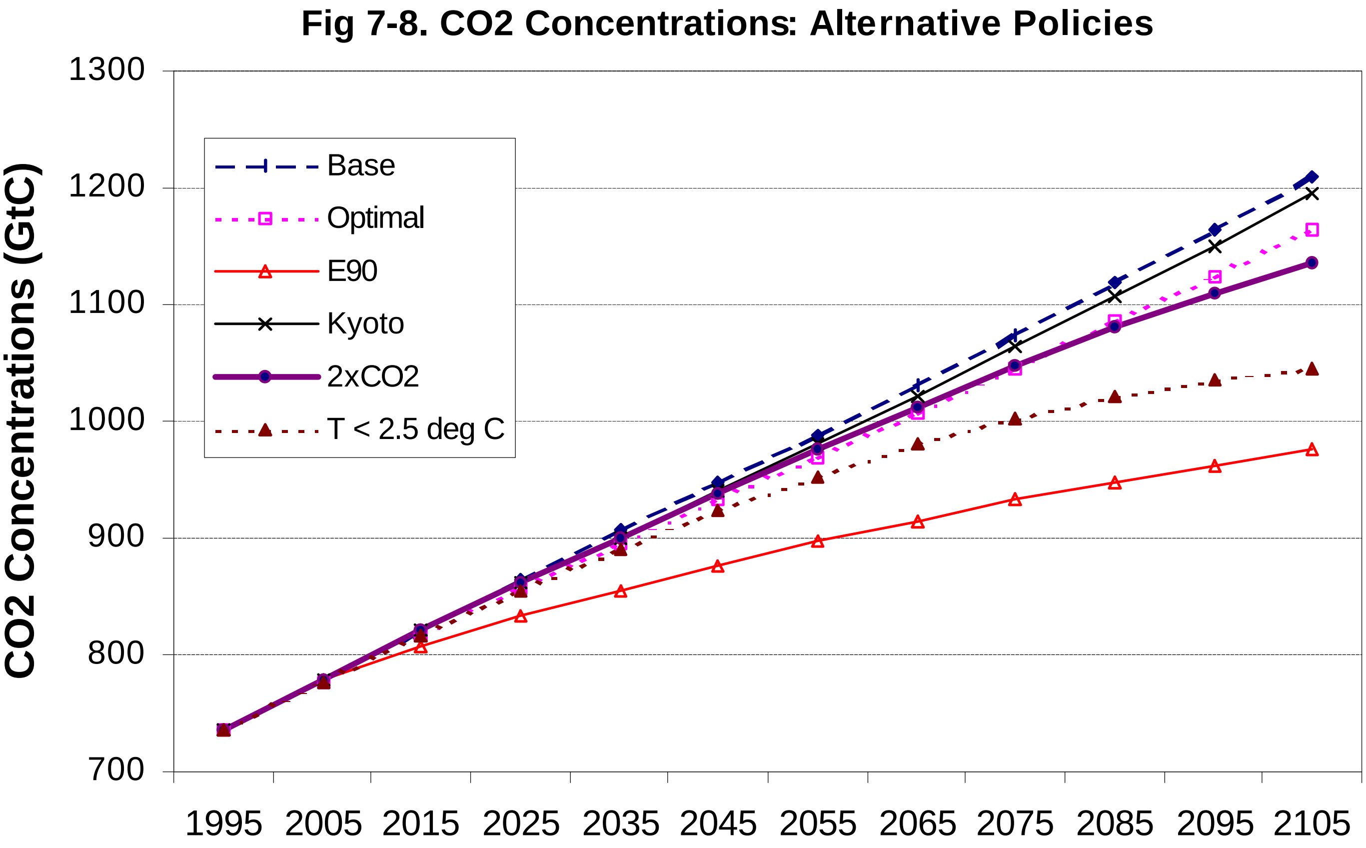


Fig 7-8. CO2 Concentrations: Alternative Policies
CO2 Concentrations (GtC)
1300
1200
1100
1000
900
800
700
1995
2005
2015
2025
2035
2045
2055
2065
2075
2085
2095
2105
Base
Optimal
E90
Kyoto
2xCO2
T < 2.5 deg C

Fig 7-9. Global Mean Temperature

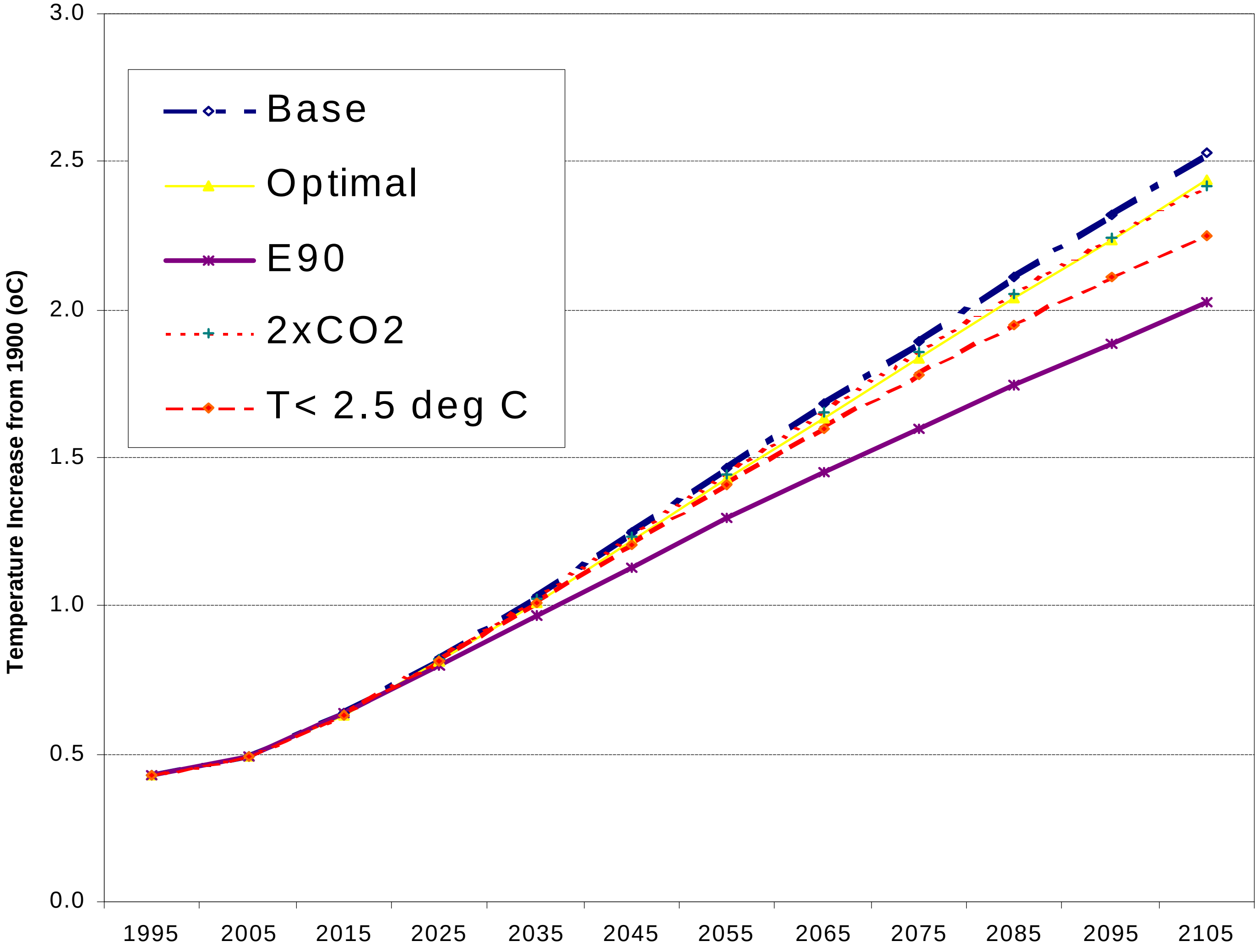


Fig 7-10. Per Capita Income in Base Run

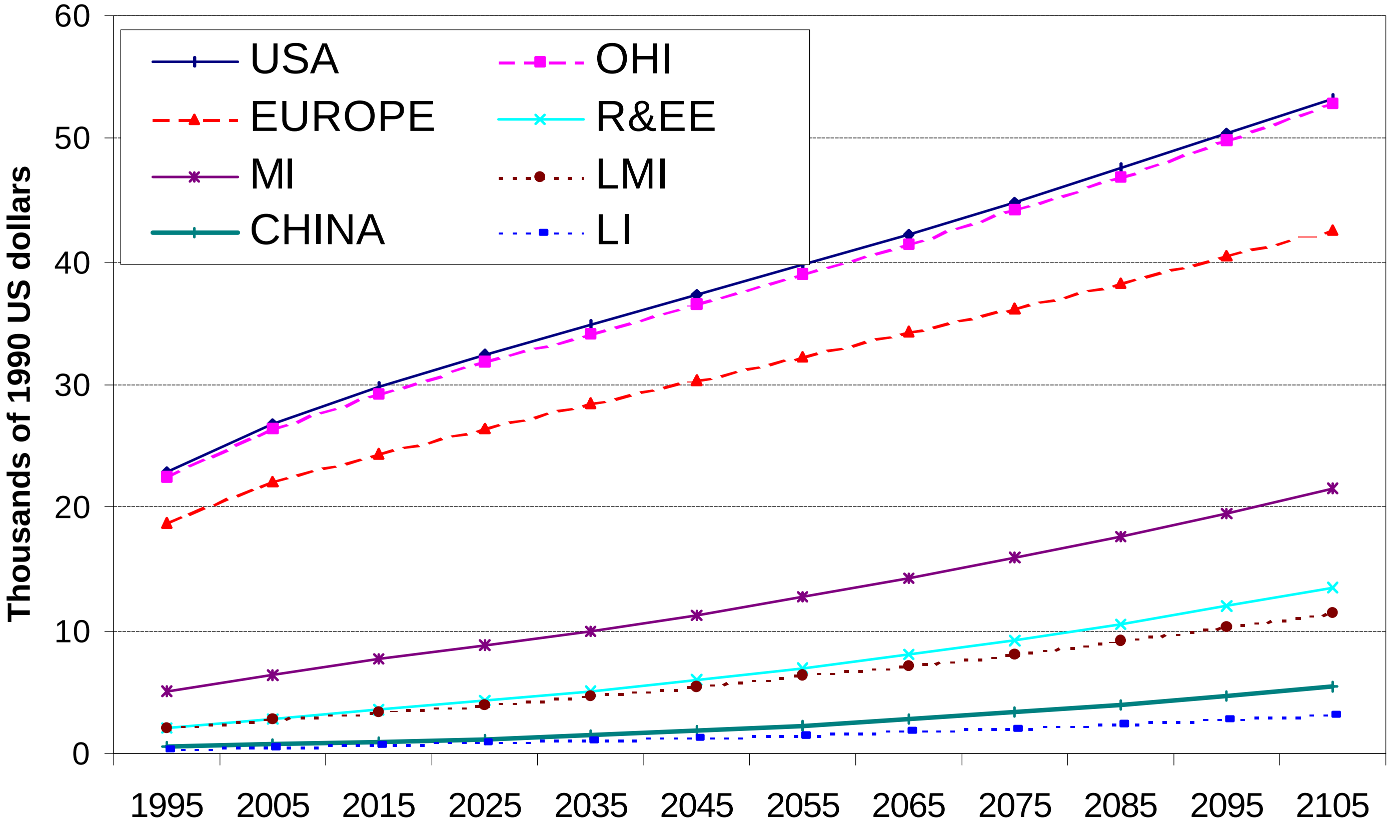
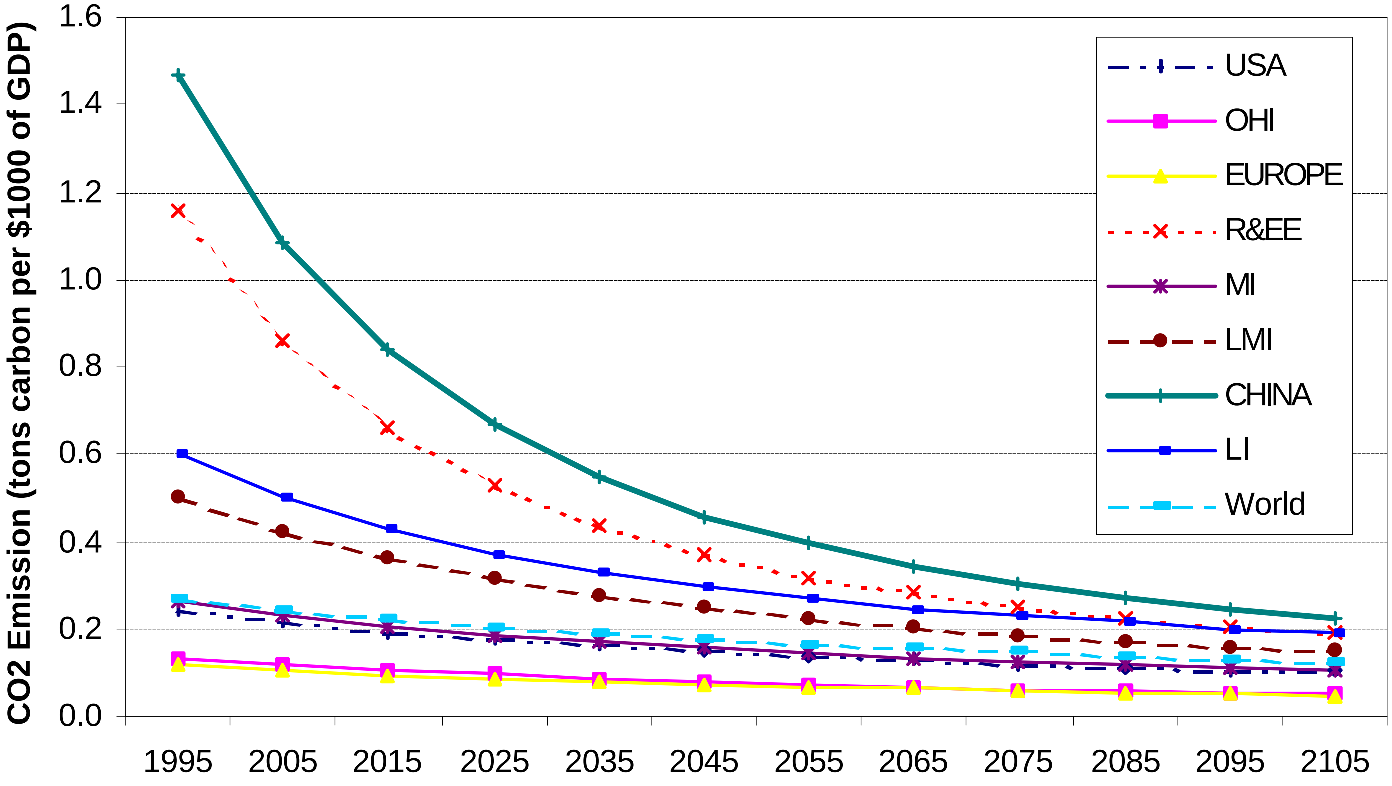


Fig 7-11. Industrial Carbon Intensity: Base Case



Endnotes:

1. If the entire world faces the same carbon tax, then the marginal cost of emissions reduction will be the same in each region. If there are two trading blocs, the marginal cost of emissions reduction will be high in one regions and low in the other.

2. Annex I in RICE-99 does not correspond exactly with the actual Annex I, because OHI includes some countries that are not part of the actual Annex I. Emissions limits and permit allocations in case number 4 and in the cases in Chapter 8 are scaled up appropriately.

3. Article 2.

4. For a recent discussion, see Toth et al. [1998], which also calculates emissions trajectories that would keep climate safely be neath a temperature trajectory that might trigger changes in the thermohaline circulation. All runs of RICE-99 are well below the trigger trajectory.

5. National Academy of Sciences [1992], p. 460. The National Academy report describes a number of options that provide the theoretical capability of unlimited offsets to the radiative effects of GHGs at a cost of less than $1 per ton C (see National Academy of Sciences [1992], Chapter 28).

6. There are two potential ways of implementing a costless geoengineering policy in RICE-99. The first, which we have pursued, is to set the damage coefficients $\theta_{1,J}$ and $\theta_{2,J}$ in equation (2.16) to zero. This would correspond to a geoengineering policy that aims to exactly offset the increase in GHG concentrations. A second approach is to optimize the global mean temperature variable. Under this alternative, costless emissions (positive or negative) are used to achieve the temperature path that will give the highest discounted value of consumption. This second approach turns out to be difficult to implement in RICE-99, but using DICE-99 we estimate that the optimal climate would have a present value of $1.7 trillion higher than the estimates presented here. While aiming for the optimal climate is an intriguing approach, it requires a much deeper knowledge of impact than we possess, so we aim for the more modest goal of offsetting climate change.

7. See IPCC [1995], Figure 6-2.