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Global 2100: Alternative Scenarios for Reducing Carbon Emissions

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This paper forms part of an OECD project which addresses the issue of the cost of reducing CO_2 emissions by comparing the results from six global models of a set of standardised reduction scenarios. The project provides evidence on: i)projected carbon dioxide emissions through the next century, and ii) the carbon taxes and output costs entailed in reducing these emissions.

* * * * *

Ce document fait partie d'un projet de l'OCDE qui s'interroge sur les coûts de réduction des émissions de CO_2 en comparant les résultats de six modèles globaux formés d'un ensemble de scénarios standardisés de réduction. Ce projet met en évidence : i) les émissions projetées de dioxyde de carbone d'ici à la fin du siècle et ii) les taxes sur le carbone et les coûts de production que suppose la réduction de ces émissions.

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The research reported in this paper was funded by the Policy Studies Branch, Economics Department, OECD. The views presented here are solely those of the individual author, and do not necessarily report the views of OECD or its members. The modelling framework is based upon joint work with Richard Richels, Electric Power Research Institute.

1. Introduction - model structure

Global 2100 (jointly developed with Richard Richels) is a model for analyzing the economic costs of limiting carbon emissions during the 21st century. The model is designed to estimate the costs but *not* the global benefits of slowing down climate change through carbon limitations. All computations are performed in parallel for five geopolitical regions: USA, OOECD (other OECD nations), USSR, China and ROW (rest of world). Except for international trade in crude oil and in carbon rights, these regions are treated independently.

The name Global 2100 has been adopted in order to emphasize both the global nature of the carbon emissions problem and also the need for a long-term perspective. The model is benchmarked against a base year of 1990, and the projections cover ten-year time intervals extending from 2000 through 2100. This is an intertemporal rather than a recursive system. It is assumed that producers and consumers will be sufficiently forward-looking to anticipate the scarcities of energy and the environmental restrictions that are likely to develop during the coming decades.

For each region, a dynamic nonlinear optimization is employed to simulate either a market or a planned economy. Supplies and demands are equilibrated within each individual time period, but there are "look-ahead" features to allow for interactions between periods. These interactions are particularly important for the depletion of exhaustible resources, for the rate of penetration of new supply technologies and for the accumulation of capital over time. Savings and investment are determined through the maximization of discounted utility. Just as in the Ramsey economic growth model, it is optimal for consumers to receive equal benefits from an additional dollar's worth of current consumption and from the future consumption generated by a dollar's worth of investment.

In order to decompose the overall problem into more manageable subproblems, it is supposed that each of the five regions faces an exogenously determined carbon emissions quota. We also show how things might work out if each region has the opportunity to trade these quota rights on an international market. In the case of international trade in crude oil, the model is *almost* consistent. It is assumed that the ROW region (which includes OPEC) sets an international price, the OECD nations are price takers, and the ROW meets their demands for net imports. Alternative scenarios (informal iterative methods) are employed to eliminate any prospective gaps between oil supplies and demands.

Within each region, the analysis is based upon a model named ETA-MACRO. Prices are determined so as to allow for two-way linkage between two submodels. The supply side of the analysis is provided by ETA, a linear activity analysis model for energy technology assessment. Demands are determined by MACRO, a continuously differentiable macroeconomic production function describing the balance of the economy. (See Figure 1.) Energy *supplies* include both exhaustible hydrocarbon resources and also "backstop" technologies. The latter are available in unlimited quantities at constant marginal costs. Associated with each of the supply technologies, there are coefficients describing the costs and the carbon emissions per unit of the activity level. There are upper bounds upon the speed of introduction of new technologies and lower bounds upon the rates of decline of obsolete ones.

To describe the production of exhaustible resources, there are four categories of hydrocarbons: low- and high-cost oil, low- and high-cost gas. Proven reserves are depleted by current production, and are augmented by new discoveries out of the remaining stock of undiscovered resources. The model is formulated so as to incorporate the Hotelling feature of forward-looking depletion policies. That is, the economic rents on depletable resources cannot rise more rapidly than the marginal productivity of capital. The model includes a similar feature with respect to the allocation of carbon rights over time. There are carbon consumption deferral activities that play a key role during periods when the value of carbon rights is rising rapidly. In effect, these variables provide for the *endogenous* allocation of carbon rights between successive periods. This type of look-ahead analysis leads to smoother price trajectories than are characteristic of recursive myopic simulations.

In order to avoid the data-intensive approach that is associated with an end-use analysis for a single country, energy *demands* are divided into just two categories: electric and nonelectric. Along with capital and labor, energy is viewed as a basic input into the economy-wide macroeconomic production function. The growth rate of the labor force (measured in 'efficiency units') determines the *potential* rate of GDP growth within each region. These rates constitute one of the key inputs into the model.

Energy consumption and carbon emissions are closely linked to the GDP, but need not grow at the same rate. Over the long run, they may be decoupled. In ETA-MACRO, these possibilities are summarized through two parameters. One is termed AEEI (autonomous energy efficiency improvements), and the other is ESUB (the elasticity of price-induced substitution between energy and other productive inputs.) In a period of rising international energy prices, both price-induced and non-price conservation will permit a significant reduction in demands. For further details on the model, see Manne and Richels (1992).

2. Business-as-usual and three alternative scenarios for reducing carbon emissions

Many of our b.a.u. (business-as-usual) assumptions are based upon the guidelines for participants in Energy Modeling Forum Study 12. Figure 2 shows index numbers for the rates of population and GDP growth employed in EMF 12. Between 1990 and 2100, world population is projected to double, and GDP to increase by more than nine-fold. These are *input* assumptions to the model. The *output* results include the growth of carbon emissions. Under b.a.u., note that carbon emissions grow almost as rapidly as GDP. As a result of price- and non-price-induced conservation - and also as a result of introducing carbon-free technologies into the electric sector - the carbon-GDP declines from 1990 to 2050. Thereafter, with the exhaustion of conventional oil and gas resources, there is a shift toward coal- and shale-based synthetic fuels. As a result of these offsetting factors, the global carbon-GDP ratio remains nearly constant from 2050 through 2100.

Caveat: These results depend heavily upon the specific guidelines adopted by EMF 12. Suppose, for example, that there had been much greater optimism on the availability of natural gas resources. Since gas has a carbon efficient less than half that of synthetic fuels, there would have been a much sharper decline in the carbon-GDP ratio. Similarly, if we had adopted a greater degree of optimism with respect to the AEEI, there would have been a lower rate of growth of energy demands and of carbon emissions. Each of these numerical assumptions needs to be probed further. One such sensitivity analysis is reported below.

Not only the numerical parameters but also the model structure may affect the cost of carbon limits. Accordingly, the OECD's Policy Studies Branch has defined four alternative carbon reduction scenarios. Each of these scenarios is being examined in parallel by different modeling groups, and the results will be integrated in an overall report. The individual modelers have been asked to begin by projecting the growth of carbon emissions under a business-as-usual scenario. Figure 3 shows the regional distribution of emissions for this scenario. Global carbon emissions increase throughout the 21st century, but the USSR's emissions are reduced in absolute terms between 2030 and 2070. Unlike the other four regions, the USSR's natural gas resources are adequate to support a high level of production during this period.

As of 1990, the industrialized countries (USA, OOECD and USSR) generated about 2/3 of the global emissions total. According to Global 2100, their emissions continue to grow during the 21st century, but those from China and the ROW will increase at a much more rapid rate. The overall result is that the share of the USA, OOECD and USSR drops to only 30% by the year 2100. Clearly, if there is to be a meaningful global agreement, the currently industrialized countries cannot be the only participants. China and the ROW will also have to bear a portion of the burden.

There are many possible ways to allocate a given global reduction between regions. The first three scenarios are specified in terms of the reduction in the *rate of growth* relative to the b.a.u. projections for each region. Under the 1% scenario, emissions in each region are to be cut by 1% per year relative to that region's b.a.u. projection. The next two cases imply a 2% and a 3% annual reduction relative to the b.a.u. case. Table 1 and Figure 4 show the global results of these allocations. Note that the 1% criterion leads to a continuing increase in emissions; 2% implies a modest decline; and 3% produces a sharp reduction. Modelers have also been asked to report on a fourth case - one in which each region's emissions remain constant at 1990 levels. For short, this is described as the "1990" scenario. Together, these four options span much of the range that is currently under consideration by policy makers.

At any given point in time, the first three scenarios lead to regional *percentage* emission shares that are identical to those indicated by Figure 3, the b.a.u. scenario. These allocations guarantee neither equity nor economic efficiency. They are designed principally to explore the technical properties of the models participating in this comparison.

3. The cost of reducing carbon emissions

In assessing the costs of carbon limits, there are two main schools of thought - those who believe in free lunch and those who do not. The first school holds that energy consumers and producers are ill-informed, or are limited in their access to capital for cost-effective conservation and for the supply of renewable forms of energy. Carbon limits will overcome these existing market imperfections through "technology forcing". That is, households and firms will be induced to adopt technologies that reduce carbon emissions and *also* reduce their life-cycle costs. This is sometimes termed a "no regrets" policy. For an exposition of this viewpoint, see Williams (1990).

Global 2100 belongs to the second school of thought. It is based on the assumption that consumers and producers are at least as well-informed as the potential regulators of carbon emissions. There is no free lunch, and a "low regrets" policy is the most that one can hope to attain. If the current system is operating optimally, government mandated limitations on carbon emissions can only lead to a reduction in conventionally measured GDP.

In Global 2100, it is assumed that carbon emission limits are imposed in such a way as to have a *minimum* impact on economic growth. For a market economy, this could be accomplished through auctioning off carbon emission rights. Alternatively, one could limit emissions by imposing uniform taxes upon the consumption of individual fuels. For each region, Global 2100 provides an estimate of the optimal allocation of carbon quotas between sectors - and also the tax rate that is implicit in these allocations.

Figure 5 shows how the USA might fare under the four OECD emission reduction scenarios. For the year 2000, the annual costs lie well below 2% of conventionally measured GDP. Initially, it is optimal to comply with carbon limitations through price-induced energy conservation, but there are diminishing returns to conservation. Post-2000, the losses rise sharply. In the most restrictive scenario, the percentage GDP losses reach a peak of over 4% in 2020. Thereafter, the system overcomes the early bottlenecks in the rate of market penetration of backstop technologies for the supply of electric and nonelectric forms of energy. Demand growth resumes, and GDP losses lie in the range of 2-3%.

Now consider a representative carbon limitation scenario - 2% annual reductions in each of the regions. (See Figure 6 and Table 2.) The level of GDP losses varies from one region to another, but the general pattern remains similar. The OOECD's losses do not exceed 1.5% in any year. The USA is in an intermediate position, and the other three regions incur losses ranging up to nearly 7% of GDP. It is reasonably clear that carbon limitations could impose high costs upon China. The country is likely to enjoy a rapid rate of economic development. Its oil and gas resources are limited, but there are ample supplies of coal available to be converted into synthetic fuels and into electricity - and therefore into carbon emissions.

There is far greater uncertainty in the outlook for the USSR and for the ROW. If perestroika is successful, it is possible that the USSR could achieve a much greater reduction in its carbon-GDP ratio than is projected here. The ROW is an enormously heterogeneous grouping. It includes Brazil, India, Korea, Nigeria and Saudi Arabia. More bottom-up analysis is needed in order to check upon the validity of our ESUB and AEEI assumptions for this group of nations. Global 2100 is designed as a framework for thinking about the cost of emission reductions, but is not intended to provide definitive numerical answers.

The next charts (Figure 7 and Table 3) refer to the *marginal* cost of carbon limitations - the region-by-region tax rates that might be associated with the 2% annual reduction scenario. These time paths are somewhat erratic, but it is often possible to distinguish three phases - first an early period during which the use of emissions rights is deferred, and the value of these rights rises at the same rate as the marginal productivity of capital (about 5% annually, in real terms). There is a middle phase during which there are high costs on the rate of introduction of backstop technologies and an overshoot beyond the long-run equilibrium rate. Finally, there is a terminal phase in which the tax rate is determined so as to make the carbon-free nonelectric backstop activity economically competitive with coal-based synthetic fuels ($208/ton in the four regions other than the USSR). The USSR is a special case. Its gas resources are so great that there is no need to rely upon coal-based synthetic fuels .

Tables 4 and 5 both refer to the 2% scenario. They show the potential impact of international trade in carbon emission rights. This type of trade would promote economic efficiency, but the gains would be modest in all regions but the USSR. Without trade, the USSR's carbon quota would be inadequate to permit the extraction of its vast resources of natural gas, and there could be a high potential value for emission rights during the second half of the 21st century. The import of these rights would permit a significant expansion of domestic natural gas production in place of high-cost nonelectric backstop supply technologies.

4. Sensitivity analysis - alternative demand parameters

There is no single consensus value for the energy demand parameters employed in Global 2100. In this model, there are two parameters that are critical for projecting the long-term options for energy conservation. ESUB measures the long-run elasticity of price-induced substitution between energy and capital-labor. The AEEI (autonomous energy efficiency improvement) measures the annual rate of non-price conservation. Specifically, it is defined as the difference between the rate of growth of GDP and that of energy - assuming that energy prices remain constant over time. For the USA, our base case assumption is that ESUB = .40, and that the AEEI = 0.5% per year. These parameter values are consistent with the 1960-1990 "backcasting analysis" reported in Manne and Richels (1992).

For purposes of this sensitivity analysis, the value of ESUB is doubled in all regions. Alternatively, 0.5% is added to the AEEI. GDP losses are presented for the fourth of OECD's scenarios - the one in which carbon emissions are to remain constant in all regions at 1990 levels. Results for the USA are shown in Figure 8. Those for all five regions are reported in Table 6. Both price- and non-price conservation make it possible to reduce the GDP losses, but these specific variations are *not* sufficient to reduce the losses to zero.

References

A. Manne and R. Richels, 1992 (forthcoming). *Buying Greenhouse Insurance - the Economic Costs of CO2 Emission Limits*, MIT Press, Cambridge, Massachusetts.

R. Williams, 1990. "Low-Cost Strategies for Coping with CO2 Emission Limits", *The Energy Journal*, vol. 11, no. 4, November.

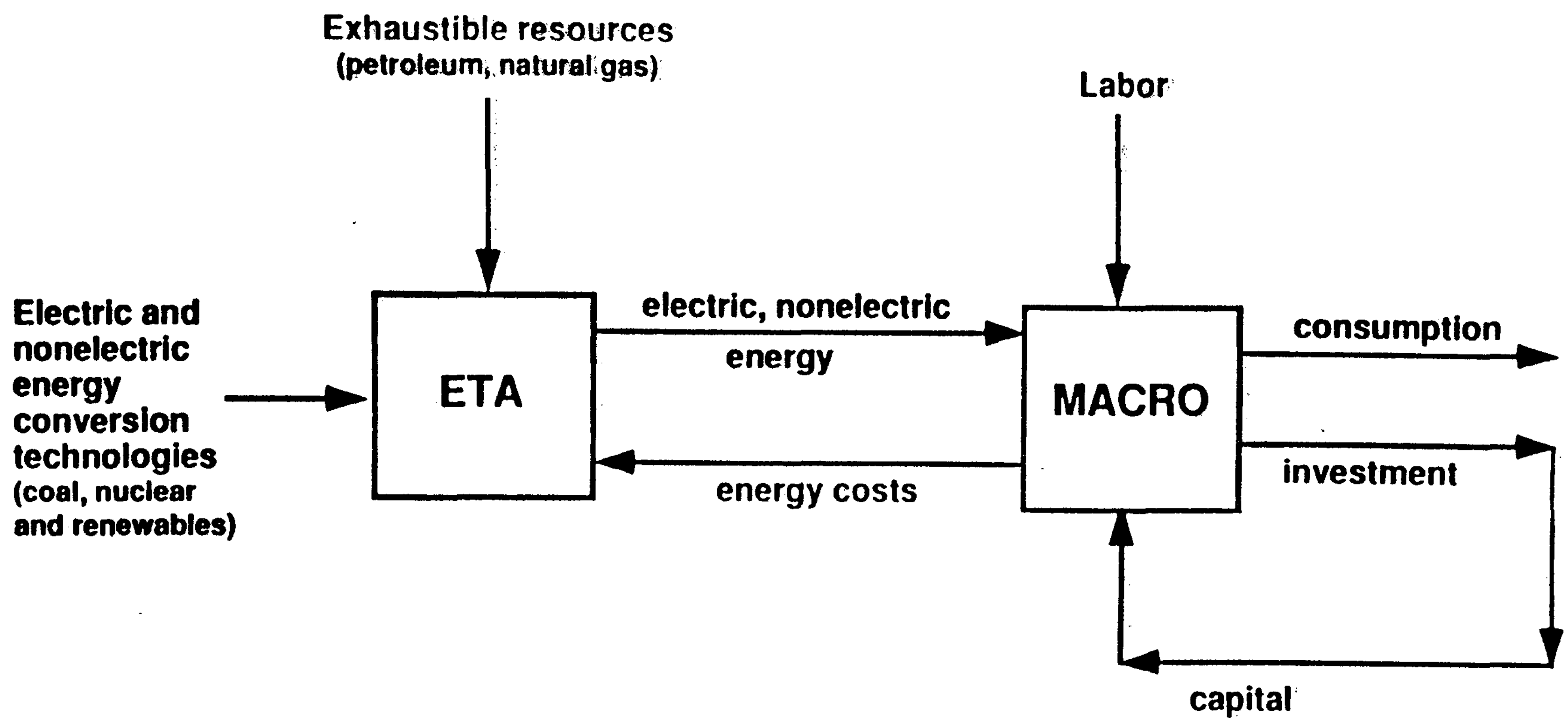


Figure 1 An Overview of ETA-MACRO

Figure 2.

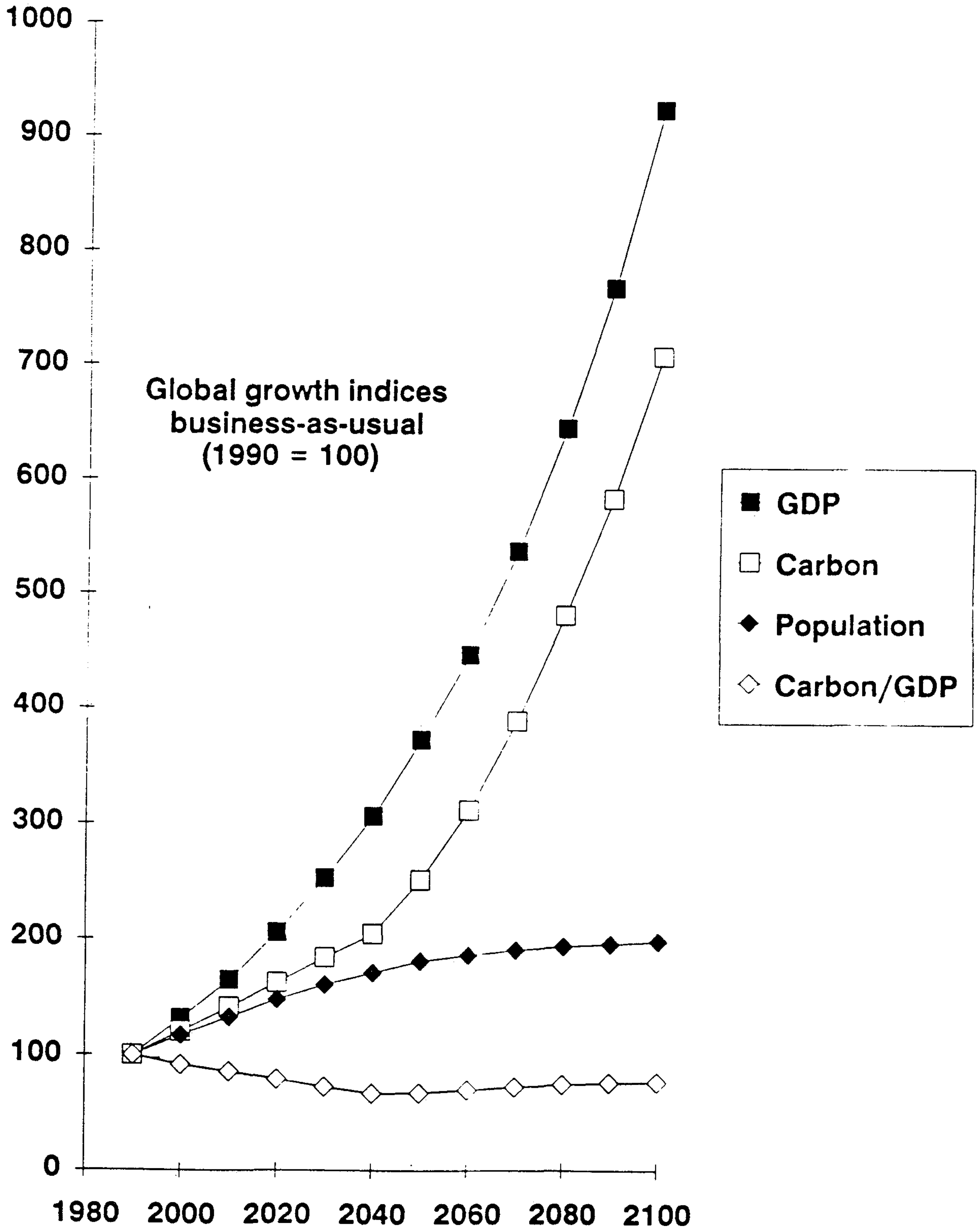
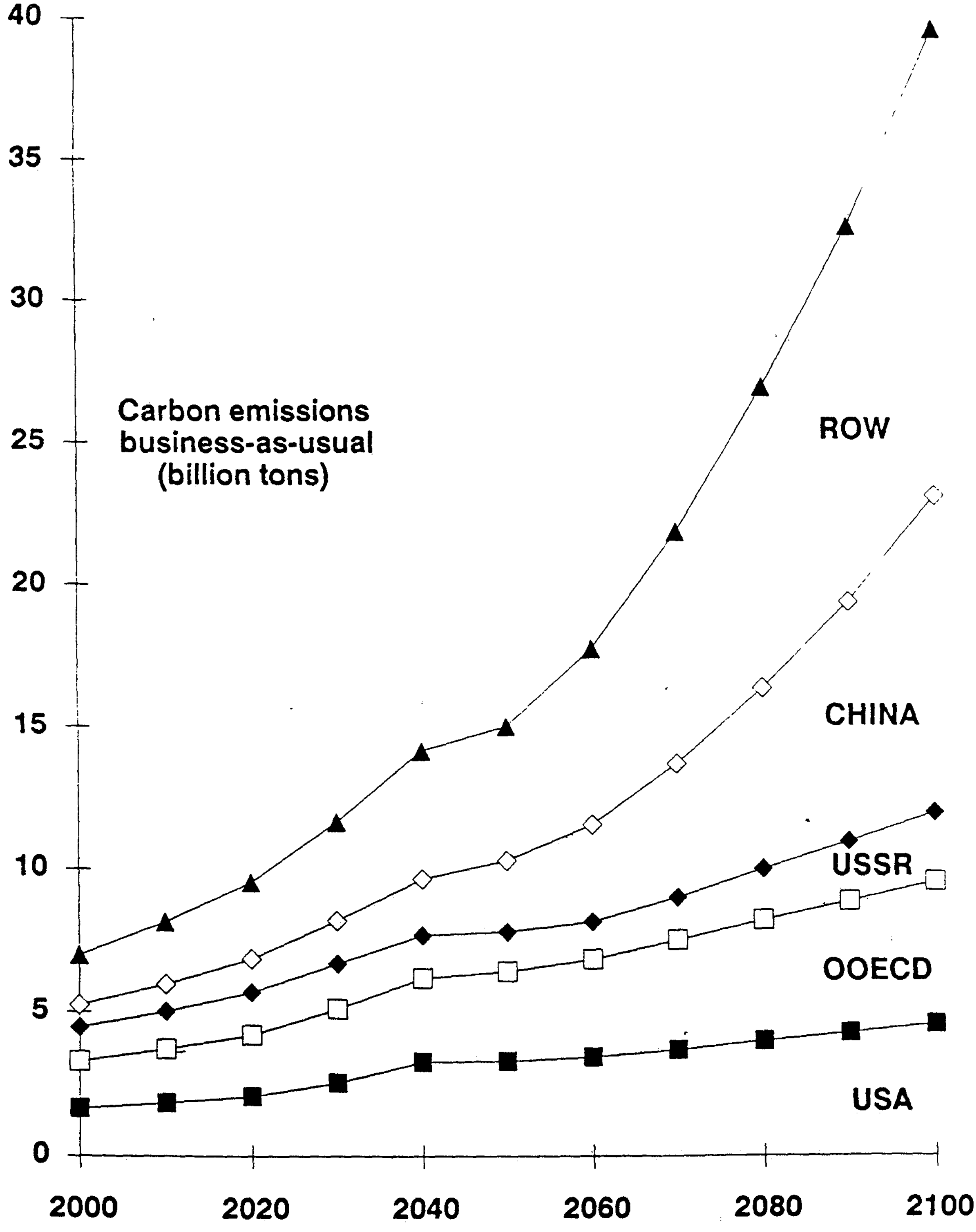
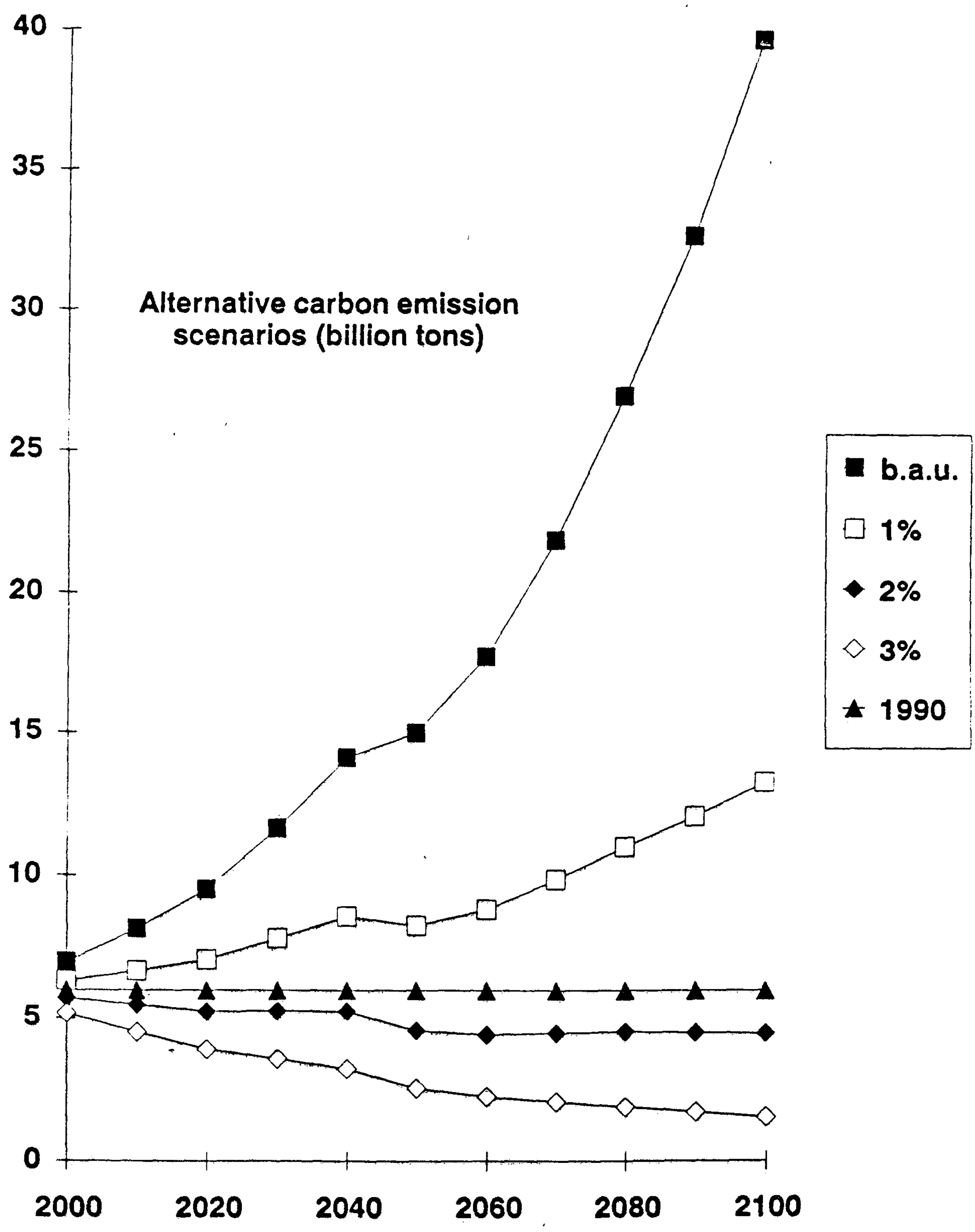

1000
900
800
700
600
500
400
300
200
100
0
Global growth indices
business-as-usual
(1990 = 100)
GDP
Carbon
Population
Carbon/GDP
1980
2000
2020
2040
2060
2080
2100

Figure 3



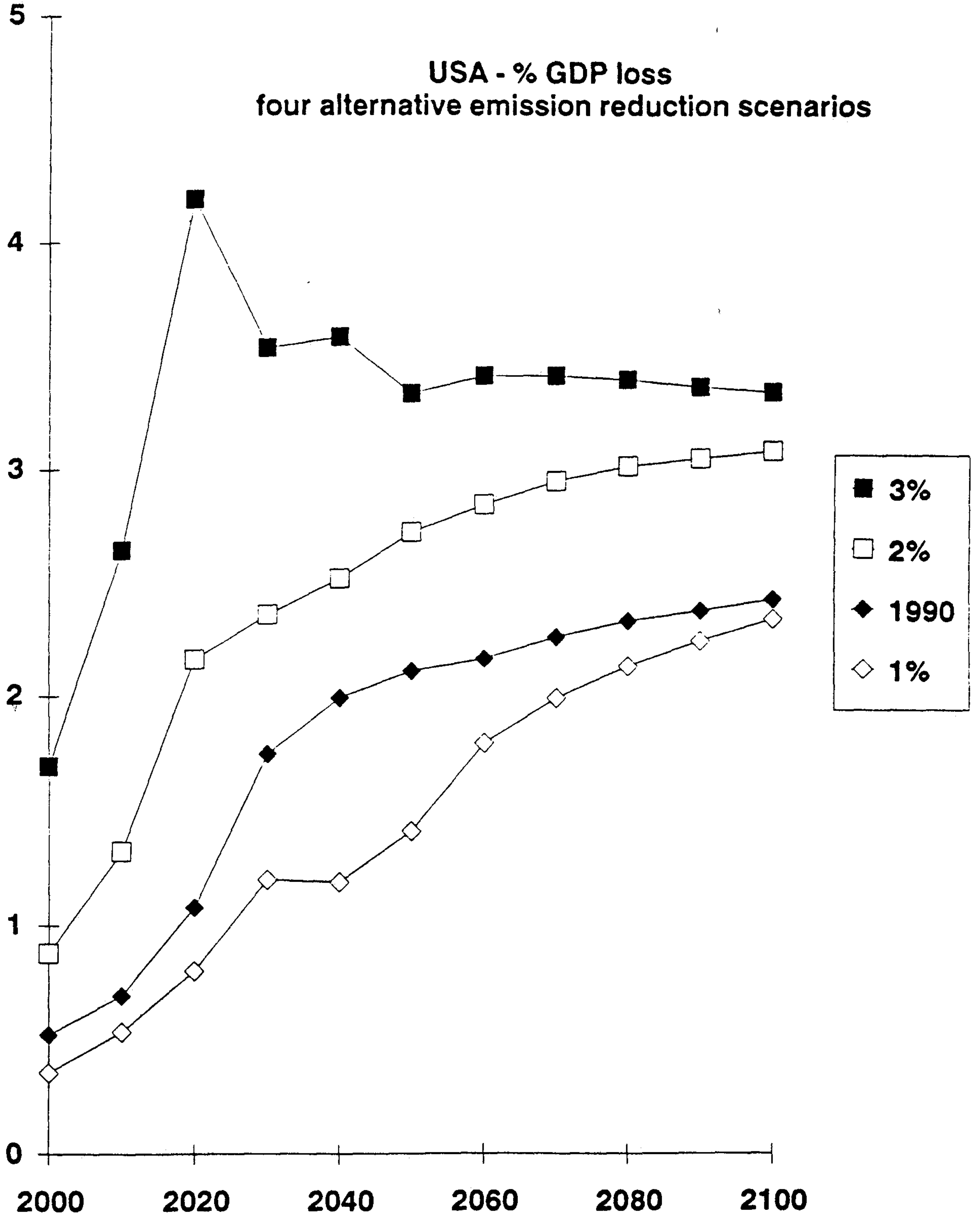
40
35
30
25
20
15
10
5
0
Carbon emissions
business-as-usual
(billion tons)
ROW
CHINA
USSR
OOECD
USA
2000
2020
2040
2060
2080
2100

Figure 4



40
35
30
25
20
15
10
5
0
Alternative carbon emission scenarios (billion tons)
b.a.u.
1%
2%
3%
1990
2000
2020
2040
2060
2080
2100

Figure 5



USA - % GDP loss
four alternative emission reduction scenarios
5
4
3
2
1
0
2000
2020
2040
2060
2080
2100
3%
2%
1990
1%

Figure 6

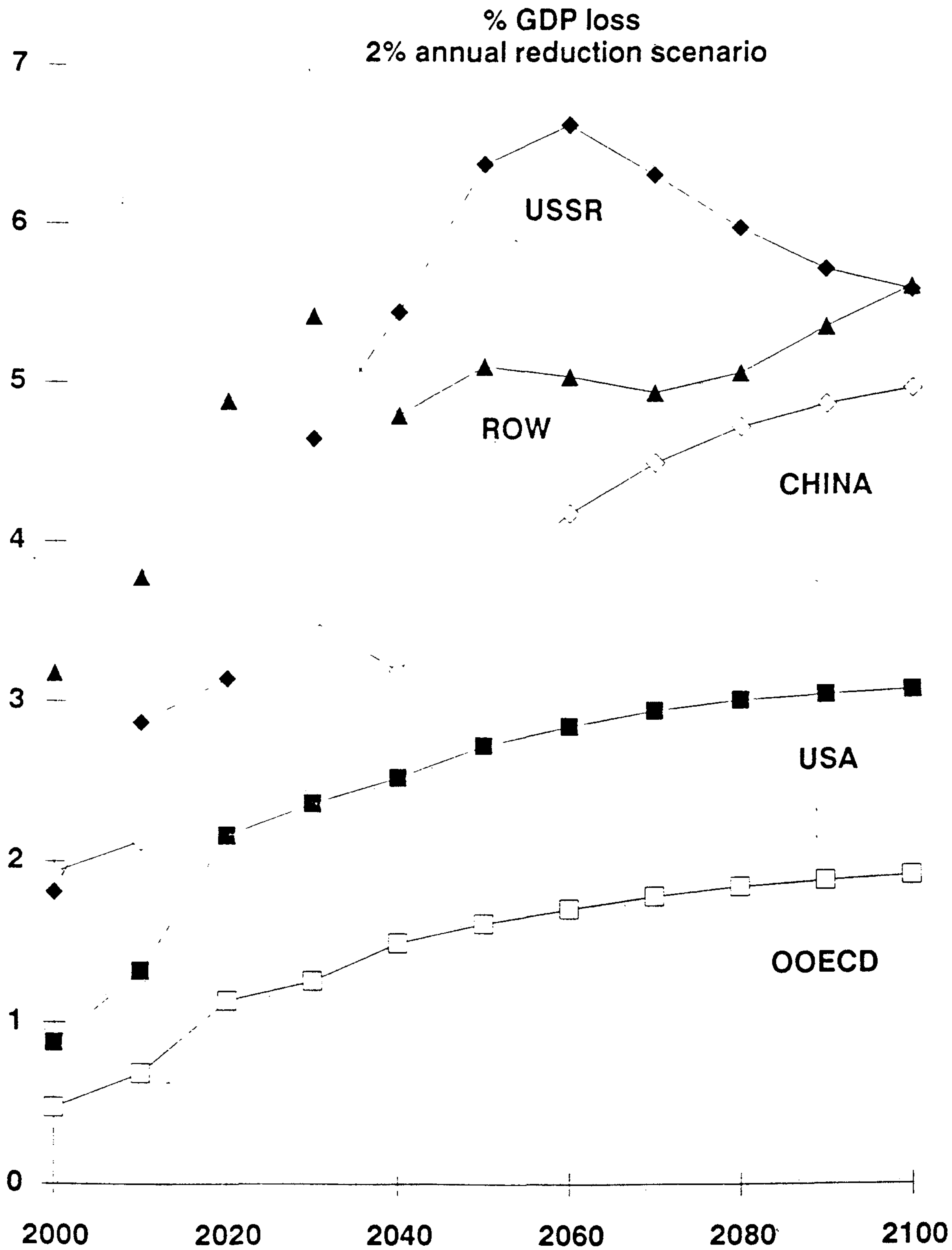

% GDP loss
2% annual reduction scenario
7
6
5
4
3
2
1
0
USSR
ROW
CHINA
USA
OOECD
2000
2020
2040
2060
2080
2100

Figure 7

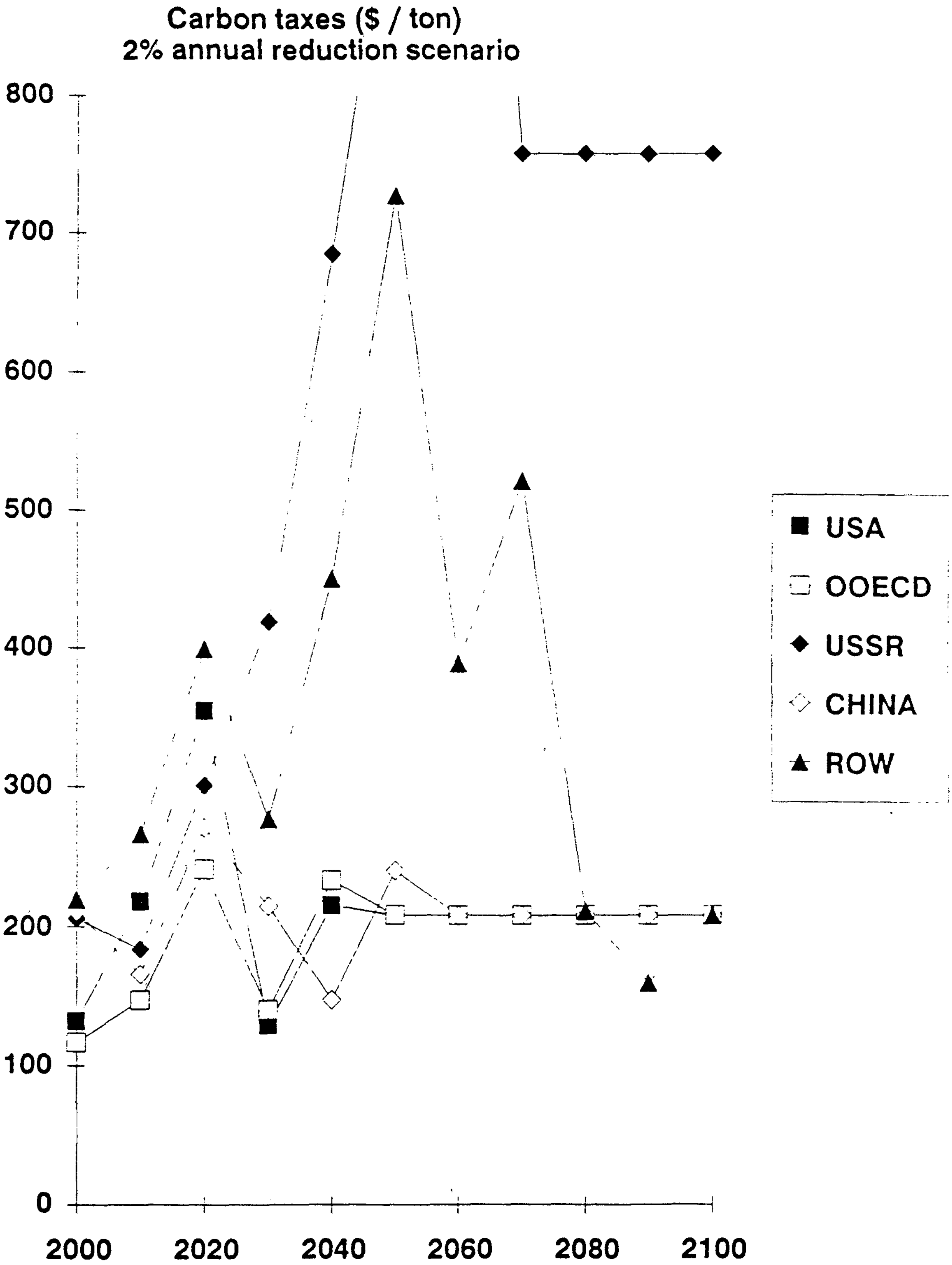
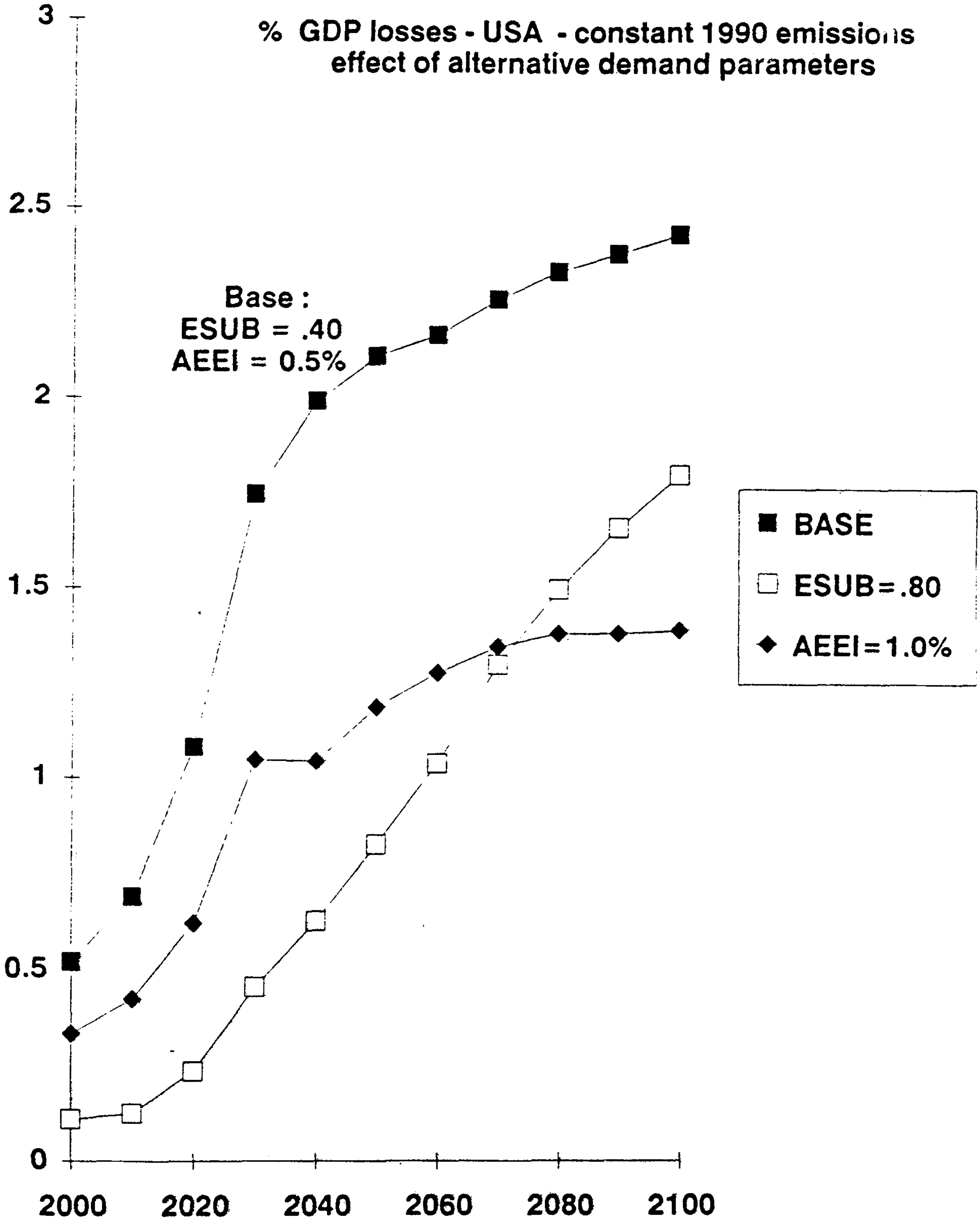

Carbon taxes ($ / ton)
2% annual reduction scenario
800
700
600
500
400
300
200
100
0
2000
2020
2040
2060
2080
2100
USA
OOECD
USSR
CHINA
ROW

Figure 8



% GDP losses - USA - constant 1990 emissions
effect of alternative demand parameters
Base :
ESUB = .40
AEEI = 0.5%
BASE
ESUB=.80
AEEI=1.0%
3
2.5
2
1.5
1
0.5
0
2000
2020
2040
2060
2080
2100

Table 1. Total carbon emissions - billion tons

	USA	OOECD	USSR	CHINA	ROW	TOTAL
Business-as-usual scenario						
1990	1.430	1.375	1.055	.641	1.502	6.003
2000	1.649	1.640	1.184	.754	1.743	6.970
2010	1.850	1.855	1.323	.937	2.189	8.153
2020	2.080	2.115	1.482	1.175	2.668	9.520
2030	2.553	2.555	1.590	1.487	3.456	11.640
2040	3.267	2.906	1.493	1.967	4.489	14.123
2050	3.278	3.129	1.372	2.508	4.704	14.992
2060	3.415	3.425	1.313	3.393	6.178	17.724
2070	3.675	3.816	1.501	4.673	8.195	21.861
2080	3.972	4.221	1.792	6.359	10.600	26.945
2090	4.262	4.600	2.098	8.413	13.285	32.658
2100	4.570	4.988	2.422	11.140	16.517	39.636
1% annual reduction scenario						
1990	1.430	1.375	1.055	.641	1.502	6.003
2000	1.493	1.485	1.072	.683	1.578	6.310
2010	1.516	1.520	1.084	.768	1.794	6.682
2020	1.543	1.569	1.100	.872	1.979	7.063
2030	1.715	1.716	1.068	.999	2.321	7.818
2040	1.986	1.767	.908	1.196	2.729	8.587
2050	1.804	1.722	.755	1.381	2.589	8.252
2060	1.702	1.707	.654	1.691	3.079	8.832
2070	1.658	1.721	.677	2.108	3.697	9.862
2080	1.622	1.724	.732	2.597	4.329	11.004
2090	1.576	1.701	.776	3.110	4.912	12.074
2100	1.530	1.669	.811	3.728	5.528	13.266
2% annual reduction scenario						
1990	1.430	1.375	1.055	.641	1.502	6.003
2000	1.353	1.345	.971	.619	1.430	5.718
2010	1.245	1.248	.890	.631	1.473	5.487
2020	1.148	1.168	.818	.649	1.473	5.256
2030	1.156	1.157	.720	.673	1.565	5.272
2040	1.214	1.080	.555	.731	1.668	5.247
2050	.999	.954	.418	.764	1.434	4.569
2060	.854	.856	.328	.848	1.545	4.431
2070	.754	.783	.308	.958	1.681	4.484
2080	.668	.710	.302	1.070	1.784	4.534
2090	.588	.635	.290	1.161	1.834	4.508
2100	.517	.565	.274	1.261	1.870	4.488
3% annual reduction scenario						
1990	1.430	1.375	1.055	.641	1.502	6.003
2000	1.227	1.220	.881	.561	1.297	5.186
2010	1.024	1.027	.733	.519	1.212	4.514
2020	.857	.871	.611	.484	1.099	3.922
2030	.783	.783	.487	.456	1.059	3.568
2040	.745	.663	.341	.449	1.024	3.222
2050	.556	.531	.233	.426	.798	2.545
2060	.431	.433	.166	.429	.780	2.238
2070	.345	.359	.141	.439	.770	2.054
2080	.278	.295	.125	.445	.741	1.884
2090	.222	.239	.109	.438	.691	1.699
2100	.177	.193	.094	.431	.639	1.535

Table 2. %GDP loss relative to business-as-usual

USA	1%	2%	3%	1990
2000	0.355	0.877	1.696	0.521
2010	0.532	1.322	2.643	0.690
2020	0.801	2.161	4.190	1.079
2030	1.198	2.359	3.533	1.745
2040	1.187	2.517	3.580	1.988
2050	1.409	2.722	3.331	2.107
2060	1.792	2.843	3.408	2.162
2070	1.989	2.945	3.408	2.257
2080	2.130	3.012	3.394	2.330
2090	2.243	3.049	3.362	2.377
2100	2.341	3.081	3.340	2.427

OOECD	1%	2%	3%	1990
2000	0.216	0.472	0.893	0.391
2010	0.347	0.684	1.388	0.484
2020	0.530	1.137	2.072	0.747
2030	0.731	1.257	2.009	1.021
2040	0.767	1.493	2.039	1.205
2050	0.913	1.616	1.959	1.307
2060	1.136	1.707	2.023	1.380
2070	1.255	1.787	2.045	1.464
2080	1.346	1.847	2.083	1.527
2090	1.421	1.887	2.095	1.569
2100	1.489	1.920	2.106	1.609

USSR	1%	2%	3%	1990
2000	0.948	1.810	2.960	1.106
2010	1.164	2.867	4.909	1.352
2020	1.282	3.144	7.285	1.341
2030	1.941	4.645	9.229	1.597
2040	1.884	5.443	8.700	1.008
2050	2.300	6.379	8.484	0.793
2060	3.144	6.626	8.078	0.670
2070	3.501	6.314	7.699	1.116
2080	3.318	5.983	7.386	1.659
2090	3.206	5.722	7.009	2.313
2100	3.200	5.594	6.730	2.869

Table 2 (continued). %GDP loss relative to business-as-usual

CHINA	1%	2%	3%	1990
2000	0.740	1.935	2.968	1.593
2010	0.783	2.127	3.925	2.008
2020	1.125	2.706	5.697	2.803
2030	2.176	3.501	6.359	3.912
2040	1.918	3.190	5.582	3.573
2050	2.219	3.752	5.488	4.047
2060	2.829	4.177	5.453	4.486
2070	3.280	4.497	5.442	4.835
2080	3.538	4.724	5.439	5.060
2090	3.747	4.866	5.415	5.168
2100	3.925	4.970	5.406	5.235

ROW	1%	2%	3%	1990
1990	0.010	0.010	0.010	0.010
2000	1.243	3.182	5.877	2.292
2010	1.059	3.781	8.168	3.013
2020	1.713	4.882	10.796	4.666
2030	2.463	5.420	11.512	5.854
2040	1.797	4.791	8.609	5.064
2050	2.269	5.103	7.835	5.201
2060	2.891	5.036	7.401	5.119
2070	3.597	4.941	6.903	5.245
2080	3.999	5.065	6.614	5.383
2090	4.295	5.358	6.438	5.505
2100	4.531	5.617	6.365	5.689

Table 3. Carbon taxes - $ per ton of carbon

1% annual reduction scenario

	USA	OOECD	USSR	CHINA	ROW
2000	70.830	59.454	163.847	165.047	165.906
2010	76.295	73.293	133.384	57.999	79.350
2020	124.531	120.203	84.449	94.696	126.680
2030	67.173	67.185	139.691	84.747	84.669
2040	111.824	111.850	230.589	93.001	81.344
2050	185.154	185.477	381.630	152.313	132.585
2060	235.444	234.967	633.541	250.708	216.261
2070	208.350	208.422	636.760	208.350	225.327
2080	208.350	208.592	608.085	208.350	208.271
2090	208.350	208.043	608.085	208.349	208.425
2100	208.350	208.434	194.325	208.350	208.353

2% annual reduction scenario

	USA	OOECD	USSR	CHINA	ROW
2000	131.967	116.634	206.239	211.078	219.567
2010	218.187	147.026	184.204	165.837	266.317
2020	354.290	240.740	300.648	270.531	399.302
2030	129.134	140.194	418.410	214.495	276.336
2040	215.337	233.225	684.724	147.639	450.471
2050	208.350	208.350	990.020	239.842	727.050
2060	208.350	208.350	1354.050	208.350	388.819
2070	208.350	208.350	758.146	208.350	521.374
2080	208.350	208.350	758.160	208.350	211.283
2090	208.350	208.350	758.143	208.350	159.494
2100	208.350	208.350	758.152	208.350	208.350

3% annual reduction scenario

	USA	OOECD	USSR	CHINA	ROW
2000	341.414	220.645	238.501	223.971	412.779
2010	387.122	328.114	328.329	276.006	629.278
2020	622.134	449.886	523.576	444.869	815.450
2030	312.096	435.142	695.071	717.987	673.943
2040	125.647	125.439	1147.121	608.085	1123.557
2050	208.350	208.349	1903.226	608.085	1821.803
2060	208.350	208.325	3185.828	608.085	889.599
2070	208.350	345.336	5288.371	608.085	608.085
2080	208.350	567.197	8865.287	608.085	996.364
2090	208.350	566.165	1012.744	608.085	608.085
2100	208.350	566.689	1012.901	608.085	791.778

Table 4. International trade in carbon emission rights - 2% annual reduction sceuario

	Prices	Exports - imports (billions of tons)					
	$/ton	USA	OOECD	USSR	CHINA	ROW	GAP
2000	209	0.038	0.080			-0.043	0.075
2010	191	0.003	0.037		0.025	-0.140	-0.075
2020	308	0.018	0.112	-0.063	0.043	-0.101	0.008
2030	233	0.210	0.166	-0.181	0.031	-0.120	0.106
2040	229	0.529	0.303	-0.300		-0.488	0.044
2050	374	0.648	0.374	-0.725	0.129	-0.585	-0.159
2060	208	0.400	0.400	-0.325		-0.475	
2070	208	0.400	0.350	-0.625		-0.125	
2080	208	0.350	0.300	-0.650			
2090	208	0.300	0.300	-0.600			
2100	208	0.300	0.300	-0.600			

Notes:

1. Between 2000 and 2050, prices and net exports have been determined through the decomposition algorithm described in chapter 8 of Manne and Richels (1992). The year-by-year "gaps" reflect the option of delaying the exercise of carbon emission rights. For the period as a whole, these gaps add up to zero.

2. From 2060 onward, it is supposed that the world economy has arrived at a backstop phase, and that the value of carbon emission rights remains constant. Because of constant returns to scale, there is some indeterminacy in the quantities supplied by individual exporting regions. An informal iterative process has been employed so as to equalize the value of emission rights between regions.

Table 5. Costs of a carbon constraint - with and without trade in carbon emission rights - 2% annual reduction scenario consumption losses through 2100 - discounted to 1990 at 5% per year - trillions of 1990 dollars

	No trade	With trade
USA	1.394	1.305
OOECD	1.319	1.245
USSR	1.357	1.020
CHINA	1.005	0.992
ROW	2.967	2.925
WORLD	8.042	7.487

Table 6. % GDP losses - constant 1990 emissions - effect of alternative demand parameters

USA	BASE	AEEI	ESUB
2000	0.521	0.335	0.109
2010	0.690	0.425	0.125
2020	1.079	0.620	0.235
2030	1.745	1.046	0.456
2040	1.988	1.042	0.626
2050	2.107	1.184	0.824
2060	2.162	1.275	1.035
2070	2.257	1.344	1.295
2080	2.330	1.380	1.495
2090	2.377	1.379	1.656
2100	2.427	1.388	1.794

OOECD	BASE	AEEI	ESUB
2000	0.391	0.267	0.102
2010	0.484	0.343	0.115
2020	0.747	0.478	0.187
2030	1.021	0.628	0.326
2040	1.205	0.647	0.413
2050	1.307	0.741	0.549
2060	1.380	0.827	0.726
2070	1.464	0.894	0.914
2080	1.527	0.931	1.056
2090	1.569	0.942	1.170
2100	1.609	0.955	1.262

USSR	BASE	AEEI	ESUB
2000	1.106	0.797	0.285
2010	1.352	0.862	0.264
2020	1.341	0.617	0.257
2030	1.597	0.529	0.178
2040	1.008	0.306	0.129
2050	0.793	0.171	0.087
2060	0.670	0.117	0.068
2070	1.116	0.106	0.084
2080	1.659	0.126	0.133
2090	2.313	0.193	0.422
2100	2.869	0.243	0.694

Table 6 (continued). % GDP losses - constant 1990 emissions - effect of alternative demand parameters

CHINA	BASE	AEEI	ESUB
2000	1.593	1.255	0.649
2010	2.008	1.447	0.963
2020	2.803	1.684	1.022
2030	3.912	2.453	1.501
2040	3.573	1.970	1.294
2050	4.047	2.566	2.202
2060	4.486	2.983	2.963
2070	4.835	3.222	3.503
2080	5.060	3.346	3.891
2090	5.168	3.347	4.154
2100	5.235	3.340	4.323

ROW	BASE	AEEI	ESUB
2000	2.292	1.693	0.982
2010	3.013	2.556	1.411
2020	4.666	2.784	1.068
2030	5.854	3.484	1.828
2040	5.064	3.328	1.332
2050	5.201	3.260	1.735
2060	5.119	3.369	2.053
2070	5.245	3.407	2.578
2080	5.383	3.440	2.961
2090	5.505	3.399	3.262
2100	5.689	3.462	3.514

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