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ABSTRACT

GROWTH AND WELFARE LOSSES FROM CARBON EMISSIONS RESTRICTIONS:

A GENERAL EQUILIBRIUM ANALYSIS FOR EGYPT*

This paper is an assessment for a particular country, Egypt, of the economic effects, under various conditions, of carbon emission restrictions. Like other work, it is an exemplification of some of the economic possibilities. However, it extends the domain of possibilities and suggests some issues that have not been considered in other studies.

The model is used to assess the sensitivity of the results to alternative specifications: changes in the level of the restrictions, changes in timing of the restrictions, changes in the rate of discount of future welfare and the presence or absence of "alternative" technologies for power generation. Since greenhouse warming is a function of the accumulated stock of greenhouse gases in the atmosphere, a more fundamental specification for the control of greenhouse warming than the limitation of annual emissions is analyzed: constraints on the accumulated emissions of carbon dioxide. The differences between the effects in the "short run" and in the "long run" and their welfare implications are also demonstrated.

It is demonstrated clearly that, while annual emissions constraints have only a modest effect on long run economic growth rates, they have a substantial effect on the achieved levels of GDP and welfare. These results do not change very much even with backstop and unconventional technologies or change in discounting. Postponing the imposition of the constraints does have a significant effect, however, as does changing the form of the constraints to one on accumulated emissions.

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I. Introduction

The analysis of the economic effects of restrictions on emissions of carbon dioxide gases has, with good reason, become a rapidly growing area of research. Although there is still considerable scientific uncertainty about the extent and effects of greenhouse warming, the potential consequences warrant careful examination of the costs of restricting greenhouse gas emissions. The case for such restrictions is considerably strengthened, if those costs are relatively small, even in the absence of a reasonable degree of scientific agreement on their effects. On the other hand, if the costs are relatively large, it is reasonable to require more scientific evidence. If there are to be policy decisions about emissions restrictions, those should be made with as much insight as possible.

This paper is intended as a contribution to the debates. Like all of the other work that has been done, it is an exemplification of some of the economic possibilities, rather than a definitive evaluation. As an exemplification, however, it extends the domain of possibilities and suggests some issues that have not been considered in other studies. It is an assessment for a particular country, Egypt, of the economic effects, under various conditions, of carbon emission restrictions.

The question of the economic effects of restrictions on the annual emissions of carbon dioxide is examined again, in this particular context. However, the model is also used to assess the sensitivity of the answer to alternative specifications of the issue: changes in the level of the restrictions, changes in timing of the restrictions, changes in the rate of discount of future welfare and the presence or absence of "alternative" technologies for power generation. Since greenhouse warming is a function of the accumulated stock of greenhouse gases in the atmosphere, a more fundamental specification for the control of greenhouse warming than the limitation of annual emissions is analyzed: a constraint on the accumulated emissions of carbon dioxide. Because the model has a time horizon of 100 years, but with detailed accounting every five years, it is also possible to be quite specific about with respect to the differences between the effects in the "short run" and in the "long run" and their welfare implications.

II. The focus on a developing country

Egypt is, of course, a developing country; according to the latest World Bank ranking, starting from the lowest level it has the forty-ninth highest per capita income among World Bank members. Countries also differ in the constraints under which they operate: of physical resources, including capital, human resources, technologies, access to markets and foreign debt. Countries also differ in their industrial structure and their use of different sources of energy and of chemicals and processes that contribute to greenhouse warming. All of this means that countries differ in their levels and achievable future goals of per capita income and consumption. As a result, constraints on carbon emissions will have differential impact across countries and even the same impact on output and income would have different welfare effects. Thus emissions policies will finally have to be made at the country level. This implies that for an analysis of the economic effects of emissions restrictions to provide reasonably detailed insights, it should be done at a country level.

By comparison, most of the existing studies of the effects of restrictions on carbon emissions have been global in nature or have focused on large regional groupings. There is an obvious and good rationale for such a wide scope: greenhouse warming would be a global phenomenon and, therefore, calls for a global assessment. The global and major regional models have served the very useful purpose of illustrating the nature of the economic problems in adjusting to emissions restrictions. There must be a clear-eyed recognition of the limits of their usefulness, however.

Experience with developing countries has, moreover, emphasized the importance of embodying their characteristic features in any policy modeling. First, the structures of these economies are quite different from those of advanced industrialized countries and are changing relatively rapidly. As examples, agriculture is much more important and the manufacturing, power and transportation sectors are expanding rapidly with changing technologies. Since the composition of output is shifting, it is important to provide as much sectoral detail as can be accommodated. Thus, analyzing the future effects of emissions restrictions from simple projections of growth rates, either in the aggregate or on a sectoral basis, would generate misleading results. Models that are driven by growth rate projections, by assumption, do not allow for interaction between emission restrictions and economic performance.

A second implication of changing economic structure is that reliance on the assumptions of steady state growth provides a particularly unsuitable approximation for developing countries, whatever the justification for advanced industrialized countries. There are grounds for legitimate differences of opinion as to the usefulness of the steady state growth assumption for the latter group of countries, but it is clearly quite contrary to the intentions and prospects for growth in developing countries.

Moreover, while countries may move into new steady state growth conditions after the imposition of emissions constraints, the adjustment process will, itself, may be of considerable importance and, therefore, deserves to be modeled explicitly. This, in turn, implies that the explicit or implicit characterization of factor mobility among sectors should not make it easier than it is in reality. For example, while the assumption of perfect capital mobility among sectors facilitates the building and computation of models, it is an assumption that will certainly make adjustment appear easier than it is in reality.

It can, in fact, be argued that modeling on the scale of global or regional aggregates will, itself, reduce the apparent difficulties of the adjustment process. Aggregation of sectors implies perfect substitutability of inputs and outputs among the sectors. Aggregation over countries and regions has the analogous implication of perfect substitutability among the countries and regions, an implication that probably would, otherwise, not be defended,except for its convenience in modeling.

III. An economy-wide, intertemporal, general equilibrium model with alternative technological possibilities

The model to be presented below is an intertemporal optimizing model and, thus, is in the same spirit as the approach by Manne and Richels (1989) and Nordhaus (1987) to the analysis of the effects of restrictions on carbon emissions. However, it is sectorally more disaggregated and is more detailed in its capital formation processes. By focusing on a single country, like the Jorgenson-Wilcoxen (1990) and a few other models, it captures some of the idiosyncratic features of the country that affect adjustment processes. Moreover, international agreements will, finally depend on decisions that reflect national policies. In addition, the data base for a national model is more specific and justifiable.

The model is driven by the maximization of a consumer welfare function, so the interactions between constraints, modifications of economic structure and overall are all endogenous and taken fully into account. The economic variables determined by the model are investment, capital capacity and production by each sector, household consumption by sector, energy demand and supply, imports and exports and relative prices. In addition carbon emissions related to fuel consumption are calculated and are subjected to alternative constraint specifications to illustrate various policies.

The basic structure of the model is well-known from previous work by the authors and many others. The complete mathematical structure of the model is presented in an appendix and only those features that are particularly important for its present application will be described here. The model was originally constructed for the analysis of energy policy in Egypt. It was adapted to the analysis of environmental issues since it is relatively detailed with respect to the sources and uses of energy, which, as noted above, is one of the primary sources of environmental offense.

The model used here has a 100 year time horizon, divided into twenty periods of five years each. Although this is a somewhat artificial pacing, it makes it possible to avoid a more detailed formulation of year-by-year interactions and dynamic processes, while still generating a close temporal approximation of growth conditions. The long time horizon provides an ample term for adjustments.

The economy is divided into ten sectors, six of which are non-energy sectors: agriculture, manufacturing, construction, transportation, services and non-competing imports. There are four energy sectors: crude oil, natural gas, petroleum products and electricity.

As noted, the model focuses only on the generation of carbon emissions due to fuel use, although the methods are adaptable to other types of emissions associated with the use of any input or to the output of particular goods with specific technologies. The carbon emissions are calculated for each sector, as well as in total, for each period.

As an optimizing model, it maximizes an objective or welfare function which is the discounted sum of aggregate consumer utility over the model's horizon. The utility of the representative consumer in each time period is a weighted logarithmic sum over all goods of the difference between its consumption of each type of good and a parametrically fixed consumption level. Individual utility is multiplied by the projected population to obtain aggregate utility. This formulation is identical to simulating the market behavior of a representative consumer modeled as a linear expenditure system. It should be noted, in the present context, that environmental conditions do not enter directly into the consumer's utility function or production functions. However, the consumer's choice of goods in the consumption basket will depend on relative prices and income levels, which are determined within the model, and those will be affected by environmental policies.

The usual material balance constraints, which require that the aggregate uses of output can be no greater than the aggregate availabilities, apply in each period. Availabilities depend on domestic production and imports, where the latter is feasible.

One of the most significant features of the model for the purposes of assessing the environmental impacts of economic activity is that, in general, production of each good can be carried out by alternative technologies, or, "activities," with different input patterns. The total output of each sector is the sum of the production from each of the technologies. Thus, there is the possibility of substitution among inputs in production processes. The substitution is endogenously determined, in response to the relative prices of inputs and outputs, which are also determined endogenously. This is important for the analysis of environmental policies that either directly or indirectly affect the cost of inputs.

The alternative requirements for production in each sector are, with one exception, specified exogenously, as if they were taken from engineering specifications. The exception is in the demand for fuels in the manufacturing, electric power and petroleum sectors. In these sectors the BTU requirements per unit of output are specified, but the requirements can be met by using either natural gas or petroleum. Here, again, the choice will be made endogenously, depending on relative prices and any constraints that affect those prices.

In addition to hydropower, only two primary hydrocarbon energy sources are distinguished, crude oil and natural gas, since Egypt uses virtually no coal. Production of each fuel is constrained by availability. Crude oil is produced from petroleum reserves and the creation and use of these and of natural gas reserves is modeled to reflect the fact that the level of reserves is a function of the rate as well as the quantity of use of the resources.and outputs to producers and consumers.

Like a number of other models that have been constructed to investigate the effects of carbon emissions restrictions, the specification of alternative power producing methods includes "back-up" technologies characterized by relatively high capital costs, but with substantially lower amounts of carbon emissions. The back-up technologies are co-generation, gas-powered transportation, nuclear power and a composite technology representing a set of "renewable" energy technologies: photovoltaic, solar-thermal, wind and dendrothermal.

Production also requires labor inputs, whose unit requirements are also specified exogenously, but differently, for each technology or activity in each sector. There is an overall constraint on labor availability and, separately, a labor constraint in the agricultural sector intended to reflect limited rural-urban labor mobility and the tightness of the rural labor market over the past decade or so.

Capital is specific to each sector and is specific as well to the particular technology that it embodies. This creates "adjustment costs" that are an essential aspect of major policy changes such as those envisaged in the imposition of emissions constraints. Capital formation in each period in each sector requires that investment be undertaken in the previous period. Depreciation rates are specified exogenously for the capital stock used by each technology in each period.

Foreign trade is confined to the tradable goods sectors: agriculture, manufacturing, transportation, other services, crude oil and petroleum products. Trade in transport services is specified exogenously. Since,for competitive goods,the model's solutions generate import substitution in some sectors and export promotion in others, constraints are placed on the rate of adjustment in order to simulate real difficulties of these changes that are not otherwise caught in the model. No constraints are placed on the imports or export of non-competitive goods.

The overall balance of payments constraint, that limits imports to what can be paid for from exports and foreign exchange resources, must also be met. Foreign borrowing is allowed, within moving upper bounds.

The problems of establishing initial and terminal conditions in a model of this sort are well-known. Here they are finessed, but in a relatively harmless manner. In the initial period the sectoral levels of investment are constrained not to be greater than those actually achieved in 1987. In the terminal period of the model, 2087, the sectoral levels of investment are determined by the condition that they be adequate to sustain an exogenously specified rate of growth of output in the sector in the post terminal period. Since these terminal conditions create some anomalies in the final periods of the model's time horizon results are reported only for the period from 1992 to 2052.

The features of the model that deal with carbon emissions can be described quickly. The quantity of carbon, V, that is generated by the use of a particular fuel, i, in a technology, k, in a particular sector, j, in period, t, is V_{ikjt}. So the total amount of carbon generated by the use of a particular fuel in the sector is obtained by summing over all technologies:

$$V_{ijt} = \Sigma_k V_{ikjt} \quad .$$

The total amount of carbon generated by the use of the particular fuel in all sectors is:

$$V_{it} = \Sigma_j V_{ijt} \quad .$$

The generation of carbon is related to the use of the particular fuel in the sector by a coefficient, v_{kijt}, i.e.,

$$V_{kijt} = v_{kijt} X_{kjt},$$

where the V_{ik}'s are understood to refer only to the fuel inputs.

These simple relationships are the conventional ones used in projecting the generation of environmental agents. The calculations are completely consistent with all other features of the projected economy, including its growth path, with all interactions being taken into account.

IV. Data base and parameterization

The data requirements to implement the model can be classified into four broad categories: technological relationships, behavioral relationships, miscellaneous exogenous or predetermined variables, and initial conditions. The estimation of these relationships and parameters is described in Blitzer, *et al* (1989) and will be reviewed here only briefly.

The interindustry transactions matrix for the 1986/87 base year was based on a 37 sector transactions matrix for 1983/84 obtained from CAPMAS.[1] The original matrix was aggregated into a ten sector classification, adjusted and updated.

The specific number of production technologies that are provided as alternatives to those implicit in the transactions matrix in 1986/87 varies among sectors. In general, these alternatives allow for substitution between fuels, electricity, labor, and capital. They were derived using a small program which has as inputs: i) the initial technology, ii) the own-price elasticity of energy for the sector; and iii) the sectoral elasticities of substitution between labor and capital, between labor and energy, between capital and energy, and between electricity and fuels. The model also takes the unit demand for fuels as fixed for each technology; but this demand can be met by using either natural gas or petroleum products. At the same time, there are limits placed on the degree to which natural gas and petroleum products can be substituted for each other.

In order to simulate improvements in productivity not associated with increases in capital intensity, such gains were introduced exogenously. An annual increase of 1 per cent in labor productivity was assumed over the entire model horizon.

The parameters of the linear expenditure system used in the objective function were first estimated econometrically, and then adjusted for consistency with the model's base year. Since the consumer demand equations are highly interrelated, a complete systems approach was used for the econometric estimates. The database for estimating these parameters was constructed by pooling cross-section family budget data which was available for two time periods, 1974/75 and 1980/81. On the whole, the expenditure elasticities estimated were within the conventional ranges. However, since the estimates for the energy sectors seemed somewhat unrealistic, elasticity estimates from other sources were relied upon. A Frisch parameter of -2 was used to generate the "subsistence" parameter of the linear expenditure system.

For the specification of changes in fuel efficiency and the capital costs of retrofitting estimates were based on an examination of the readily available literature. These were chosen to reflect cautious optimism as to what is feasible. However, the authors would not attempt a vigorous defense for any of their guesses, but, as noted, represent them only as a plausible means of illustrating the methodology and the general nature of the results that might be expected.

V. Scenarios of emissions reductions

An optimizing model has some advantages and disadvantages in the kind of application to which it is put here. In the analysis of the application of a particular policy to an economy questions are always asked as to the assumptions made about the character of the adjustment to the policy? Is the adjustment an efficient one or do individuals and firms adapt inefficiently? In this model, the adjustment is optimal, in terms of the maximization of the objective function. Moreover, it is done with perfect foresight over the model's time horizon. The implicit assumption is that agents in the economy do not wait until the crisis is upon them, but anticipate the economic adjustments that will be necessary before the actual events overtake them and act efficiently to maximize their welfare.

As is customary in such modeling, a single solution is of less interest than the comparisons among solutions, which provide insights into the problems and opportunities in adjusting to the new constraints. In the application reported on here, the comparison will be between economic outcomes with and without alternative patterns of carbon emission controls. In all cases the solutions are dynamically efficient with respect to the objective function. Therefore, it is less clear, in this case, that the results with respect to the effects of emission constraints should be interpreted as, "optimistic," since the basis for the comparison is also an optimal result.

There are alternatives to the structure presented above for building preferences for lower emissions into a model of the sort presented. Emissions could be introduced into the objective function being maximized, with a negative sign. Or reductions in emissions could be put into the objective function with a positive sign. Solutions could then be found with different weights on the emissions variables in the objective function and the consequences traced out, just as we will trace out the consequences of different levels of constraints.

We believe that this approach would provide less insight than the direct application of constraints on emissions. That is partly because policy is most often discussed in just these terms: what are the economic consequences of constraining emissions? That question can be answered directly from the results of this type of model.

One further issue which must be addressed is the base to which emission reductions are related. Perhaps the approach that receives the most publicity is the stipulation of reductions as a fixed percentage of a base level of emissions. For example, goals are often articulated in terms of a reduction of emissions to a fraction of what they were in some base year. The only virtue of this specification is its simplicity. It can be, but is usually not translated into the size of the net addition to atmospheric stocks of the greenhouse gas. In the calculations to be described below emissions constraints are specified in alternative ways: in terms of reductions in rates of emissions and in terms of reductions in the cumulated net emissions.

Even without actually solving the model we know what the general nature of the results must be, if additional restrictions in the form of lower emissions are imposed. If the constraints are binding, and it is expected that they will be, economic performance measured in terms of the objective function and the related output and income levels will suffer. Only on the assumption that there are costless ways of adjusting to the constraints could the results be different. While there are assertions that there are many and important costless changes that could be put into place,the evidence is slim.[2] Moreover, such changes would be once-and-for-all modifications whose effects are less important than the impact of continuous, compounded growth.

Solutions of the models have been calculated for a number of alternative scenarios of emissions reductions. Most of the alternative solutions reflect different rates and timing of reductions in the rates of emissions. That is true of the scenarios I, II and III, listed below. Scenario IV extends several of the solutions in the previous scenarios, but without discounting the utility generated in each period, in order to help isolate the effects of such discounting in the various solutions. Scenario V investigates the consequences of making "backstop" and "renewables" technologies available for power generation.

The reference for presentation of the results of the alternative scenarios is the Base Solution, in which emissions are not constrained. It should be emphasized that this is different reference from that often used, which is the level of emissions in a single base year. The latter would be a much more restrictive standard. It could be defended for an industrialized country already at high levels of output and consumption. It is less defensible and relevant for developing countries, still at an early stage of their hoped-for transition to income levels that approximate those of advanced economies.

<u>I.</u> <u>To test effects of increasing required rate of emissions reductions with alternative beginning dates</u>

I.1 20% reduction in C_{O2} emissions starting in 1997

I.2 30% reduction in C_{O2} emissions starting in 1997

I.3 40% reduction in C_{O2} emissions starting in 1997

I.4 50% reduction in C_{O2} emissions starting in 1997

I.5 20% reduction in CO_2 emissions starting in 2007

I.6 40% reduction in CO_2 emissions starting in 2007

I.7 30% reduction in CO_2 emissions starting in 2007

I.8 50% reduction in CO_2 emissions starting in 2007

<u>II. To test effects of postponing beginning of emissions reductions</u>

II.1 20% reduction in CO_2 emissions starting in 1992

II.2 20% reduction in CO_2 emissions starting in 1997

II.3 20% reduction in CO_2 emissions starting in 2007

II.4 20% reduction in CO_2 emissions starting in 2012

II.5 30% reduction in CO_2 emissions starting in 1992

II.6 30% reduction in CO_2 emissions starting in 1997

II.7 30% reduction in CO_2 emissions starting in 2007

II.8 30% reduction in CO_2 emissions starting in 2012

These scenarios reflect the common preoccupation with rates of emissions. Since global warming is related to the concentration of greenhouse gases, the accumulation of emissions over the model's time horizon is, fundamentally, of greater environmental interest. Scenario III focuses on this variable.

<u>III. To test effects of reductions in accumulated emissions over entire time horizon</u>

III.1 10% reduction in accumulated emissions over the reported time horizon

III.2 20% reduction in accumulated emissions over the reported time horizon

III.3 30% reduction in accumulated emissions over the reported time horizon

III.4 40% reduction in accumulated emissions over the reported time horizon

III.5 50% reduction in accumulated emissions over the reported time horizon

The role of discounting in the analysis of the effects of greenhouse warming has been the subject of some controversy. There is, consequently, some interest in identifying the consequences of discounting in analyses such as those presented here of the consequences of emissions restrictions, intended to ameliorate global warming. The set of scenarios under IV are intended to elucidate these issues by computing solutions for several of the previous specifications, but with the discount rate set at zero. The comparisons with the results for the cases with discounting of utility then permit isolation of the effects of discounting.

IV. <u>To investigate the consequences of discounting of utility in the objective function</u>

IV.1 Base solution with no discounting of utility

IV.2 30% annual reduction in C_{02} emissions starting in 1992 with no discounting of utility

IV.3 30% reduction in accumulated emissions over the reported time horizon starting in 1992 with no discounting of utility

There has been considerable interest in the potential contribution of "backstop" technologies to the reduction of greenhouse gas emissions. There are a number of such technologies, which have low or non-existent emissions, when in operation, although production of the capital involved will itself generate greenhouse gas emissions. The implications of the potential adoption of two types of such technologies are investigated here. The first type is a relatively conventional set of technologies, co-generation, nuclear power and gas-powered automobiles and trucks. The second type represents more "exotic" electricity generating technologies: photovoltaic power, solar-thermal power, and dendroelectric power. These are summarized in a single representative "renewables" technology. Since these renewables technologies are more speculative, alternative dates of availability are considered in separate solutions.

V. <u>To test effects of conventional backstop technologies</u>

V.1 Co-generation, nuclear and gas-transport and I.1

V.2 Co-generation, nuclear and gas-transport and I.2

V.3 Co-generation, nuclear and gas-transport and I.3

V.4 Co-generation, nuclear and gas-transport and III.3.

VI. <u>To test effects of conventional and renewables backstop technologies</u>

VI.1 Original renewables technology with low insolation levels and I.3

VI.2 Original renewables technology with medium insolation levels and I.3

VI.3 Original renewables technology with high insolation levels and I.3

VI.4 Renewables technology with lowest marginal cost in 2032 with high insolation levels and I.3

VI.5 Renewables technology with lowest marginal cost in 2042 with high insolation levels and I.3

VI.6 Renewables technology with lowest marginal cost in 2052 with high insolation levels and I.3

Not all of these alternative specifications will be reported upon; they are listed to illustrate the variety of policy alternatives of potential interest that can be tested. The results in each case are the full panoply of endogenous variables, which is too much detail to present and more detail than is of interest. The emphasis in the results reported will be on the associated changes in welfare and gross domestic product and total emissions. Other shifts in critical variables that are of particular interest will also be noted.

VI. Characteristics of the Base Solution

The Base Solution, which will serve as the reference to which all the alternative scenario solutions are compared, was computed with the structure and parameters as described above. It is not intended to be a projection of what would actually happen in Egypt, if there were no carbon emissions restriction imposed. Nor does it necessarily represent a set of policies that Egypt should follow. It should, we believe, be regarded as the outline of a path of development that is potentially consistent, feasible and with important desirable attributes in terms of satisfaction of consumer demands.

It will be useful to examine the characteristics of this Base Solution in some modest detail, to provide background for the survey of its differences with the alternative scenarios.

As can be seen in Table 1, the Basic Solution generates plausible growth rates in the macroeconomic variables. It may be recalled that most of the real constraints on the Egyptian economy are represented in the model, including capital and labor availabilities, petroleum and natural gas reserves and the international borrowing constraints. The growth rates of GDP accelerate slowly to 2042 after which they decline somewhat, as a result of the declining reserves of crude oil and natural gas. The initial high rate of growth of investment growth reflects the internal decisions in the model to carry out a substantial restructuring of the economy. The model reacts to the real relative scarcities reflected in the data and parameters that represent the economy, rather than the distorted prices which characterize the initial conditions.

A substantial amount of time is required to restructure the economy and break various bottlenecks, all within the domestic resource and international borrowing constraints. As a result there is some unevenness in the early periods in the growth rates of consumption and investment. The uniform rates of growth of government consumption, which might catch the eye, reflect an exogenous specification.

Table 2 shows the substantial changes which occur over time in the structure of the model economy over time. While there is, in the first fifteen years, a growth in the relative share of the agricultural sector, after 2002 there is a steady decline. This initial growth in agriculture is the result of the relatively

Table 1
Average Annual Growth Rates of Macroeconomic Variables in Basic Solution
(per cent)

	GDP	PRIVATE CONSUMPTION	INVEST-MENT	GOVERNMENT CONSUMPTION	EXPORTS	IMPORTS
1992	3.73	1.95	6.93	2.5	2.25	0.74
1997	3.98	4.78	1.01	2.5	2.79	1.08
2002	3.38	2.72	5.34	2.5	3.73	3.10
2007	4.02	4.02	4.07	2.5	4.55	3.51
2012	4.02	3.56	5.24	2.5	5.09	4.07
2017	4.37	4.24	4.54	2.5	6.10	4.00
2022	4.57	3.84	6.13	2.5	6.78	5.65
2027	5.18	4.85	5.84	2.5	7.19	6.15
2032	5.56	5.18	6.19	2.5	7.55	6.55
2037	5.86	6.35	4.54	2.5	7.64	6.64
2042	5.32	5.25	5.19	2.5	8.13	7.90
2047	4.79	5.30	3.75	2.5	8.33	8.95
2052	4.49	4.94	3.14	2.5	8.48	8.95

high initial demand for manufactured goods to supply the investment that is desired. That also requires relatively large amounts of imports. The relative expansion of domestic agriculture helps make up for a relative reduction in imports of agricultural products. After the system adjusts its capacity to the relative demands, it more obviously seeks out its fundamental comparative advantage.[3]

The share of manufacturing in total GDP grows steadily. The share of construction in the economy reflects the changing share of investment in total output. While the transport sector grows, the intermediate and final demands for its services do not require that it grow as fast as the economy as a whole, so its share declines. The long term decline in agriculture and the expansion of the manufacturing sectors reflects the relative productivity of resources in the two sectors and the relative earnings of the exports of the two sectors.

Table 2
Structure of Production in Base Solution:
Share of GDP (percent)

	AGRICULTURE	MANUFACTURING	CONSTRUCTION	TRANSPORT
1987	0.2096	0.3249	0.0678	0.0734
1992	0.2076	0.3526	0.0850	0.0645
1997	0.2297	0.3518	0.0729	0.0614
2002	0.2325	0.3636	0.0800	0.0583
2007	0.2314	0.3772	0.0794	0.0556
2012	0.2246	0.3865	0.0838	0.0533
2017	0.2213	0.3983	0.0828	0.0503
2022	0.2137	0.4132	0.0878	0.0473
2027	0.2126	0.4299	0.0887	0.0443
2032	0.1986	0.4515	0.0907	0.0422
2037	0.1818	0.4797	0.0845	0.0412
2042	0.1623	0.4996	0.0830	0.0417
2047	0.1464	0.5337	0.0784	0.0408
2052	0.1221	0.5745	0.0716	0.0403

Table 3 presents the share of the energy sectors in total output, which also reflects the changing relative importance of these sectors. The decline in the share of the crude oil sector reflects the growing relative scarcity of crude oil reserves. Although an increase in reserves is built into the specification of the data, it is not sufficient to keep up with the growing demands. A similar pattern exists for natural gas, which also declines relative to the economy as a whole. The forces at work are also demonstrated by the steadily increasing demand for petroleum products, reflected by its increasing share. However, this demand is increasingly satisfied by imports of crude that are refined domestically.

It is interesting to note the declining share of the electricity sector. The high initial level in 1987 reflects, to a considerable extent, the artificially low price in that sector. As the real relative scarcity increases, relative demands fall for about 20 years, after which the changes are modest.

Table 4 presents information on the sources of projected carbon emissions. Three sectors are clearly the most important: Manufacturing, Electricity and Transport. This foreshadows a

Table 3

Structure Of The Energy Sectors in Base Solution
Shares in GDP (percent)

	OIL	GAS	PETROLEUM PRODUCTS	ELECTRICITY
1987	0.0414	0.0087	0.0335	0.0109
1992	0.0301	0.0151	0.0173	0.0091
1997	0.0214	0.0146	0.0146	0.0083
2002	0.0158	0.0146	0.0131	0.0078
2007	0.0118	0.0147	0.0118	0.0074
2012	0.0089	0.0133	0.0127	0.0071
2017	0.0068	0.0100	0.0156	0.0070
2022	0.0052	0.0075	0.0180	0.0070
2027	0.0038	0.0056	0.0199	0.0070
2032	0.0028	0.0041	0.0216	0.0071
2037	0.0021	0.0030	0.0233	0.0072
2042	0.0016	0.0023	0.0239	0.0072
2047	0.0012	0.0018	0.0229	0.0067
2052	0.0010	0.0014	0.0228	0.0066

result that is to come, which is that backup technologies in these sectors, if introduced, will be particularly effective at reducing carbon emissions. The growing importance of emissions from manufacturing is a result of the relative expansion of this sector.

There is an initial fall and a subsequent increase in emissions from the electricity sector which is the net consequence of two factors at work. In the model solution the scarcity price of electricity is higher than it was in the data for the base year for Egypt, when was kept at an artificially low level. As a result of the higher scarcity price, substitution away from electric power use begins to occur immediately in private consumption. It also occurs in production technologies, but at a slower pace, since new capital is required. However, it is also possible to substitute natural gas for petroleum in electricity generation and that begins both to reduce emissions and conserve petroleum for other uses. Since natural gas has fewer carbon

Table 4

SECTORAL CONTRIBUTIONS TO TOTAL CARBON EMISSIONS IN BASE SOLUTION (per cent)

	AGR.	MAN.	PET.	ELEC.	CON.	TRANS.	SERV.	PRODUCTION	CONSUMPTION
1987	0.012	0.210	0.015	0.356	0.044	0.276	0.007	0.847	0.1530
1992	0.015	0.204	0.007	0.278	0.067	0.295	0.008	0.874	0.1260
1997	0.019	0.223	0.007	0.282	0.065	0.276	0.009	0.881	0.1190
2002	0.020	0.241	0.006	0.281	0.076	0.259	0.009	0.993	0.1070
2007	0.021	0.258	0.006	0.277	0.080	0.248	0.010	0.898	0.1020
2012	0.021	0.271	0.007	0.274	0.085	0.233	0.010	0.900	0.1000
2017	0.022	0.295	0.009	0.288	0.081	0.212	0.009	0.916	0.0840
2022	0.023	0.313	0.010	0.295	0.084	0.192	0.009	0.925	0.0750
2027	0.024	0.329	0.011	0.299	0.082	0.175	0.008	0.928	0.0720
2032	0.023	0.348	0.012	0.301	0.082	0.162	0.007	0.935	0.0650
2037	0.021	0.364	0.013	0.301	0.074	0.152	0.007	0.932	0.0680
2042	0.019	0.382	0.014	0.305	0.072	0.139	0.007	0.938	0.0620
2047	0.018	0.380	0.014	0.303	0.072	0.138	0.007	0.932	0.0680
2052	0.015	0.388	0.014	0.302	0.067	0.135	0.007	0.929	0.0710

emissions than petroleum, that also contributes to the initial decline in the share of emissions from electricity. The delayed increase in the share of emissions from the electricity sector is at first to slower growth of output from the sector as increasing real prices in the solution constrain demand. The increases from 2017 onward reflect increasing producer demands, in particular.

The decline in the share of emissions due to private consumption is a relative one. It is influenced by the effects of the higher price of petroleum products that is created in the model, as compared to the market prices that originally prevailed.

VII. Insights from the alternative scenarios

The alternative scenarios provide a rich set of insights as to the consequences of the various forms of emissions restrictions. The macroeconomic consequences are the result of the underlying microeconomic adjustments, which are both intricate and extensive. In this survey, the major consequences will be described with a short rationale provided. In general, as pointed out above, it should not be surprising that with additional constraints, the performance of the economy deteriorates. The demonstration that the form and the timing of the constraints have important consequences for their impact may be of considerable practical interest.

It should be recalled that the first period in the model's solution is 1992. In that period there are many readjustments in the structure of the model economy in the base case model solution, as compared to the initial conditions, even without carbon emissions restrictions. That is because the structure of the Egyptian economy, in the initial conditions, is substantially different from that desired within the model solution. By 1997, there have been ten years of adjustment of initial capital stocks and preparation for the imposition of carbon emissions. By 2007 there have been twenty years of adjustment and preparation for the emissions restrictions and by 2012, twenty-five years of adjustment.

Effects of increasingly restrictive limits on annual emissions

Scenario I imposes different levels of constraints on emission with different starting points. It seems to have become conventional in the modeling of the economic effects of imposing emissions restrictions to report the losses in GDP that result. While there is doubt as to whether this is the most relevant set of observations, it will provide a starting point for analysis of the results.

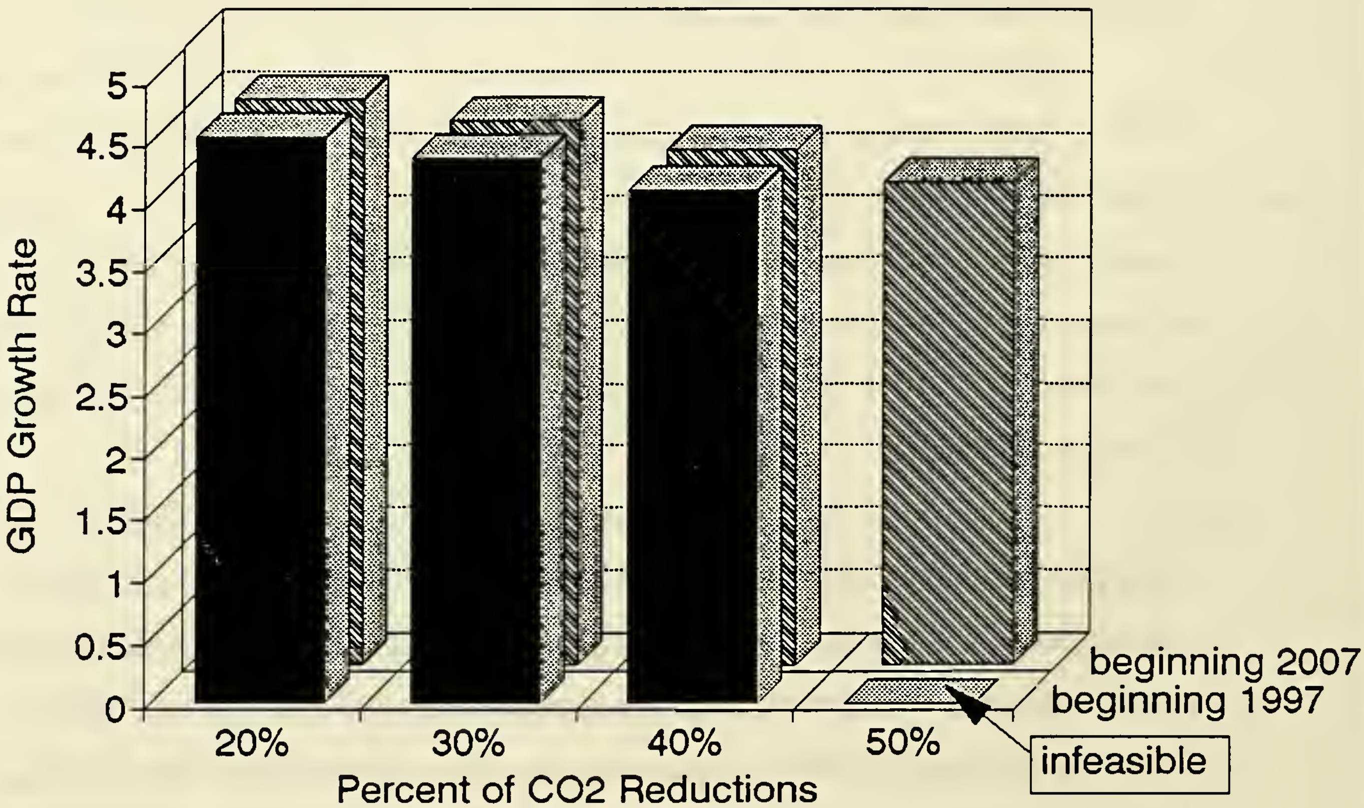
Chart 1 reports the reductions in the overall GDP growth rates due to emissions restrictions, as compared to the Base Solution, with alternative beginning dates for the imposition of constraints. There are discernible differences in the overall growth rates that are achieved, with lower growth rates being associated with higher levels of emissions restrictions and earlier starting dates. However, it is, perhaps, even more striking that the differences in the GDP growth rates are relatively small.

The percentage reduction in GDP is virtually the same for each specified rate of reduction in carbon emissions, whenever

Chart 1

GDP Growth Effects of CO2 Reductions

With Alternative Beginning Dates



that constraint is applied. If the constraint is a 20 percent reduction in carbon emissions, the GDP loss is 4.5 per cent, whether that requirement is imposed in 1987, 1997, 2007 or 2012. If the constraint is a 30 per cent rate of reduction in carbon emissions, the GDP loss is roughly 4.4 percent, whatever the beginning date for policy. If the required rate of reduction is 40 per cent, the GDP loss is always roughly 4.1 percent.

The exception to these generalizations is that the model simply could not find a feasible solution when the required rate of reduction in emissions was 40 per cent beginning in 1987. It should come as no surprise that there are emissions reduction requirements that simply cannot be met, even in this optimizing model, with perfect foresight and efficiency in the allocation of resources.

That low sensitivity of GDP growth to restrictions on carbon emissions would seem to be consistent with the results of other models that have found relatively small losses in GDP from the imposition of carbon emissions restrictions. As will be noted, however, this is a misleading conclusion.

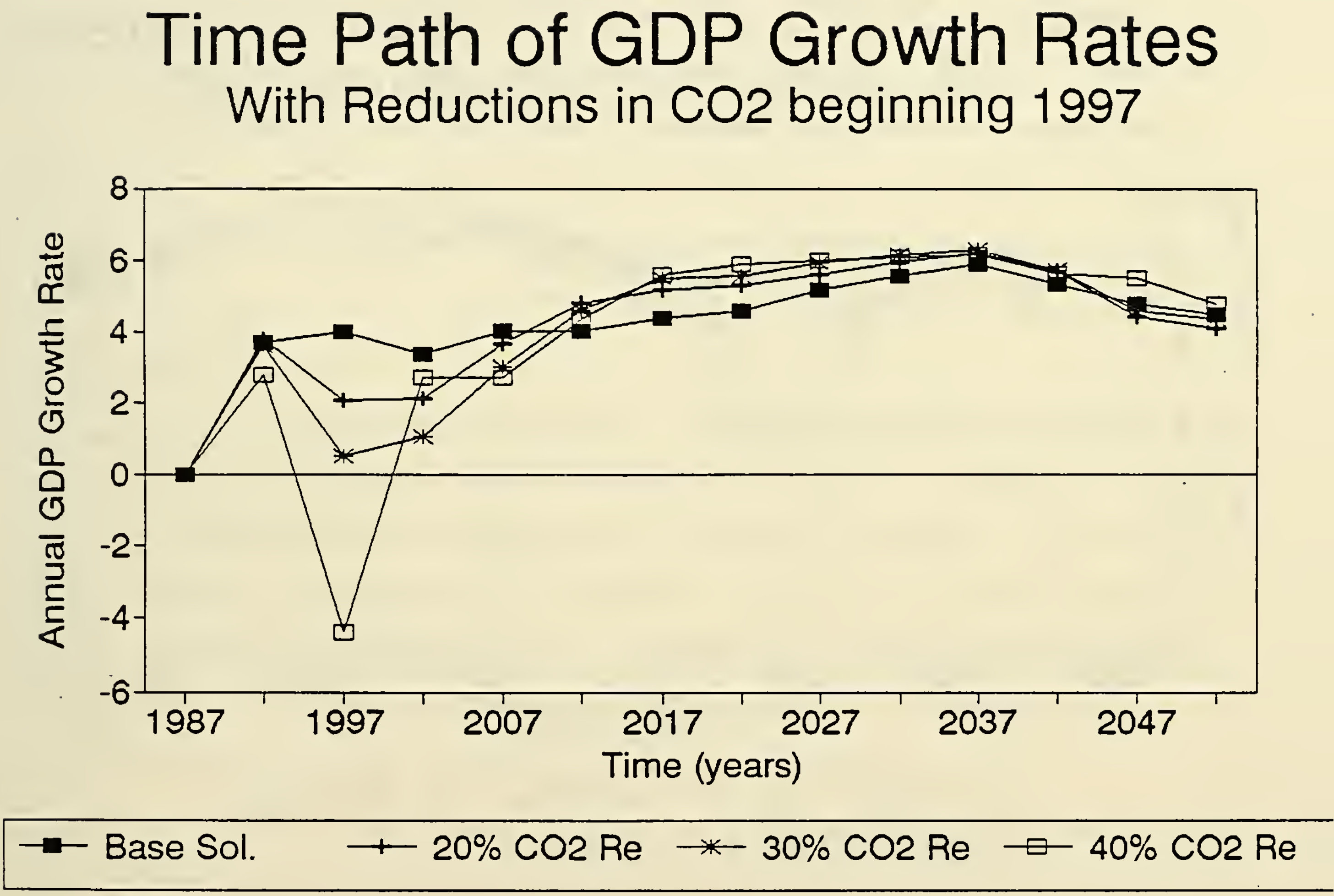
The roughly similar GDP growth losses, for a given level of carbon emissions constraints, with different starting years, are the result of two factors. The first and most important determinant of the results is the very long run horizon of the model. The emissions constraints begin at alternative times, but all begin in the early years of the model horizon. The later years dominate in terms of the GDP growth achievement over the entire horizon cf the model. The second determinant is the fact that, after some initial adjustments in capital stock and labor force, this model uses all the resources available. So the differences in GDP are, in part due only to some small differences in relative prices.

These points are made very clearly in Charts 2A and 2B, which track the GDP growth rates period by period during the entire time horizon of the model for the alternative constraints of Scenario I. The charts illustrate the striking convergence of the growth rates over time.

On reflection, that should not have been surprising. The time horizon of the model is sufficiently long that the solution comes as close to steady state conditions as the exogenously specified economic constraints permit. We know, from our economic theory, that steady state growth conditions are not much affected by constraints such as those imposed on carbon emissions, which can be interpreted as a kind of tax. So the convergence of growth rates should not have been unexpected.

These results show how misleading long run growth rates can be as indicators of the burdens imposed by the carbon emissions restrictions. That is further demonstrated by Charts 3A and 3B in which the time paths of the levels of GDP are presented for the alternatives of Scenario I. These charts show the substantial initial reductions in GDP, relative to the levels achieved in the Base Solution, that occur after the imposition of the

Chart 2A


Time Path of GDP Growth Rates
With Reductions in CO2 beginning 1997
Annual GDP Growth Rate
8
6
4
2
0
-2
-4
-6
1987
1997
2007
2017
2027
2037
2047
Time (years)
Base Sol.
20% CO2 Re
30% CO2 Re
40% CO2 Re

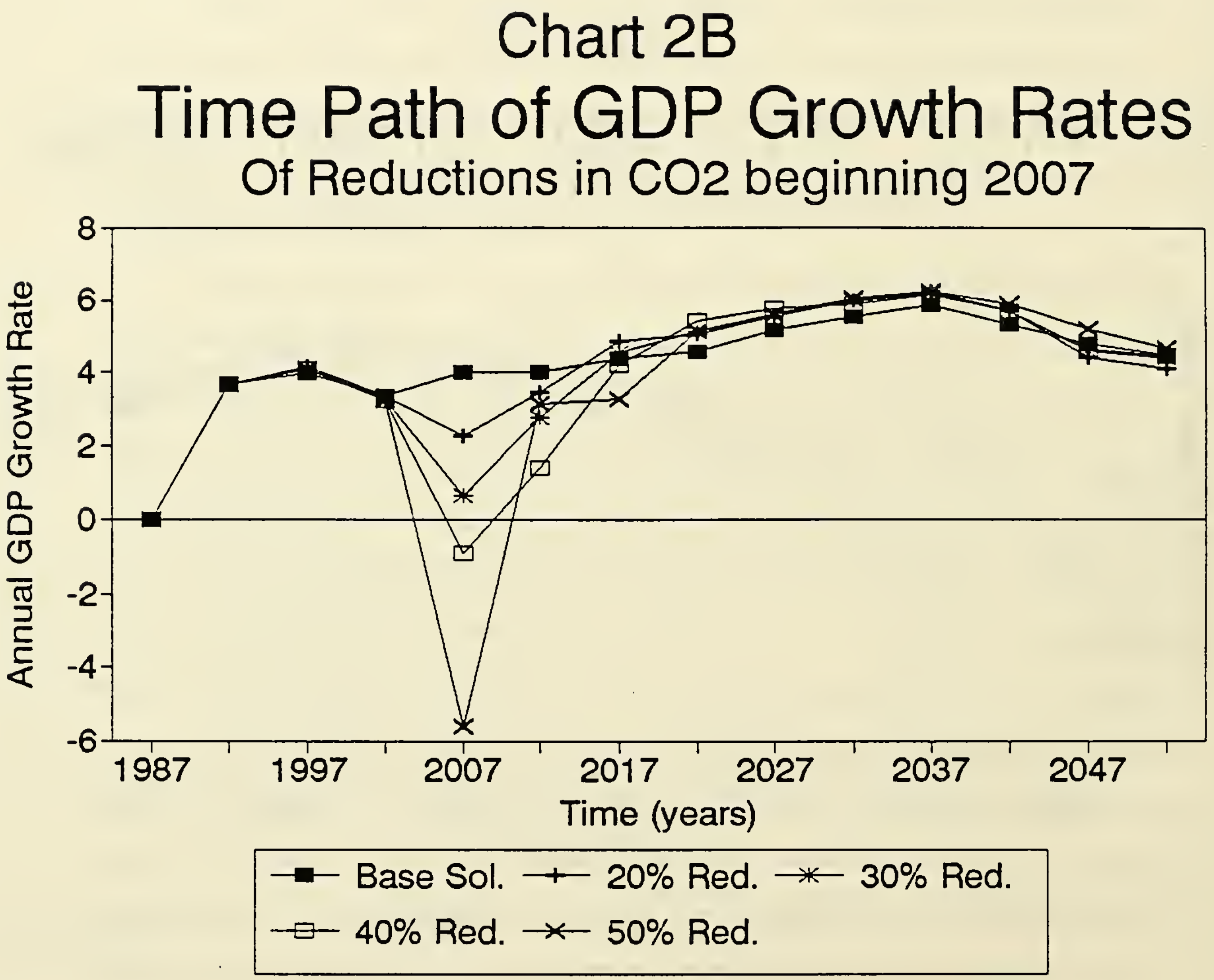


Chart 2B
Time Path of GDP Growth Rates
Of Reductions in CO2 beginning 2007
Annual GDP Growth Rate
8
6
4
2
0
-2
-4
-6
1987
1997
2007
2017
2027
2037
2047
Time (years)
Base Sol.
20% Red.
30% Red.
40% Red.
50% Red.

emissions constraints. The differences in projected achieved GDP levels range from a maximum of about 15 per cent for the case of 20 percent required reduction in carbon dioxide emissions,to almost three times that if the required reduction in CO_2 is doubled to 40 per cent. By 2052 the reductions in achieved levels of GDP, relative to the Base Solution are roughly half the maximum, except for the case of 40 per cent required reductions.

In assessing these results relative to other models,it is important to recall that the emissions reductions are enforced relative to the results of the Base Solution, in which emissions grow over time without constraints. If the limitation on emissions were imposed relative to the emissions levels of 1987, the initial year,the effects of the constraint would be much more severe.

To provide a completely rigorous explanation of the differences between these results and those of other models would require applying the methodologies of the other models to the data of this model or, alternatively, applying this model to the data of the other models. However it is possible to identify the sources of the differences, if not to quantify their significance.

The first point is the one just demonstrated: very long term results, including steady state results, can completely misrepresent the costs of adjusting to carbon emissions restrictions. This would be true of any other model characteristic that mimics long term or steady state characteristics, including

Chart 3A

GDP Reductions Due to Emissions Limits

Constraints Beginning in 1997

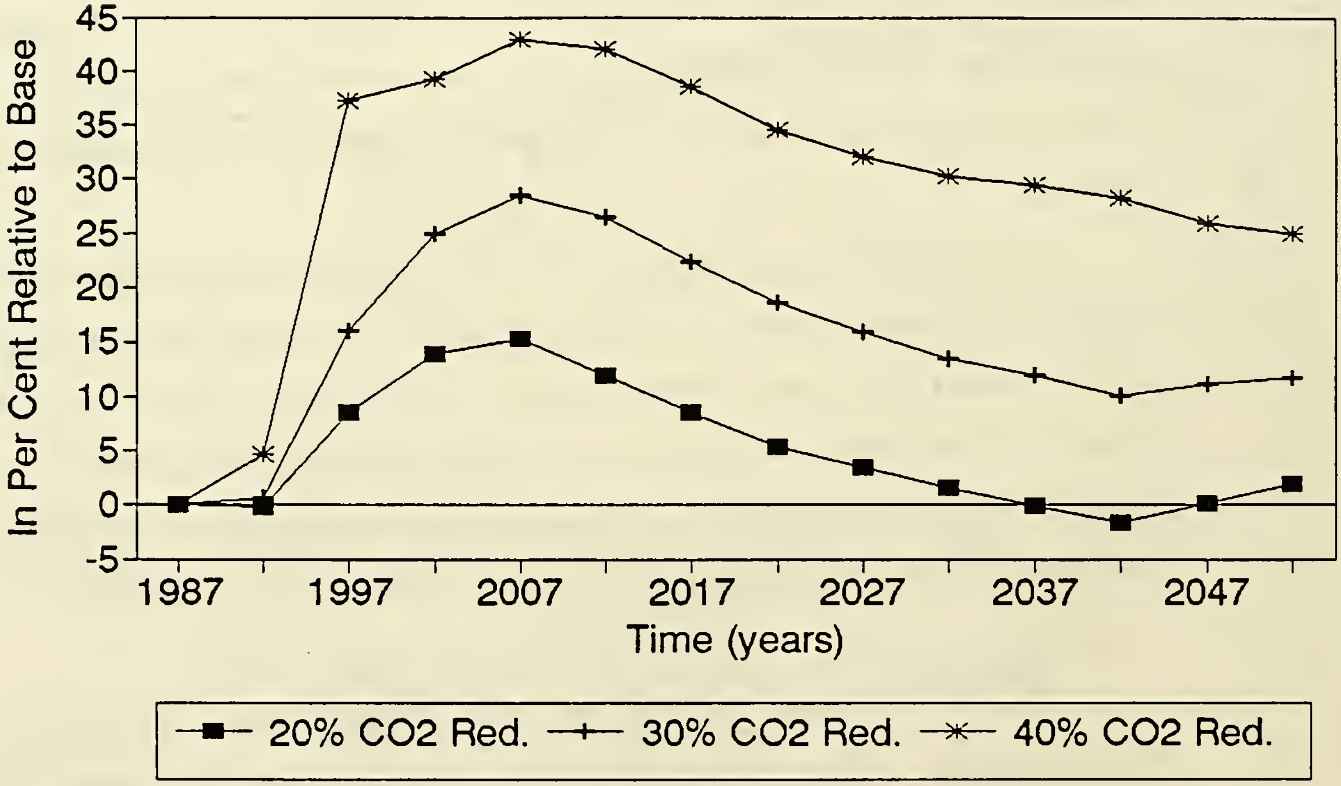
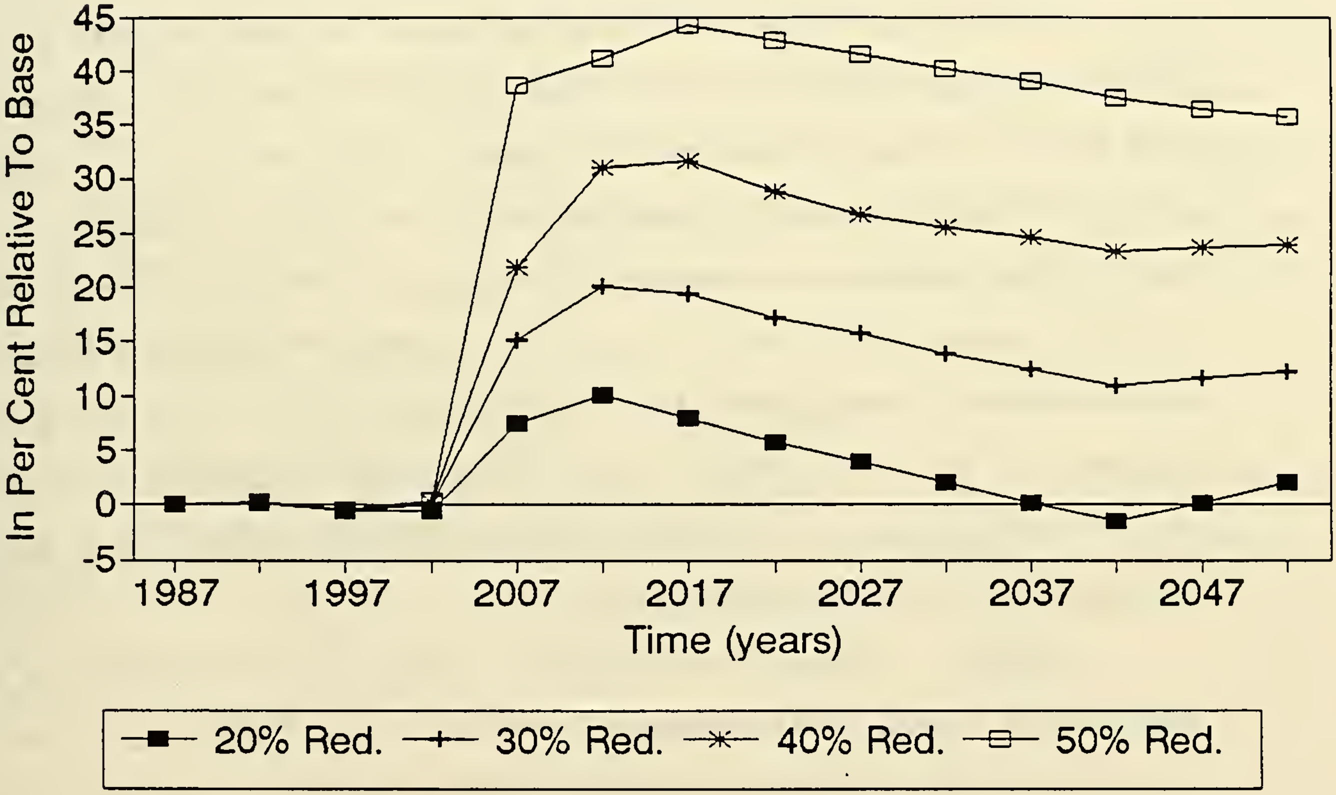


Chart 3B

GDP Reductions Due to Emissions Limits

Constraints Beginning in 2007



assumptions of costless mobility of resources among productive sectors. In this model all capital goods and, to a much lesser extent, labor are not mobile among sectors, which makes adjustment of resources more difficult.

A related point is that this model is relatively disaggregated, as compared to other models used for the same purpose. That means there is less substitutability in this model, since the implicit assumption of aggregation is that all output and resources within a sectoral aggregate are assumed to be perfect substitutes.

Third, Egypt uses petroleum products and natural gas as fuels and virtually no coal. Thus, substitution of the former, and particularly natural gas, for coal, which can be a major type of adjustment to lower carbon emissions in other economies, is already an essential feature of the Egyptian economy. This makes another point, that requiring uniform rates of emissions reductions across economies would be quite inequitable. It would completely ignore their current emissions levels relative to their economic activity, which reflects, among other things, the composition of the fuels they use.

Finally, like many other developing countries, Egypt is a relatively constrained economy, in terms of resources and, because of a substantial international debt which limits their future access to international capital markets.

Changes in gross domestic product are, as is generally recognized, only a rough measure of welfare changes. Since this model explicitly maximizes a welfare function, it is possible to report directly the welfare effects of constraining carbon emissions, as will be done shortly. The welfare function that is maximized in this model is "synthetic" in several senses. Certainly it is not deduced from first principles. Secondly, limitations of data restrict the potential of the econometric methods used to estimate the consumption parameters. Third, the welfare function leaves out any distributional effects that might be associated with the important economic changes being modeled. Finally, all the potential benefits from restricting emissions have been omitted. These would include the direct personal environmental benefits that have been widely, if not unanimously predicted to flow from reducing carbon emissions. The indirect benefits would be the avoidance of the additional real costs imposed of production and infrastructure to offset the effects of any global warming.

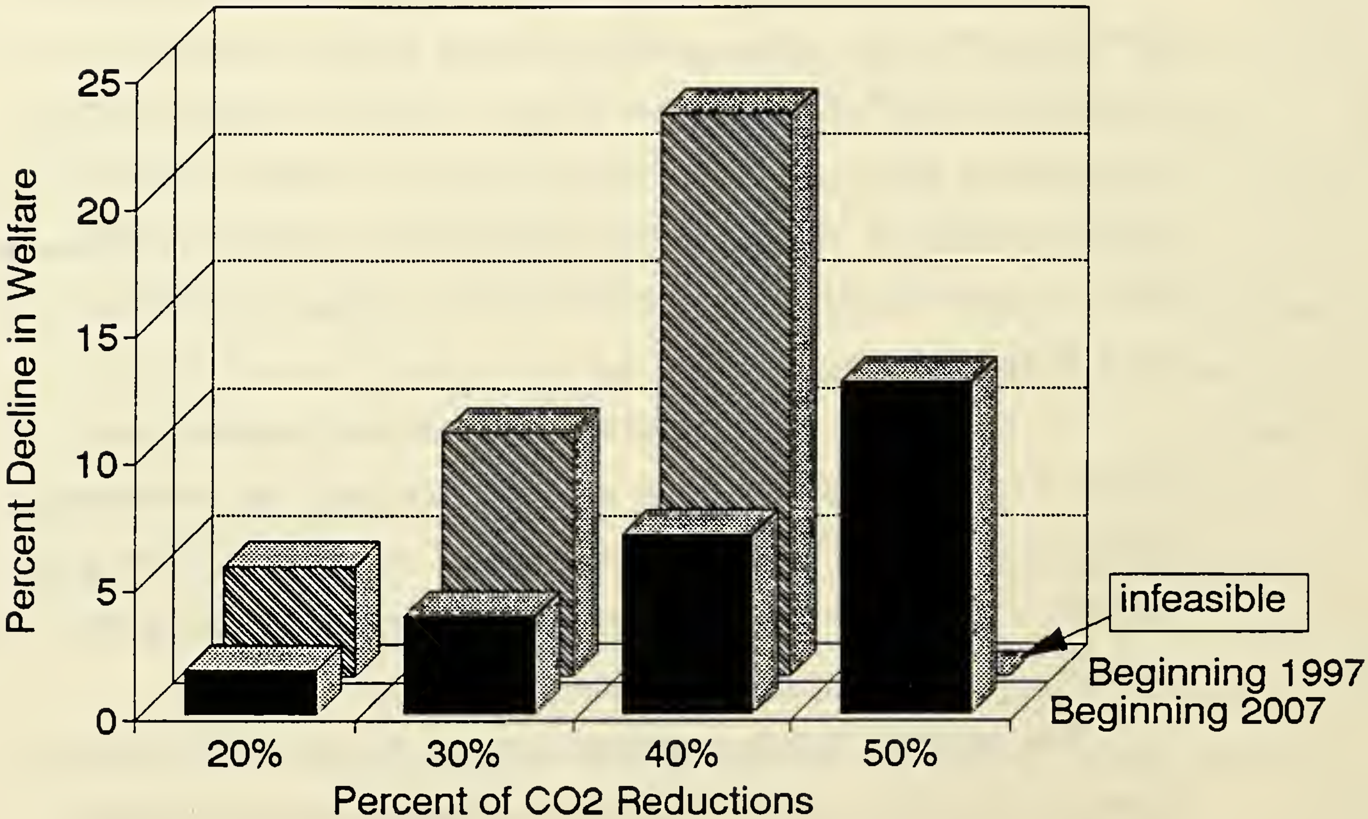
It may offset some natural skepticism if, rather than thinking of the maximand as a welfare function, it is regarded simply as a weighted index of discounted consumption. The particular index chosen is a plausible one, but subject to many disclaimers.

The welfare losses, as compared to the base solution, of imposing different rates of carbon emissions reductions with alternate beginning dates, are shown in Chart 4.[4] If the reductions must begin in 1992, the welfare losses are 4.3 per cent for twenty per cent reductions in CO_2, 9.5 per cent for 30 per cent

Chart 4

Welfare Effects of CO2 Reductions

With Alternative Beginning Dates



reductions in emissions rates and 22 per cent for 40 per cent reductions in emissions rates.

After the imposition of emissions constraints there is, in the long term, some relative recovery of aggregate consumption. However distant consumption carries a heavier discount factor than present consumption, which is suffers most from the process of adjusting to the emissions constraints. The welfare comparisons are, of course, foreshadowed by the comparisons of the achieved levels of GDP.

Postponing the date at which the emissions reductions must begin allows the model more time in which to adjust the sectoral location of its resources and the technologies it uses. The welfare effects are striking. Focusing first on the welfare loss associated with requiring a 20 per cent reduction in emissions rates, a ten year delay in imposing the constraint reduces the welfare losses by about 40 per cent; a twenty year delay reduces by more than two-thirds and a 25 year delay would reduce the welfare losses by almost 80 per cent, to less than two per cent of the base year total welfare.

As a visual inspection of Chart 4 reveals, the effects are quite nonlinear with respect to both the magnitudes of the required reductions in carbon emissions and with respect to timing. The elasticity of welfare, with respect to emissions reductions is .02 at the 20 per cent required rate of reductions, .32 at the 30 percent required rate of reductions and .55 at the 40 per cent required rate of reductions.

It should also be noted that this model tries its best to use all the resources available to it, whether for consumption or investment. Adjustment to emissions constraints forces the redirection of resource allocation with consequent changes in relative prices. For the most part, however, resources are fully employed. So the GDP effects of adjusting to emissions constraints will, to a considerable extent, show up mainly as the effects of changing relative prices.

These results clarify a somewhat troubling issue. For example, William Nordhaus, in discussing projections of relatively high short run costs of reducing emissions of carbon dioxide, says, "Note, however, that the short run gradually turns into the long run so that the high short run costs of a surprise increase in prices soon becomes the lower long run costs."[5] That is, of course, true. But, the high short run costs create high welfare losses, as indicated in Charts 3 and 4 above and those welfare losses do not go away.

The losses are not simply the result of a, "surprise," increase in prices, since in none of solutions described above are the emissions constraints a, "surpise." In one set of solutions the model has five years to adjust before the constraints are imposed; in another set, there are ten years prior to the imposition of emissions constraints. In both sets the future imposition of the constraints is perfectly foreseen.

The losses come about because there are costs of adjustment and because the constraints require the use of different technologies and different resource and output allocations that are less efficient than those without the constraints. That is not to say that the benefits in future climate conditions may more than offset the costs. However, the present game is simply the calculation of costs.

Turning to other aspects of the Scenario I solutions, Chart 5 shows the impact of those constraints on the sectoral patterns of output over the model's time horizon. In all cases there is a shift away from manufacturing, transport and electricity generation, as these have relatively high carbon emissions ratios. The model solution compensates in two ways: first by substituting the output of other sectors against the output of these high emitting sectors when that is possible, in response to the endogenous increase in the prices of these two sectors. Second, by increasing the imports of manufactures, noting that imports of transport and electricity are not possible.

In the Base Solution, the model shifted resources out of agriculture. In the solutions shown in Chart 5, when the emissions reductions are 20 percent, there is an increase in domestic agricultural production, as compared to the base solution. That is an aspect of the substitution mentioned above. Since agriculture, relatively, has low emissions, the model increases its domestic production. The foreign exchange resources that had been used to import agricultural goods are now used to import manufactures. These adjustments demonstrate the effects of the emissions restrictions in changing comparative advantage. They

Chart 5A

Sectoral Growth Effects of Reductions in CO2 beginning 1997

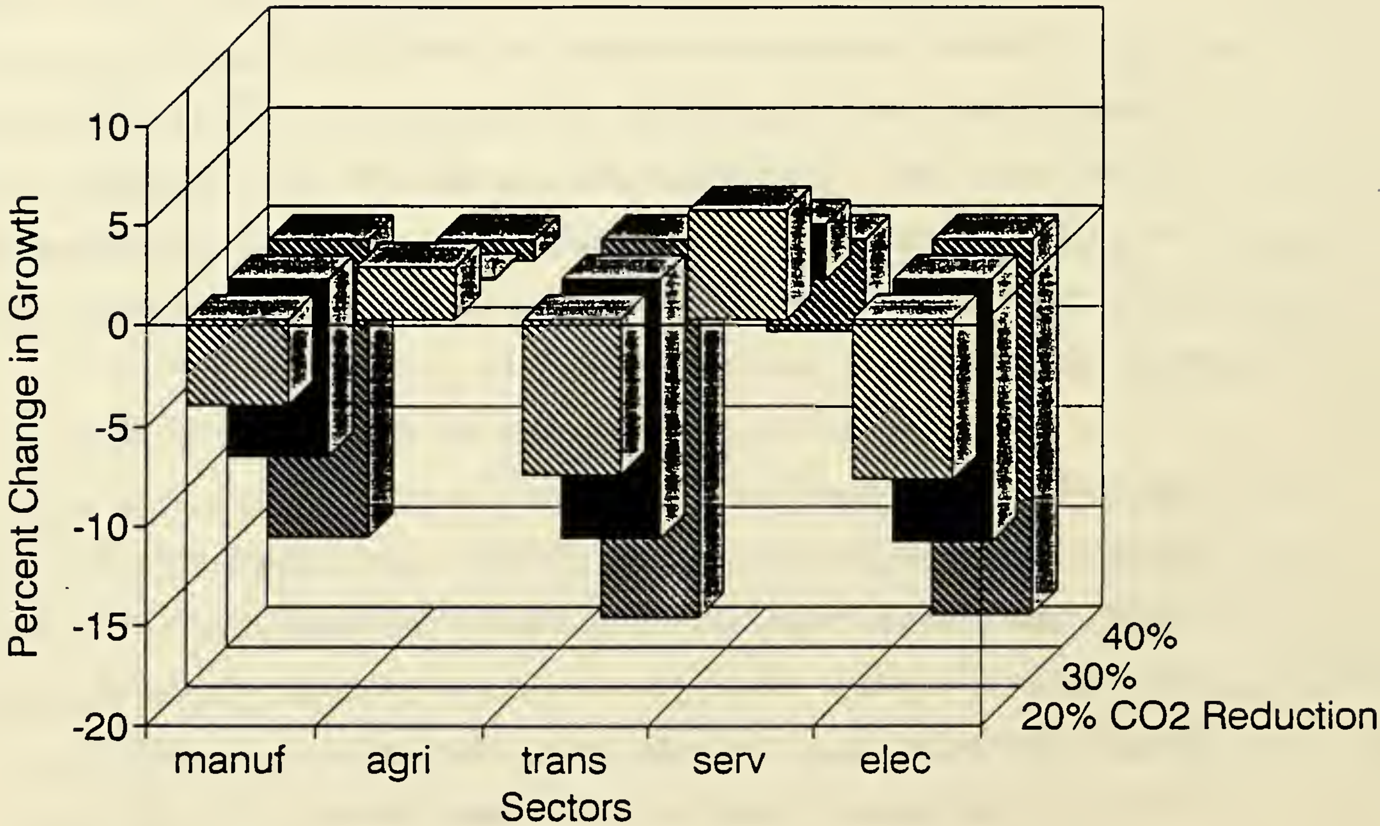
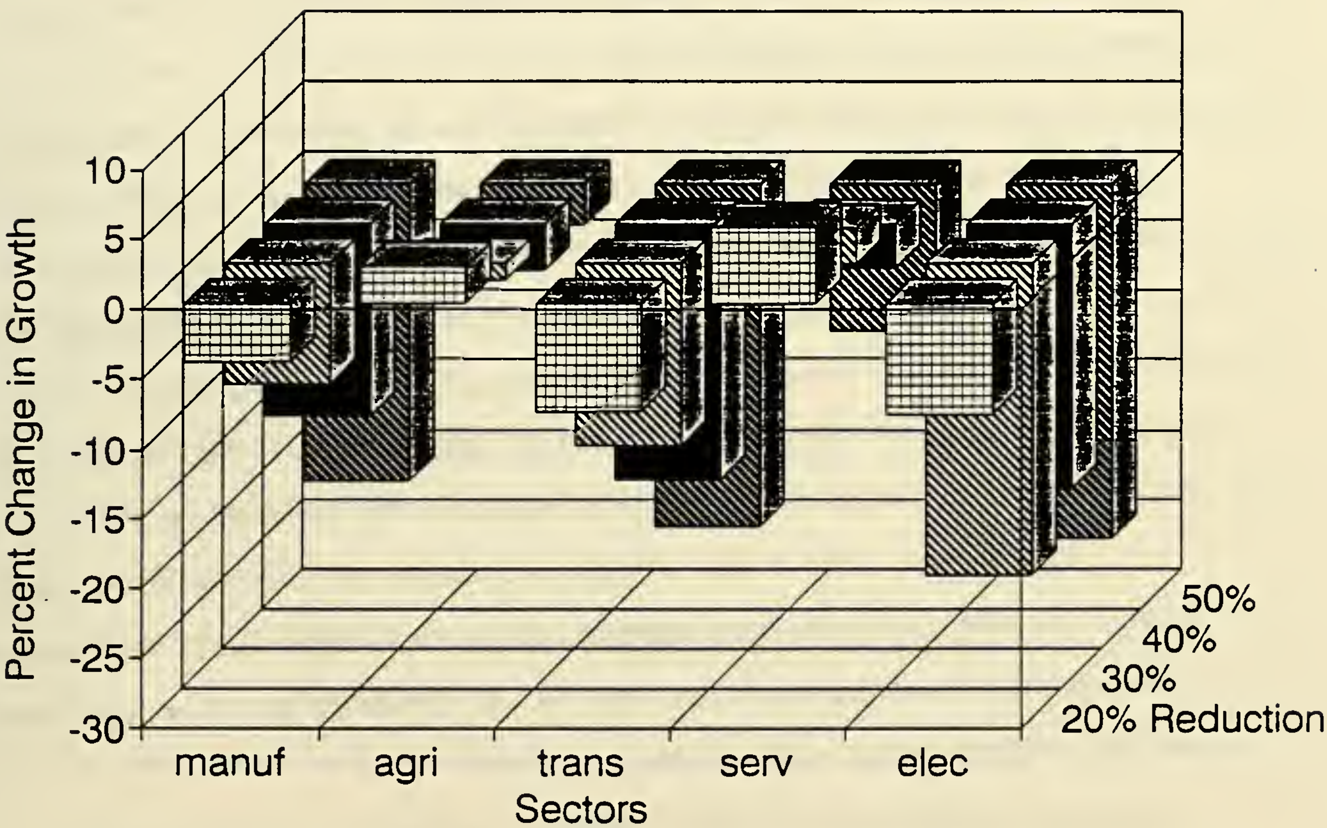


Chart 5B

Sectoral Growth Effects of Reductions in CO2 beginning 2007



also show the natural tendency to follow a, "dirty thy neighbor," policy by importing products whose production generate a relatively large quantity of unwanted emissions and producing relatively clean products at home.

Chart 5 also indicates that when the rate of reduction of emissions is increased to 30 per cent and above, the increase in agricultural production is much less than at 20 percent carbon emissions reductions. This is the result of the increased difficulty in the economy of maintaining production under the emissions constraints. At 40 percent carbon emissions reductions, even agriculture must contract.

Chart 5 shows similar changes for solutions of the model for which the starting date for the reduction in emissions is 2007, again with alternative degrees of reduction in emissions rates. As noted above, in all cases there is a shift away from dependence on petroleum toward increasing use of natural gas, which has lower carbon emissions rates per btu. That adjustment is limited, however, by the availability of natural gas reserves.

There are many other subtle adjustments in the model solutions in the patterns of exports, imports, borrowing, investment allocations, and so on. These are passed over here as incidental to the main points made above.

Effects of postponing constraints on annual CO_2 emissions

Scenario II was designed to explore further the effects of postponing the beginning of the emissions restrictions. The time paths of GDP associated with alternative rates of emissions restrictions and alternative beginning dates for the imposition of the restrictions are shown in Charts 6A, 6B and 6C. It is clear that postponing the emissions permits higher levels of GDP. Chart 7 shows the welfare reductions associated with the different alternatives of Scenario II. Again, welfare losses are reduced by this postponement.

There are three major reasons for these results of Scenario II. Postponing the beginning of the emissions restriction allows the model more time to adjust the technologies in use and the structure of capital to the emissions restrictions. That is particularly important for the earlier and larger emissions restrictions. In addition, postponing the emissions restrictions simply allows more time for the model to produce closer to its, "business as usual," patterns. That means there can be more consumption in the earlier years of the model. Finally, it should be remembered that any losses in the near future have a heavier weight in the maximand than losses in the more distant future simply because since utility is discounted. The effects of discounting will be explored in Scenario IV.

Effects of constraints on accumulated emissions

The scenarios listed under III may seem to be hardly different from those specified previously. However they imply a major shift in policy. Rather than stipulating changes in the rates of emissions, they stipulate changes in the accumulated emissions over the entire model horizon, relative to the accumulated emissions in the base solution in which emissions are not

Chart 6A

Time Path of GDP Reductions

Due to a 20% Reduction in CO_2

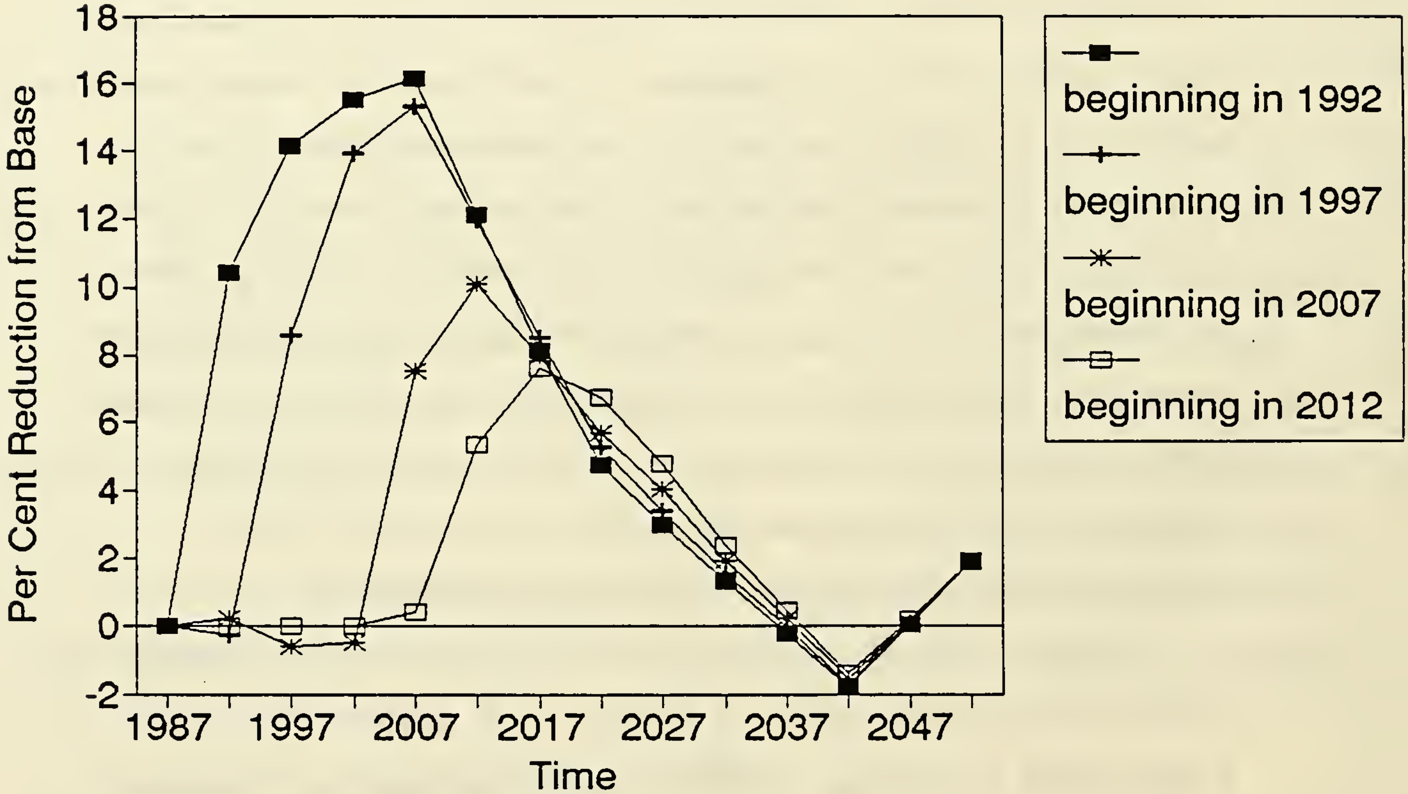


Chart 6B

Time Path of GDP Reductions

Due to a 30% Reduction in CO2

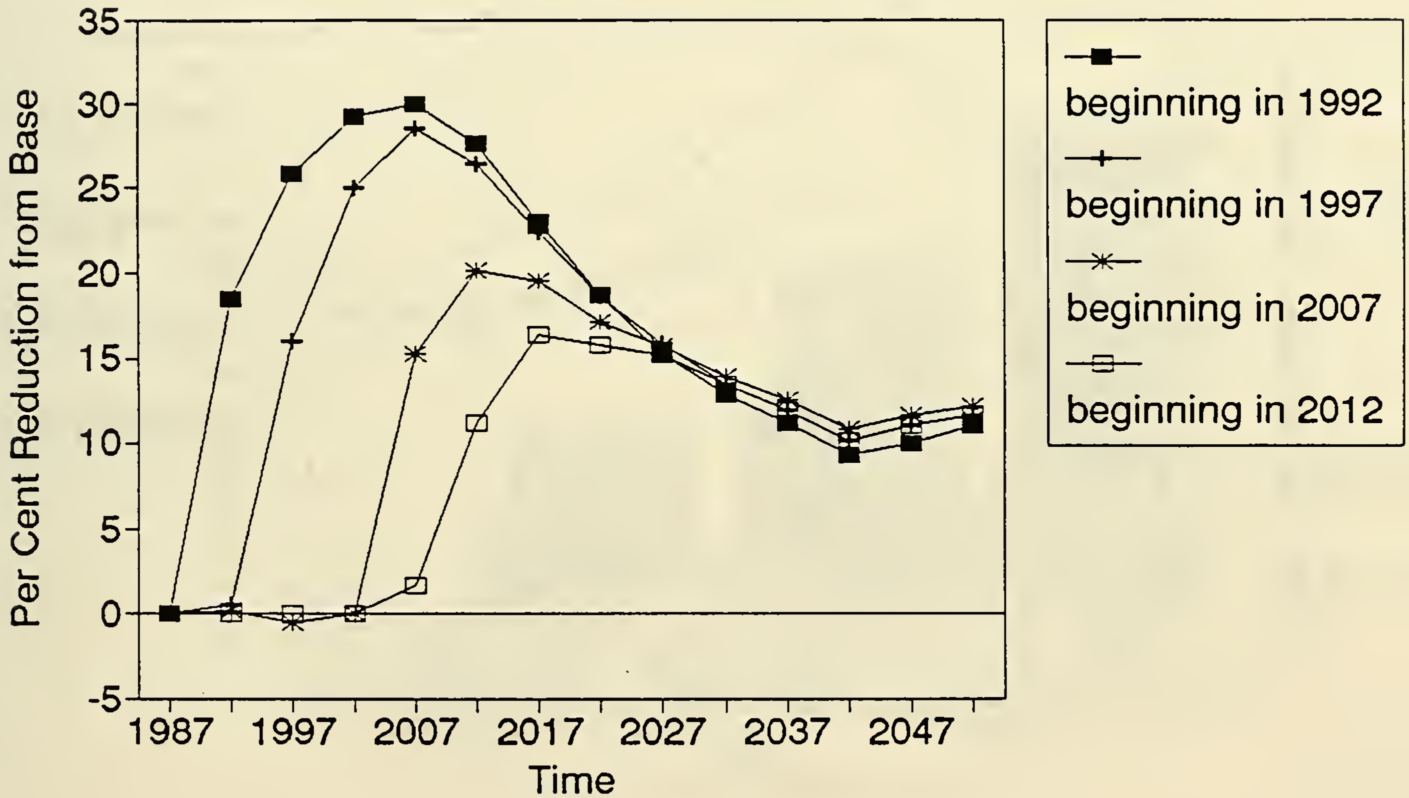


Chart 6C

Time Path of GDP Reductions

Due to a 40% Reduction in CO2

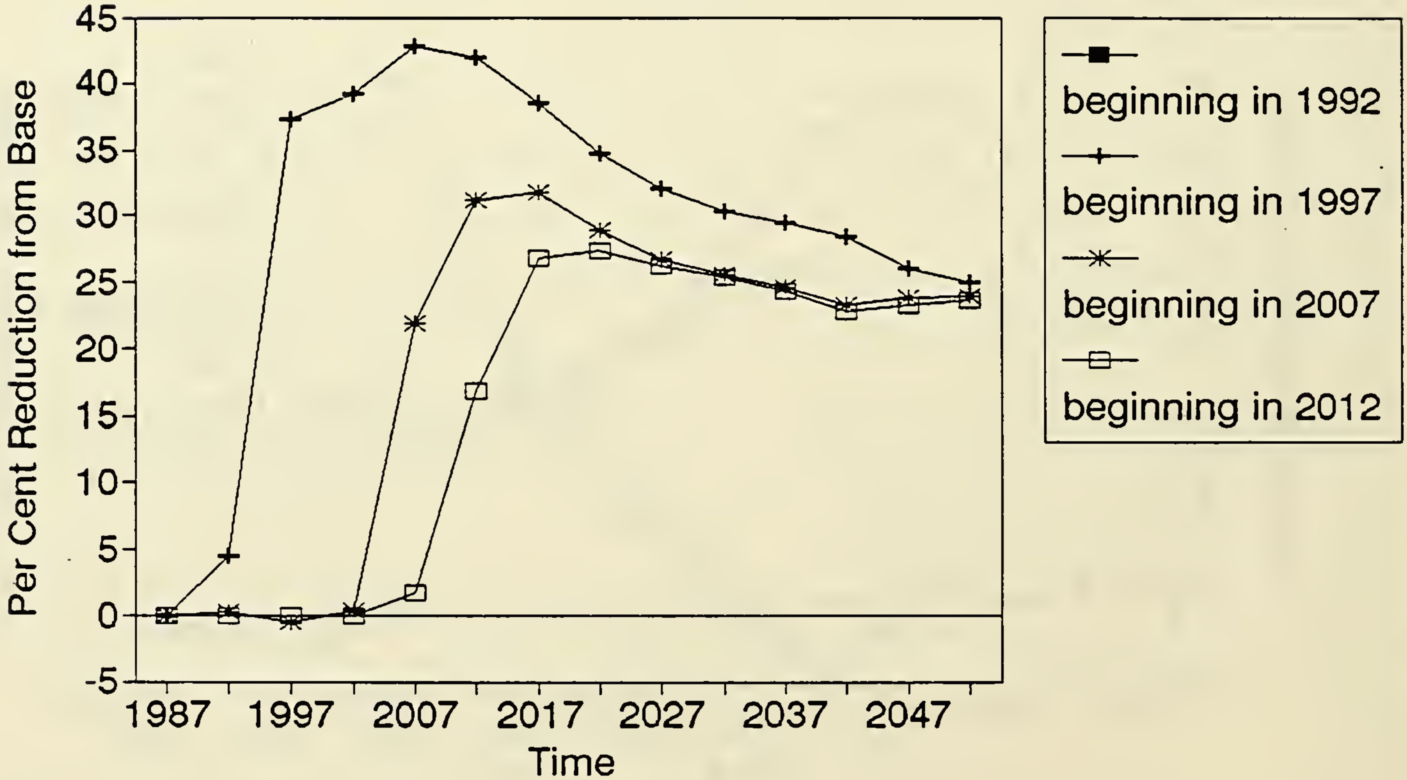
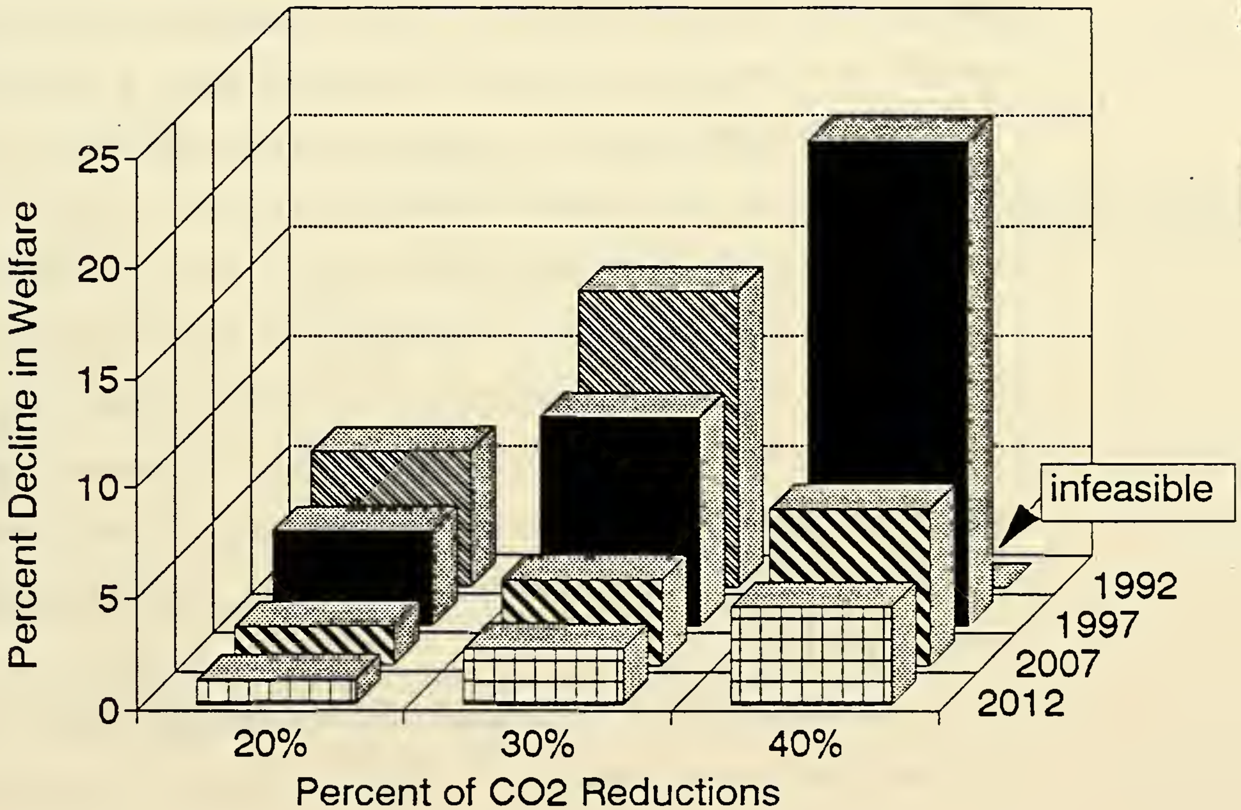


Chart 7

Welfare Effects of CO2 Reductions

With Alternative Beginning Dates



constrained at all. There are several reasons why this is actually a preferable set of policies. Control of accumulated emissions is more closely identified with the source of global warming, which is the total amount of greenhouse gases in the environment. The effectiveness of emissions control policies should, therefore, be judged in terms of accumulated emissions over the policy horizon, rather than the emissions rate in any particular period. Imposing the constraint on accumulated emissions also provides an important additional degree of freedom for policy, as it allows a country to choose its own optimal degree and timing of emissions reductions, consistent with meeting a target for reduction of total emissions over a specified period.

The consequences of stipulating reductions in accumulated emissions over the model's horizon are best shown by comparing results with the outcomes when annual rates of emissions reduction are specified. These consequences are shown in Charts 8A, 8B and 8C, comparing reductions in levels of GDP. It is clear that, using the GDP measure, economic performance under the emissions accumulation constraint is superior to that under annual emissions constraints. Chart 9 presents the corresponding welfare measures.

The additional freedom which the accumulation constraint provides is significant in two ways. First, it provides more

Chart 8A

GDP Reductions Due to Emissions Limits

20% CO2 Reduction Starting in 1992

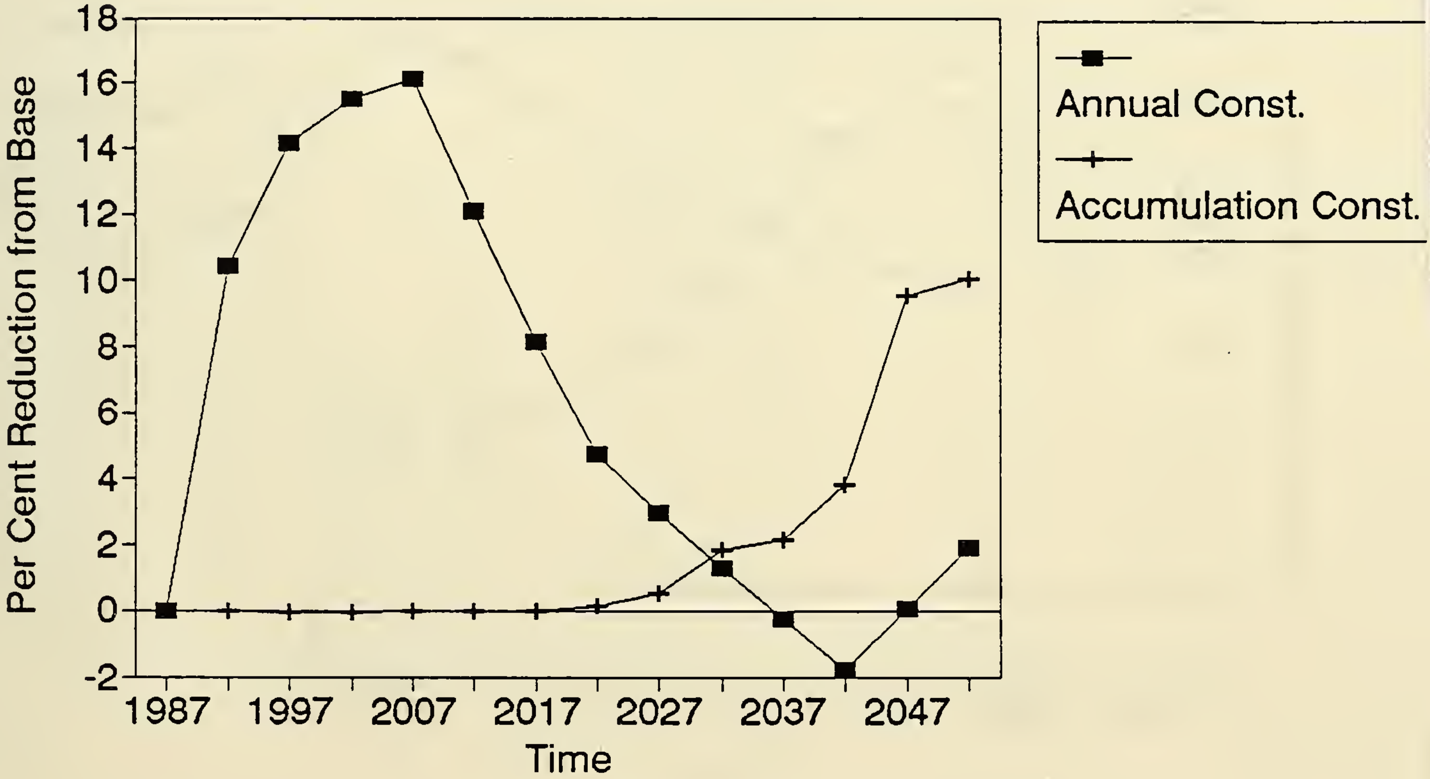


Chart 8B

GDP Reductions Due to Emissions Limits

30% CO2 Reductiion Starting in 1992

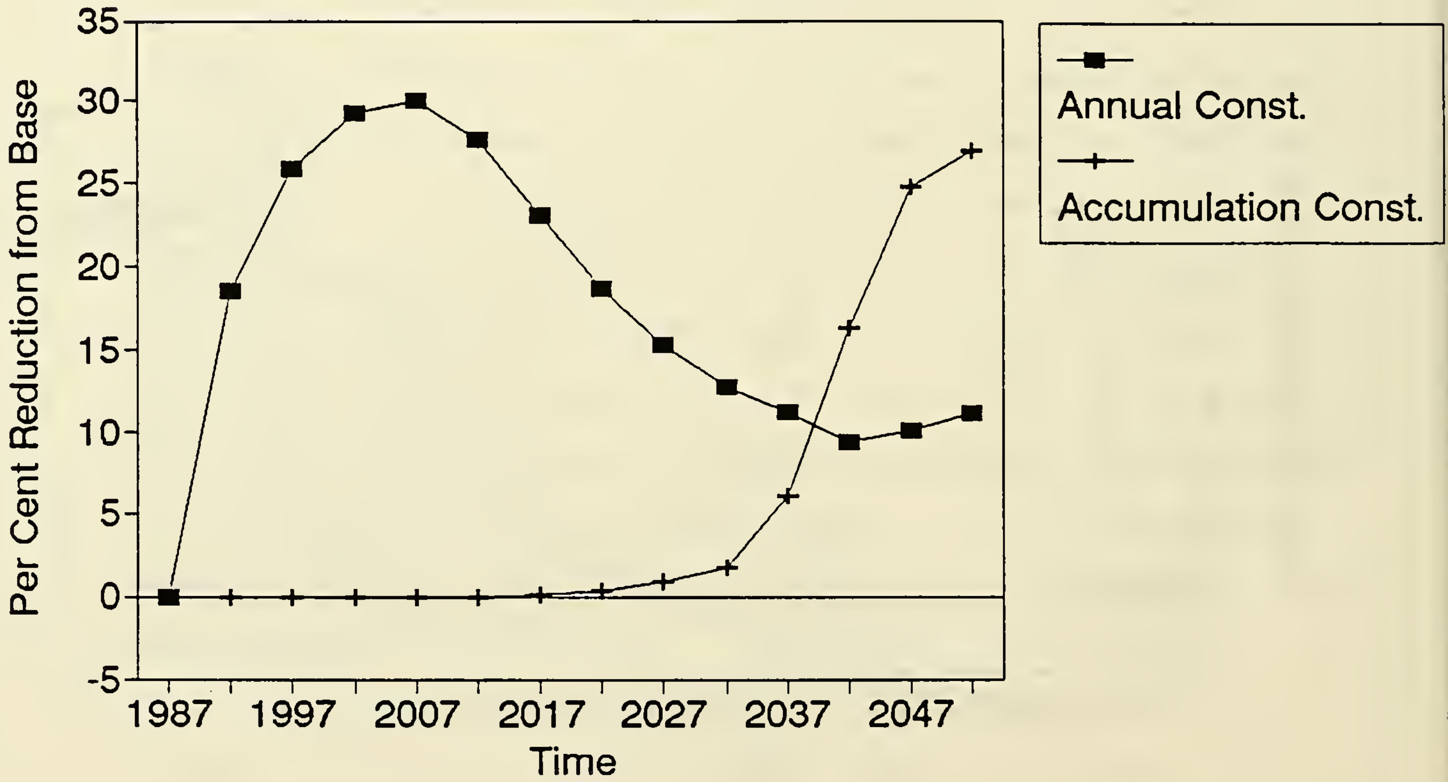
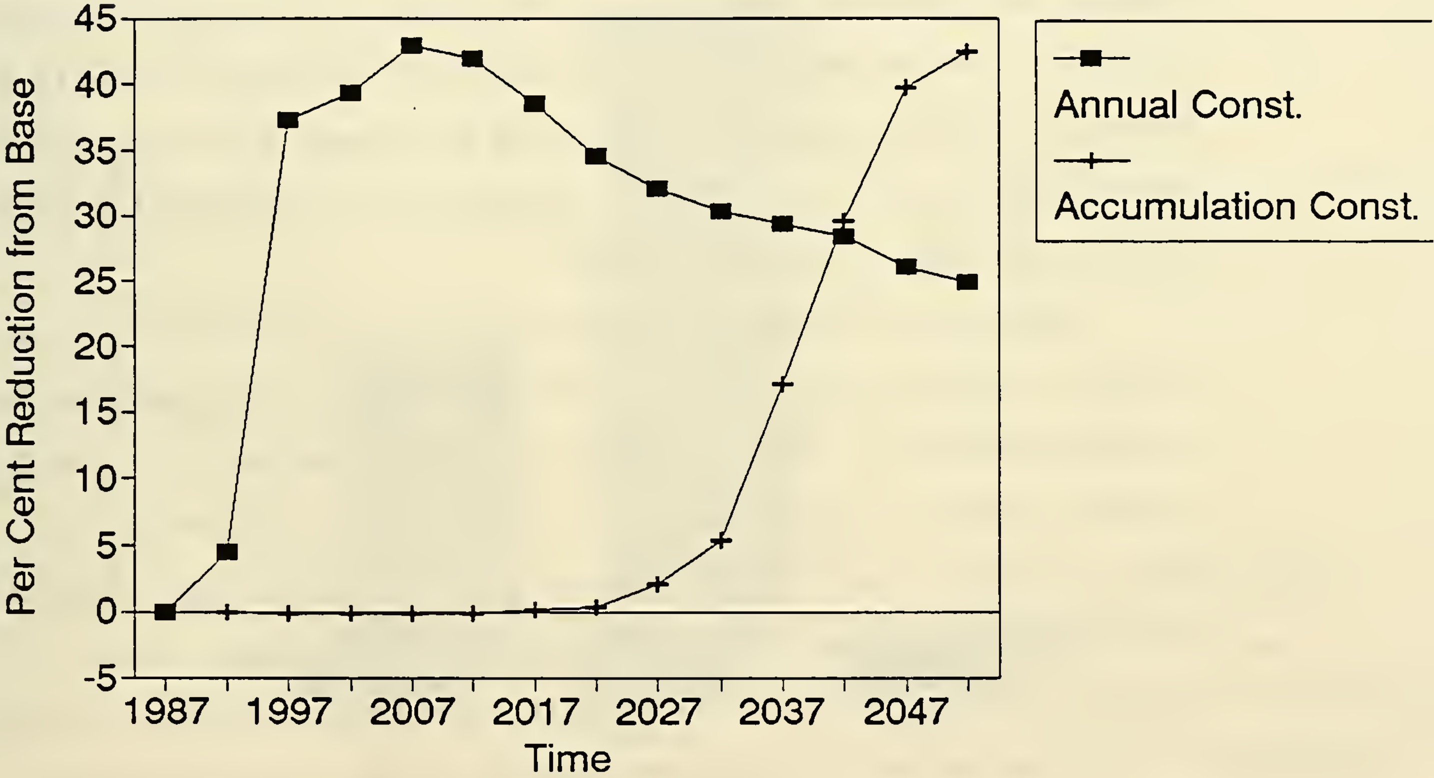


Chart 8C

GDP Reductions Due to Emissions Limits

40% CO2 Reduction Starting in 1992



time for the adjustments to the expected emissions constraint. Second, there is always a welfare gain from postponing reductions in consumption, since there is discounting in the welfare function.

The manner in which the model utilizes the added freedom is shown in Chart 10, which traces the time path of CO_2 reductions for a set of scenarios with constraints on annual rates of emissions and constraints on accumulated emissions as compared to the emissions in the Base Solution. In each alternative, with a modest exception for the 50 per cent reduction case, the model chooses to delay the beginning of the cutback in carbon emissions until 2022, or 35 years after the start of the model and halfway through the entire model horizon. In all cases also, the maximum annual reduction rate, which is attained, is substantially above the average annual reduction rate.

There is an important lesson from the last scenario. It is that to achieve a specified reduction in the accumulation of greenhouse gases in the atmosphere, it is better by far to allow freedom in the choice of timing of adjustment policies rather than to impose them. The lesson is a general one, applicable to advanced countries as well: rigidities in the imposition of limits on emissions controls have an unnecessary economic costs.

There may be an important qualification imposed by the physical processes of greenhouse warming, which is that the timing of any delay in reduction of emissions will, itself, have consequences for the ultimate change in temperature, etc.. It

Chart 9

Welfare Effects of CO2 Reductions

With Alternative Emission Constraints

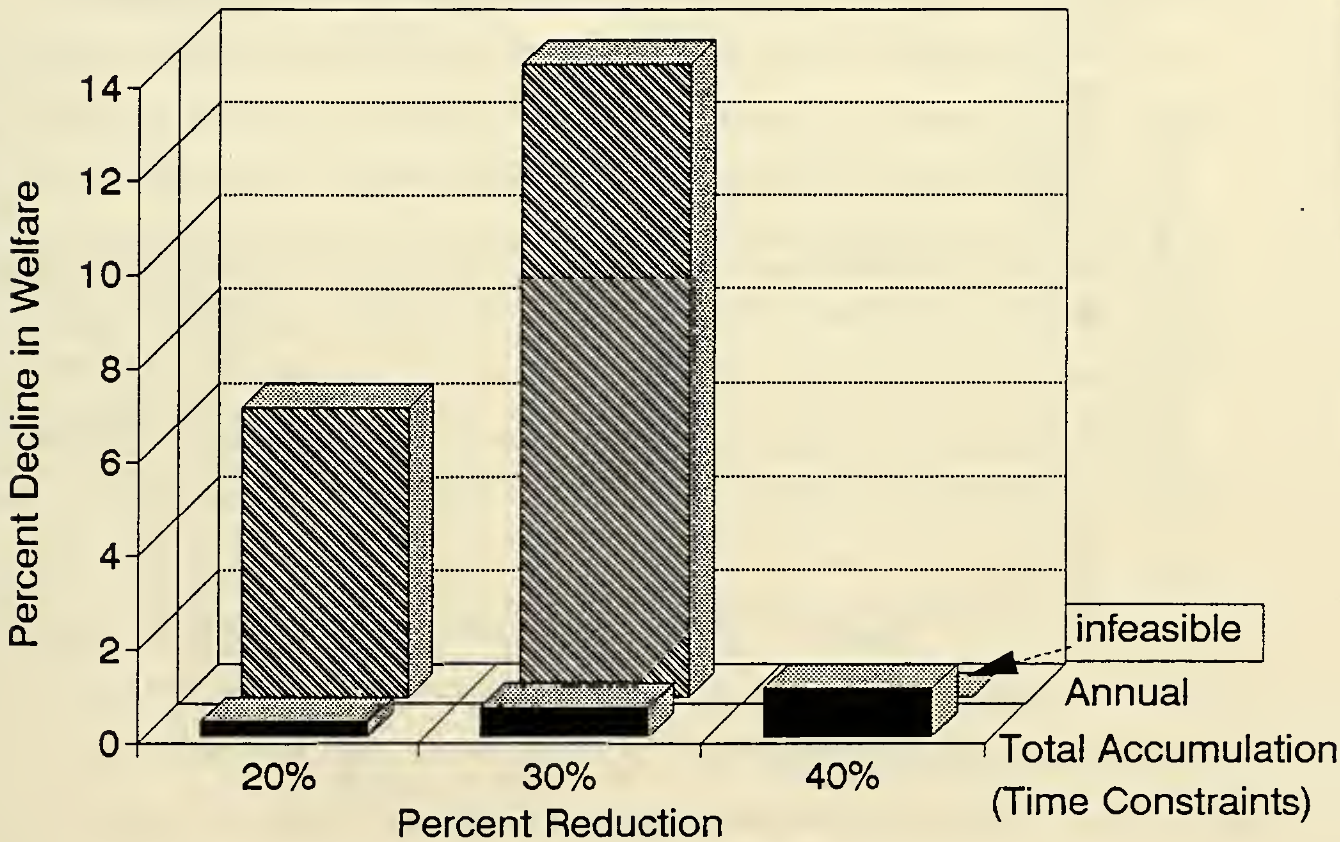
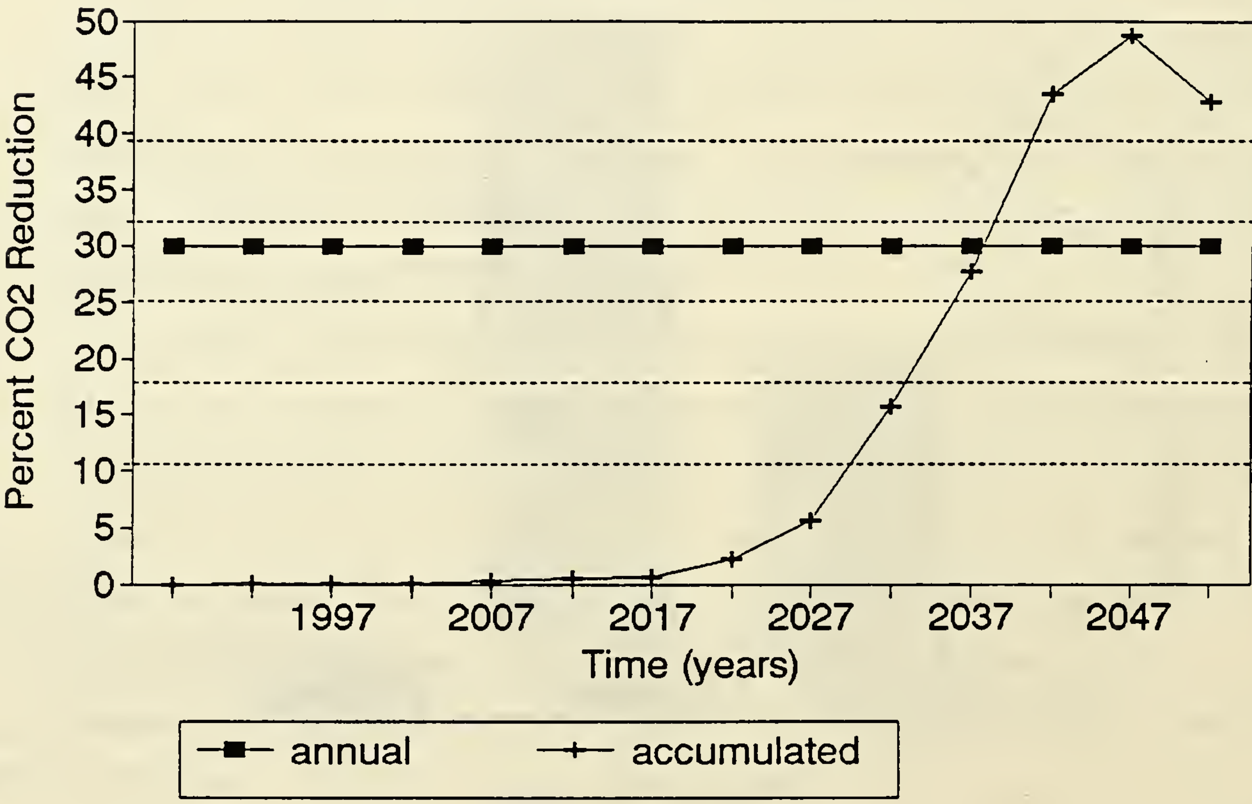


Chart 10

Time-path of CO2 Reductions

under a 30% emissions constraint



has not been possible to find an analysis of this question in the literature. The analysis which has been done, of the consequences of delaying the start of emissions restrictions does not deal with the stipulated pattern of emissions restrictions in Scenario III. In the solutions obtained for this Scenario, although the starting date of the emissions restrictions is delayed, the total amount of emissions reduction is the same as in corresponding solutions to which comparisons are made in Charts 8 and 9

There is one other significant qualification to the results when constraints are imposed on accumulated emissions. In effect, Scenario III simulates the outcome of a commitment to an allowable total accumulation of emissions. The benefits are manifest and would be enjoyed in the relatively early years of the commitment. The costs appear in the later years and appearing with them would be the temptation to violate the commitment.

<u>Effects of not discounting utility in the objective function</u>

The solutions to the scenarios without discounting of utility in the welfare function demonstrate that, in general, the results are not very sensitive to the discount rate of 7 per cent that was used in the solutions to the various scenarios. This can be seen for the Base Solution, without emissions constraints, as shown in accompanying Table 5. The table lists values of the ratios of GDP, Consumption and Investment in the solution obtained with no discounting to the same values obtained in the solution with discounting in the objective function.

Since it is the utility of consumption which appears in the objective function, it is useful to focus first on column 1, with the ratios of consumption in the undiscounted solution to the consumption in the discounted solution. It can be seen that in the first two periods consumption in the undiscounted solution is lower, but with a substantial difference only in the first period. After that, except for some quirky behavior, in 2032 and close to the end of the reporting period, consumption in the undiscounted solution is higher. That quirky behavior is, most likely, the result of the exhaustion of some resource or some other change in constraints.

The improvement in consumption is explained by the second column, which gives the same ratios for investment. The initial reduction in consumption makes possible a substantial relative increase in investment in the first period. The subsequent relatively larger consumption, investment and GDP are the payoffs from that initial difference in investment. The lower consumption in the first period in the undiscounted solution is more than offset by the later increases, simply because of those later increases are not discounted.

The solutions with constraints on annual emissions and accumulated emissions show generally similar behavior in the sense that it is not the discounting which accounts for the temporal patterns of consumption. There is some shifting around in the relative results but those are not of great significance as compared to the overall patterns.

Table 5

RATIOS OF GDP, CONSUMPTION AND INVESTMENT IN BASE SOLUTION
WITH DISCOUNTING OF OBJECTIVE FUNCTION
TO VALUES IN BASE SOLUTION WITHOUT DISCOUNTING

YEAR	GDP w.o. Dis./ GDP w. Dis.	CONS w.o. Dis./ CONS w.DIS.	INV w.o. Dis./ INV w. DIS.
1987	1.0000	1.0000	1.0000
1992	0.9849	0.9408	1.0943
1997	1.0148	0.9944	1.0866
2002	1.0310	1.0204	1.0748
2007	1.0363	1.0203	1.0980
2012	1.0501	1.0369	1.1103
2017	1.0596	1.0584	1.0933
2022	1.0600	1.0680	1.0722
2027	1.0483	1.0338	1.1105
2032	1.0480	0.8503	1.1119
2037	1.0418	0.9969	1.1886
2042	1.0532	1.0879	1.0330
2047	1.0336	1.0480	1.0302
2052	1.0268	1.0117	1.0580
2057	1.0216	1.0079	1.0530
2062	0.9996	1.0045	1.0363
2067	0.9983	1.0040	1.0319
2072	0.9978	1.0057	1.0289
2077	0.9985	0.9927	1.0073
2082	1.0253	0.9380	1.4421
2087	1.0059	1.1658	1.0985

All of this is entirely consistent with noticeable differences in the objective functions with and without discounting, since the calculated discounted values of those functions will be quite different.

Table 6 shows confirmation of this judgment. In this Table the annual levels of consumption are shown for the Base Case and for the Scenarios with 30 per cent required reductions in emission, first, imposed as annual constraints as compared to the Base Case and, second, imposed as a constraint on total accumulation of emissions over the model's horizon. Comparing the discounted solutions in columns 3 and 4, the manner in which the model reacts to the increased freedom in meeting only a constraint on accumulated emissions can be observed directly. Essentially it puts off adjustment to the emission constraint, when it is an accumulation constraint, and increases consumption, relatively.

TABLE 6

ANNUAL LEVELS OF CONSUMPTION

	DISCOUNTED SOLUTIONS (starting 1992)			UNDISCOUNTED SOLUTIONS (starting 1992)		
	BASE CASE	30% REQUIRED ANNUAL REDUCTIONS	30% REQUIRED ACCUMULATED REDUCTIONS	BASE CASE	30% REQUIRED ANNUAL REDUCTIONS	30% REQUIRED ACCUMULATED REDUCTIONS
1992	31937	27229	31931	48532	25674	29972
1997	40326	29820	40323	60794	26758	39905
2002	46124	31488	46155	72926	27049	47186
2007	56169	36033	56198	89272	30966	55700
2012	66916	43599	66956	110168	39132	66830
2017	82365	56829	82497	137671	54432	83342
2022	99453	73048	99003	172166	74427	101999
2027	126000	98445	121990	219165	108140	131571
2032	162175	132923	160681	287116	141866	168816
2037	220585	186123	215190	379440	183083	224753
2042	284877	261777	267835	496942	248514	280397
2047	368797	337815	291447	616389	338097	311829
2052	469113	411478	302928	762821	439673	348623

Moving to columns 5 and 6, it can be seen that this behavior is not simply the result of discounting. Columns 5 and 6 present the annual levels of consumption for undiscounted solutions. Essentially the same relative behavior is apparent in these solutions, in neither of which there is discounting in the objective function, as in similar solutions in which there is discounting. When given the freedom to put off the adjustment, the model utilizes that by increasing consumption, relatively, in the earlier periods, at the expense of later periods.

The contribution of backstop technologies

All the alternative solutions discussed so far have been with data representing the "conventional" technologies currently in use in Egypt, or modifications of those technologies in response to changes in inputs prices. In the next two scenarios, additional technologies are provided: in Scenario V, the "new" technologies are well-known, co-generation, nuclear power and gas-powered transport, although they are not currently in use in Egypt to any substantial extent.

The availability of these backstop technologies substantially improves the performance of the model economy. The growth of GDP in the critical early years of the time horizon and the overall welfare delivered by the system are both generally substantially higher. These differences are shown in Chart 11 and Chart 12.

The backstop technologies are used when they become available in period 2002 and permit an improvement in overall performance as they reduce the overall effect of the carbon

CHART 11

Time Path of GDP % Reduction from Base For Alternative Emissions Reductions

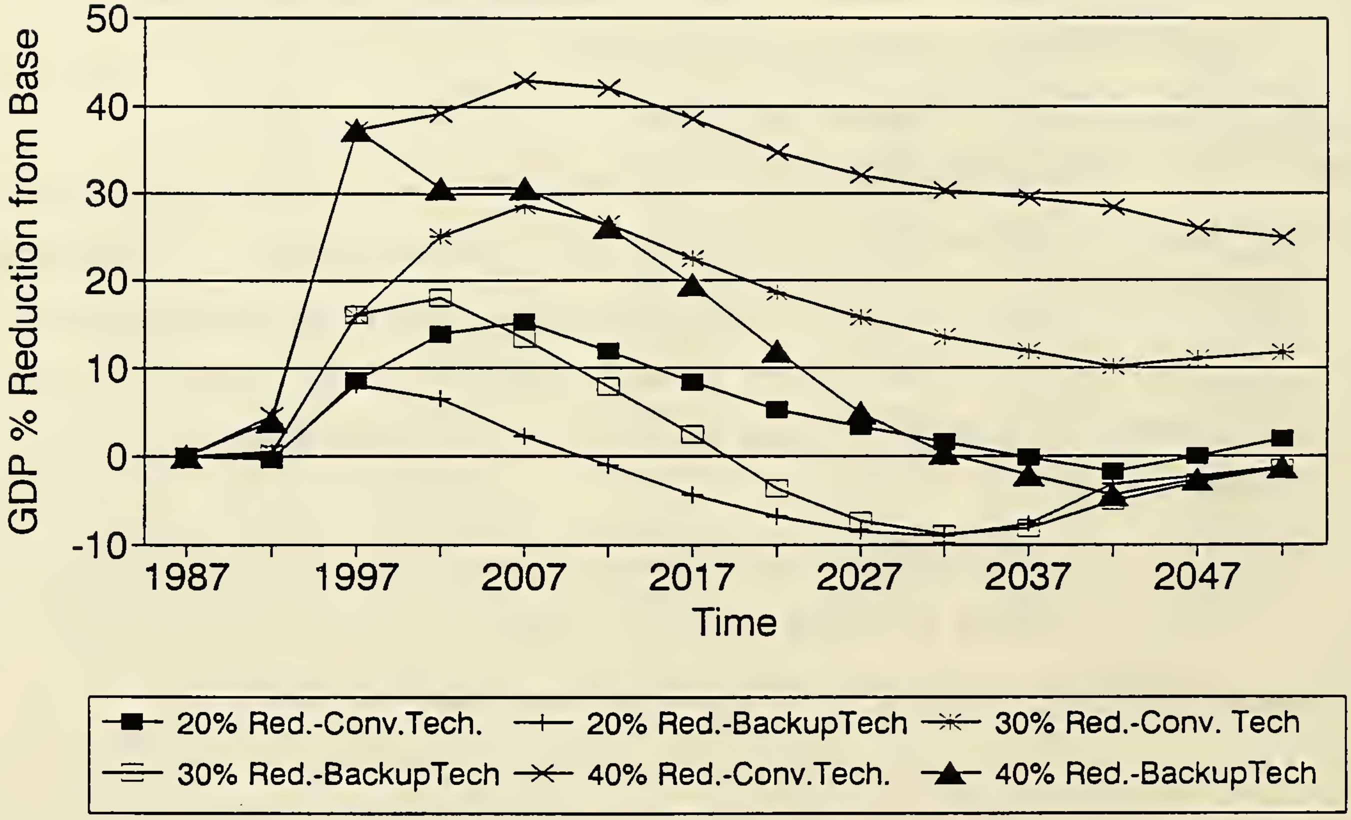
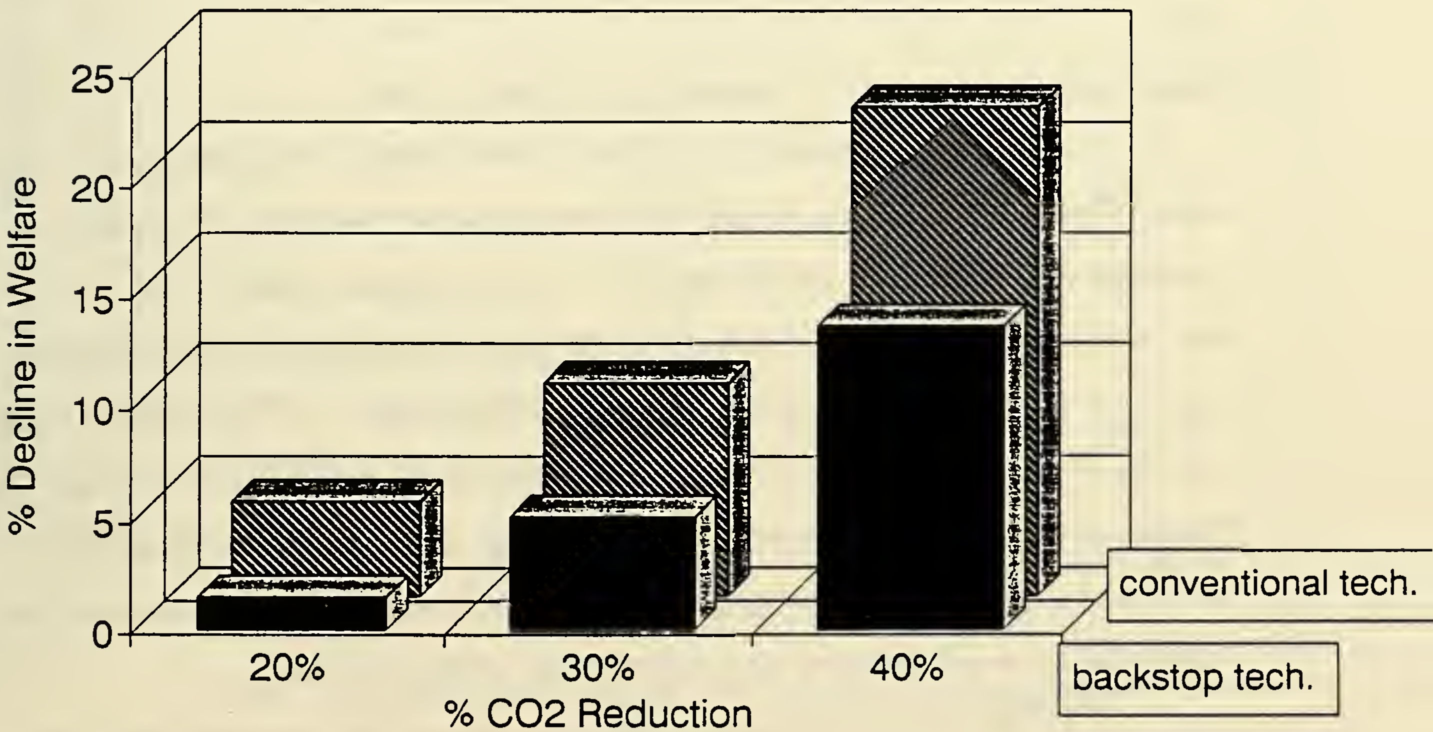


Chart 12

Welfare Effects of CO2 Reduction

With Alternative Emission Constraints



emissions restrictions. While co-generation is used in electric power production for a number of periods, depending on the emissions constraint, it is gradually phased out in favor of nuclear power generation.

The gas powered transport technological option is also used when it becomes available and until the price of natural gas rises due to depletion of domestic reserves.

When the carbon emissions constraints are in the form of limits on total accumulations, rather than on annual rates, the differences in performance, with and without the backstop technologies, are quite significant. This is shown in Charts 13 and 14.

<u>The contribution of "renewable" technologies</u>

Finally, in Scenario V, the experiments with the model were done with "renewables" electricity generating technologies, representing photovoltaic power, solar-thermal power, and dendroelectric power. These, with the "backstop" technologies are all summarized in a single representative "alternative" technology. This technology embodies different assumptions about the "renewables" technologies, depending on the degree of sunlight available and on a time dependent reduction in costs, reflecting expectations of future technological improvements.

The lowest unit costs, for each level of insolation, are reached in 2022 in Scenarios V-1, V-2 and V-3. In Scenarios V-4, V-5 and V-6, high insolation levels are assumed but the date at

Chart 13

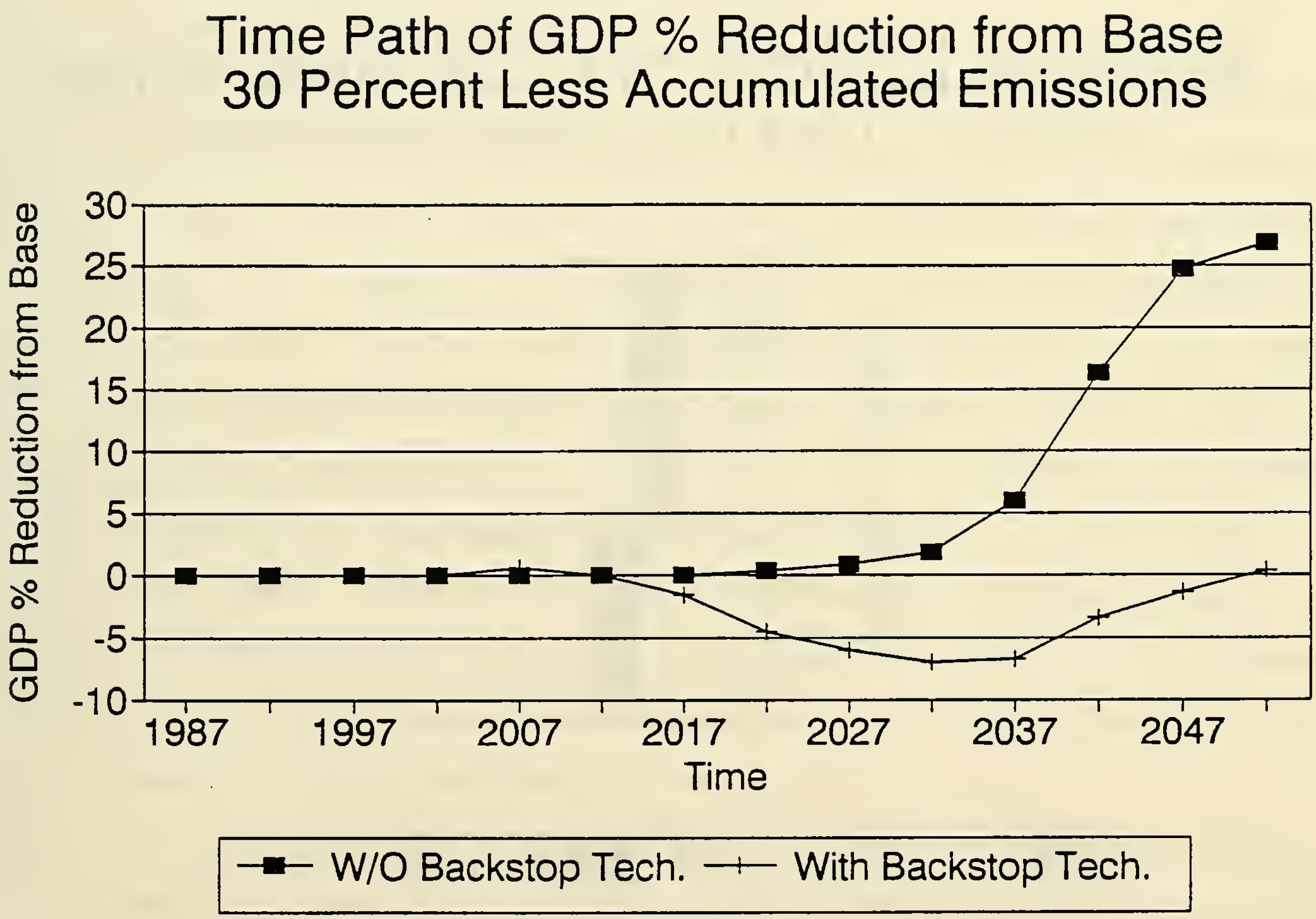
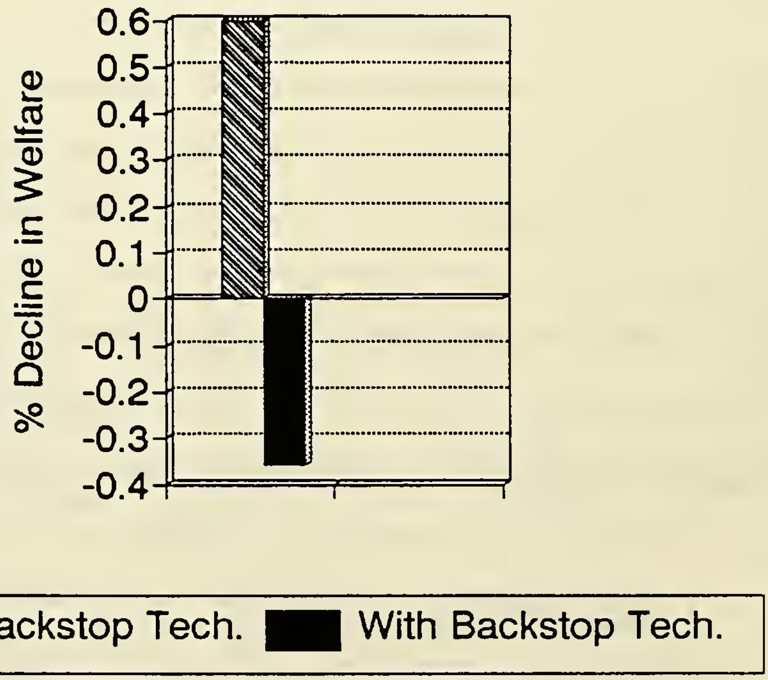

Time Path of GDP % Reduction from Base
30 Percent Less Accumulated Emissions
GDP % Reduction from Base
30
25
20
15
10
5
0
-5
-10
1987
1997
2007
2017
2027
2037
2047
Time
W/O Backstop Tech.
With Backstop Tech.

Chart 14

Welfare Effects of CO2 Reduction

With 30 % Less Accumulated Emissions



which the minimum cost is achieved is stretched to 2032, 2042 and 2052, respectively. The renewables technology was added to the previous set of trials using the backstop technologies of co-generation, nuclear power and gas-powered transport. Again, only a few results are presented.

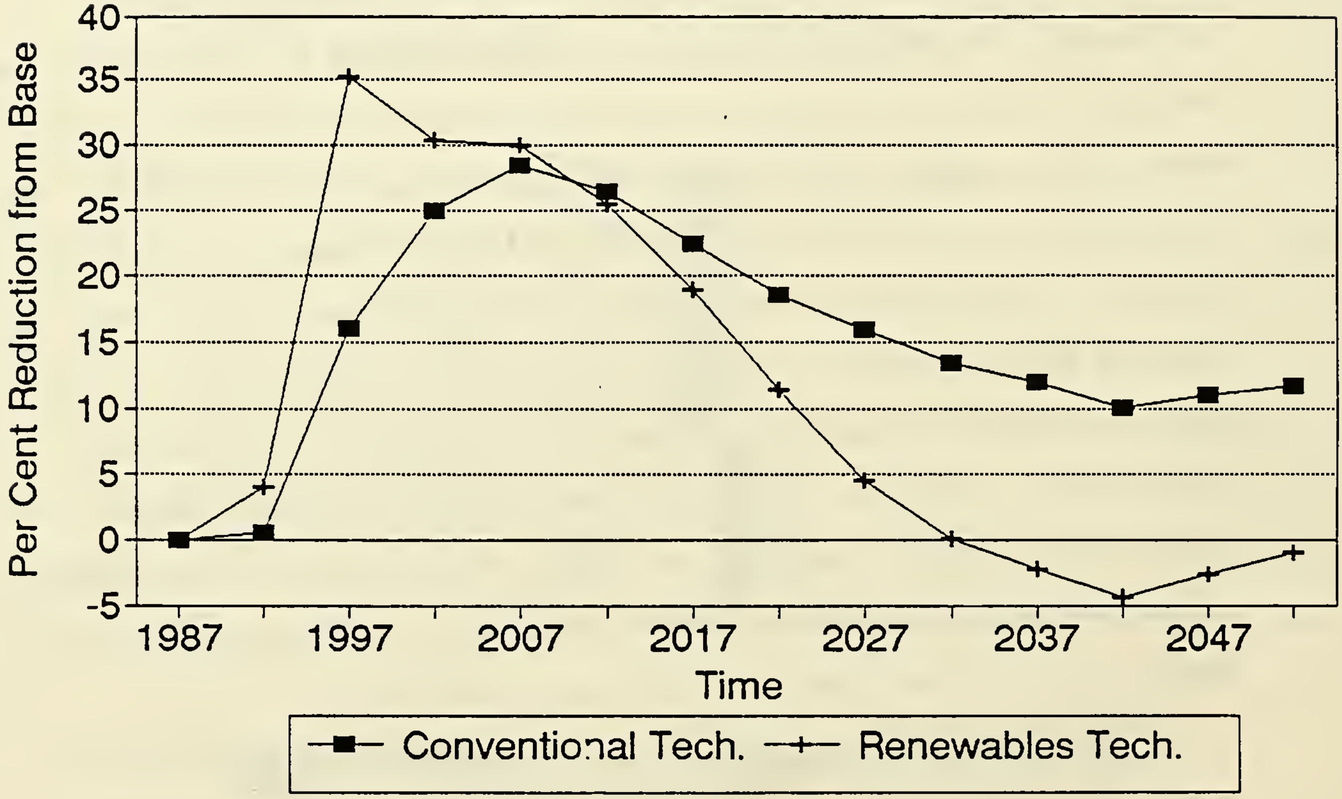
It turned out that the direct and indirect costs of the renewables technology for generating electric power were relatively high, as compared to the backstop and conventional technologies, for all except the cases in which high levels of sunlight were assumed. As a result, the solutions with the renewables and backstop technology show improvements in performance as compared to the solutions with only the more conventional backstop technologies. The renewables technology was introduced into the solution by the model in 1997, before the date at which the backstop technologies were assumed to become available. This indicates their potential ability to compete with the most conventional electric power technologies when carbon emissions are restricted. However, when the backstop technologies become available in 2002, there is no further investment in the renewables technology and its capital is allowed to depreciate. The results are illustrated for one case in Chart 15.

The renewables technology, with assumed high insolation, was used intensively when domestic gas reserves were severely depleted and carbon emissions restrictions were severe.

Chart 15

Time Path of GDP Reduction

Due to a 30% Reduction in CO_2



VIII. Summary and conclusions

The solutions to the alternative specifications of the different scenarios provide new methodological and substantive insights. The methodological insights lead to a more informed interpretation of the results of this and other models of the effects of carbon emissions restrictions. The substantive insights indicate the comparative advantages of alternative forms of carbon emissions restrictions and, as well, the particular contributions of conventional and unconventional backstop technologies for electric power production.

The model was solved with a time horizon of 100 years, although results are reported for only a 60 year period. In this period of time, the model economy substantially deplete its hydrocarbon reserves, which are the only nonproduced resource. As a result the system moves close to a steady state growth path, dependent mainly on labor and capital accumulation, although constraints on trade and international borrowing remain. In any case, the effect is to create endogenous steady state growth paths with a growth rates that are much the same, with and without carbon emissions restrictions.

The differences in GDP growth results created by carbon emissions restriction that have been reported from models of this type and, presumably, other models are, therefore, not mainly the result of the particular emissions restrictions that have been imposed. Rather such differences are mainly the result of factors leading to divergence in implicit steady state growth conditions.

These conclusions do not imply that carbon emissions restriction make no difference to the performance of an economy. A better measure of performance than GDP growth rates is the welfare that an economy generates. Since there is an explicit welfare maximand in this model, we have used this measure of performance. It may be recalled that, in this model, welfare is simply the discounted weighted sum of consumption in each period. The discounting, of course, gives greater weight to consumption in the near future than in the distant future. However, in this, and similar models, there is nearly full use of all the resources available. That means that the GDP achieved is at full-employment levels, though the adjustments due to carbon emissions restrictions create differences in effective productivity of the resources used. For this reason also, a measure of consumption that the model economy can deliver is a better indicator of performance than GDP.

The welfare losses due to the imposition of annual restrictions on the rate of carbon emissions are quite substantial, ranging from 4.5 for a 20 per cent reduction in annual carbon emissions to 22 per cent for a 40 per cent reduction in emissions. The effects of the annual carbon emissions restrictions are quite nonlinear as well.

The results show that the timing of the emissions restrictions is also quite critical. Postponing their imposition provides a longer period during which adjustments can be made, as well as making it possible to continue to deliver consumption goods in a relatively unconstrained manner.

The form of the emissions restrictions is important as well. Although all of the results from other models and nearly all of the debate has been conducted in terms of annual rates of emissions, the critical issue is the total addition to the accumulation of greenhouse gases in the environment. When the emissions constraint is imposed in the form of constraints on total additions to the accumulation of greenhouse gases, the model's performance undergoes a striking, but understandable change. Accumulation restrictions also provide more time for adjustment. The model also puts off the reduction in emissions restrictions in order to provide consumption goods relatively early in its horizon, when the discounting is less severe. The welfare losses in this case are much lower than when constraints are imposed on annual emissions rates.

To investigate the significance of discounting of utility in the objective function, solutions were calculated for scenarios in which the discount rate was set to zero. These solutions indicated that the outcomes were not sensitive to the 7 per cent discount rate that was used in solutions with otherwise similar conditions. This does not, of course, imply that the solutions would not be sensitive to higher discount rates.

Backstop technologies are important in maintaining output and consumption. The conventional backstop technologies of co-generation, nuclear power and gas-powered transport are much more significant than an unconventional set of "renewables" technologies. The latter, in effect, cannot compete on cost grounds.

Results from models of the type developed and used here should not be interpreted as forecasts of the future. They are intended to be used to compare the results of generic, "What if...?" questions. While there may be further questions of this sort to examine, the results so far have justified the efforts.

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National Academy of Sciences, Policy Implications of Greenhouse Warming, National Academy Press, Washington, D.C., 1991

FOOTNOTES

1 Central Agency for Public Mobilization and Statistics (CAPMAS).

2 The case is made in National Academy of Sciences (1991). however the evidence on costs is rather too sparse to inspire confidence.

3 It should be noted that the evolution of agricultural output depends very much on the availability of labor, which was increasingly constrained by the large labor outflows after 1973. The partial reversal of those flows in 1991 might change the projections.

4 The welfare losses shown have been computed for the period to 1930 only.

5 W. Nordhaus, (1991).

APPENDIX

Table 7

Parameters and Exogenous Variables

a_i	Maximum annual rate of depletion of hydrocarbon resource i (oil or natural gas)
$a_{i,j,k}$	Input of good i per unit of production of good j using technology k
$a_{fuel,j,k,t}$	Input fuel per unit of production of good j using technology k in year t
$a_{gas,j,k,t}$	Input of natural gas per unit of production of good j using technology k in year t
$a_{pet,j,k,t}$	Input of petroleum products per unit of production of good j using technology k in year t
$b_{i,j,k}$	Proportion of capital good i in the capital required to produce good i using technology k
$d_{i,k}$	Five-year rate of depreciation of capital for production of good i using technology k
ds_t	Factor of atmospheric dissipation of carbon emission in period t
e_i	Maximum rate of increase of exports of good i between two periods
i_t	Interest rate of foreign debt in year t
g_i	Minimal post-terminal growth rate for sector i
$h_{agr,t}$	Growth in agricultural labor productivity in year t
h_t	Growth in labor productivity in year t
$f_{i,k}$	Capacity conversion factor for capital producing good i using technology k
$ICOR_{i,k,t}$	Incremental capital-output ratio for production of good i using technology k in year t
$l_{i,k,t}$	Demand for labor per unit of production of good i using technology k in year t
$l_{agr,k,t}$	Demand for labor per unit of agricultural production using technology k in year t
m_i	Maximum rate of fall of imports of good i between two periods
q_i	Conversion factor for hydrocarbon resource i (oil or natural gas)
$s_{j,k,t}$	Maximum share of natural gas in meeting fuel demand of producing good j using technology k in year t

Table 7 (continued)

β_i	Elasticity parameter for consumption good i
γ_i	Intercept parameter for consumption good i
ρ	Utility discount rate between periods
$\bar{B}_t$	Maximum net foreign borrowing in year t
$\bar{G}_{i,t}$	Public consumption of good i in year t
$\bar{I}_{1987}$	Aggregate investment in 1987
$\bar{L}_t$	Total supply of labor in year t
$\bar{L}_{agr,t}$	Supply of agricultural labor in year t
$\bar{N}_t$	Population in year t
$\overline{\Delta R}_{i,t+1}$	Discoveries of resource i (oil or natural gas) between year t and year t+1
$\bar{T}_t$	Other foreign exchange transfers in year t
$\overline{FP}_t$	Foreign firms' profit remittances in year t
$\bar{W}_t$	Workers' remittances in year t
$P^e_{i,t}$	World price of exports at good i in year t
$P^m_{i,t}$	World price of imports at good i in year t
$\bar{V}_t$	Maximum amount of carbon that may be generated in period t
$\bar{S}_{em}$	Stock or cumulative emission of carbon

Table 8

Endogenous Variables

B_t	Net foreign borrowing in year t
$C_{i,t}$	Private consumption of good i in year t
D_t	Foreign debt in year t
$E_{i,t}$	Exports of good i in year t
$I_{i,t}$	Investment demand for good i in year t
$I_{i,j,k,t}$	Demand for investment good i by sector j, technology k, in year t
$K_{i,k,t}$	Installed capacity in year t to produce good i using technology k
$\Delta K_{i,k,t}$	New capacity to produce good i using technology k, first available in year t
$M_{i,t}$	Imports of good i in year t
$P_{i,t}$	Shadow price of good i in year t
$R_{i,t}$	Reserves of hydrocarbon i (oil or natural gas) in year t
$U(C_t)$	Utility of per capita consumption in year t
W	Total discounted utility: the maximand
$X_{i,t}$	Gross domestic output of good i in year t
$X_{i,k,t}$	Gross output of good i, produced using technology k, in year t
$Z_{i,t}$	Intermediate deliveries of good i in year t
$V_{i,t}$	Total amount of carbon generated by the use of a particular fuel, i, in period t
$V_{i,j,t}$	Total amount of carbon generated by the use of a particular fuel, i, in sector j, in period t
$V_{i,k,j,t}$	Amount of carbon generated by the use of a fuel i, using technology k, in sector j, in period t
$V_{i,c,t}$	Amount of carbon generated by the use of a particular fuel i, in consumption in period t
$v_{i,k,j,t}$	Quantity of carbon emission <u>per</u> <u>unit</u> use of particular fuel i, using technology k, in sector j, in period t
$v_{i,c,t}$	Quantity of carbon emission per unit use of a fuel i, in consumption in period t

MODEL

Accounting Identities

$$X_{i,t} + M_{i,t} = Z_{i,t} + C_{i,t} + \bar{G}_{i,t} + I_{i,t} + E_{i,t} \tag{1}$$

$$X_{i,t} = \sum_{k} X_{i,k,t} \tag{2}$$

$$Z_{i,t} = \sum_{j} \sum_{k} a_{i,j,k} X_{j,k,t} \tag{3}$$

$$\sum_{i} P^{e}_{i,t} E_{i,t} + \bar{W}_{t} + \bar{T}_{t} + B_{t} = \sum_{i} P^{m}_{i,t} M_{i,t} + i_{t} D_{t} + \overline{FP}_{t} \tag{4}$$

Technology and Production Constraints

$$a_{gas,j,k,t} + a_{pet,j,k,t} = a_{fuel,j,k,t} \tag{5}$$

$$a_{gas,j,k,t} \le s_{j,k} \, a_{fuel,j,k,t} \tag{6}$$

$$\sum_{i} \sum_{k} l_{i,k} X_{i,k,t} \le h_{t} \bar{L}_{t} \tag{7}$$

$$\sum_{k} l_{agr,k} X_{agr,k,t} \le h_{agr,t} \bar{L}_{agr,t} \tag{8}$$

$$X_{i,k,t} \le K_{i,k,t} \tag{9}$$

$$q_{i} X_{i,t} \le a_{i} R_{i,t} \tag{10}$$

Balance of Payments and Trade Constraints

$$B_{t} \le \bar{B}_{t} \tag{11}$$

$$M_{i,t} \ge (1-m_{i}) M_{i,t-1} \tag{12}$$

$$E_{i,t} \le (1+e_{i}) E_{i,t-1} \tag{13}$$

Dynamic Linkages

$$K_{i,k,t+1} = K_{i,k,t}(1-d_{i,k}) + f_{i,k} \Delta K_{i,k,t} \tag{14}$$

$$R_{i,t+1} = R_{i,t} + \overline{\Delta R}_{i,t+1} - 2.5(X_{i,t+1} + X_{i,t})q_{i} \tag{15}$$

$$D_{t+1} = D_{t} + 2.5(B_{t+1} + B_{t}) \tag{16}$$

Investment Demand

$$I_{i,t} = \sum_{j} \sum_{k} I_{i,j,k,t} \tag{17}$$

$$I_{i,j,k,t} = b_{i,j,k} \; ICOR_{j,k,t} \; \Delta K_{j,k,t+1} \tag{18}$$

$$\sum_{i} I_{i,1987} \leq \bar{I}_{1987} \tag{19}$$

$$\sum_{k} K_{i,k,2082} \geq (1+\bar{g}_{i}) \sum_{k} K_{i,k,2087} \tag{20}$$

Carbon Emissions

$$V_{i,j,t} = \sum_{k} V_{i,k,j,t} \tag{21}$$

$$V_{i,t} = \sum_{j} V_{i,j,t} \tag{22}$$

$$V_{i,c,t} = v_{i,c,t} C_{i,t} \tag{23}$$

$$V_{k,i,j,t} = v_{k,i,j,t} \; X_{k,j,t} \tag{24}$$

$$\sum_{i} (V_{i,t} + V_{i,c,t}) \leq \bar{V}_{t} \tag{25}$$

$$\sum_{t} \sum_{i} ds_{t}(V_{i,t} + V_{i,c,t}) = \bar{S}_{em} \tag{26}$$

Objective Function

$$W = \sum_{t} \left(\frac{1}{1+\rho}\right)^{t} N_{t} \; U(C_{t}) \tag{27}$$

$$U(C_{t}) = \sum_{i} \beta_{i} \log \left(\frac{C_{i,t}}{\bar{N}_{t}} - \gamma_{i} \right) \tag{28}$$