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World Development Report

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Background paper for World Development Report 1992

Growth and Welfare Losses from Carbon Emissions Restrictions

A General Equilibrium Analysis for Egypt

Charles R. Blitzer
R. S. Eckaus
Supriya Lahiri
and
Alexander Meeraus

To achieve a specified reduction in the accumulation of greenhouses gases in the atmosphere, it is far better to allow for flexibility in the timing of adjustment policies than to impose a particular deadline. This lesson applies to all countries: rigidly imposed limits on emissions controls entail unnecessary economic costs.

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This paper — a product of the Office of the Vice President, Development Economics — is one in a series of background papers prepared for the *World Development Report 1992*. The *Report*, on development and the environment, discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Copies of this and other *World Development Report* background papers are available free from the World Bank, 1818 H Street, NW, Washington, DC 20433. Please contact the *World Development Report* office, room T7-101, extension 31393 (August 1992, 40 pages).

Blitzer, Eckaus, Lahiri, and Meeraus assess the economic effects on Egypt, under various conditions, of restricting carbon dioxide emissions. They use their model to assess the sensitivity of these effects to alternative specifications: changes in the level or timing of restrictions, changes in the rate of discount of future welfare, and the presence or absence of alternative technologies for generating power.

They also analyze a constraint on accumulated emissions of carbon dioxide. Their model has a time horizon of 100 years, with detailed accounting for every five years, so they can be specific about differences between short- and long-run effects and their implications.

However, the results reported here cover only a 60-year period — and are intended only to compare the results of generic, "what if?" questions, not as forecasts. In that 60-year period, the model economy substantially depletes its hydrocarbon reserves, which are the only nonproduced resource.

The authors find that welfare losses due to the imposition of annual restrictions on the rate of carbon dioxide emissions are substantial — ranging from 4.5 percent for a 20 percent reduction in annual carbon dioxide emissions to 22 percent for a 40 percent reduction. The effects of the annual emissions restrictions are relatively nonlinear.

The timing of the restrictions is significant. Postponing them provides a longer period for adjustment and makes it possible to continue delivering consumption goods in a relatively unconstrained manner.

The form of the emissions restrictions is also important. Welfare losses are much higher when constraints are imposed on annual emissions rates rather than on total additions to the accumulation of greenhouse gases.

Conventional backstop technologies for maintaining output and consumption — cogeneration, nuclear power, and gas-powered transport — are more significant than unconventional "renewable" technologies, which cannot compete for cost.

Produced by the Policy Research Dissemination Center

Growth and Welfare Losses from Carbon Emissions Restrictions: A General Equilibrium Analysis for Egypt*

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Prepared as a Background Paper for the
World Development Report 1992

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The World Development Report 1992, "Development and the Environment," discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Under current practices, the result could be appalling environmental conditions in both urban and rural areas. The World Development Report presents an alternative, albeit more difficult, path - one that, if taken, would allow future generations to witness improved environmental conditions accompanied by rapid economic development and the virtual eradication of widespread poverty. Choosing this path will require that both industrial and developing countries seize the current moment of opportunity to reform policies, institutions, and aid programs. A two-fold strategy is required.

- First, take advantage of the positive links between economic efficiency, income growth, and protection of the environment. This calls for accelerating programs for reducing poverty, removing distortions that encourage the economically inefficient and environmentally damaging use of natural resources, clarifying property rights, expanding programs for education (especially for girls), family planning services, sanitation and clean water, and agricultural extension, credit and research.
- Second, break the negative links between economic activity and the environment. Certain targeted measures, described in the Report, can bring dramatic improvements in environmental quality at modest cost in investment and economic efficiency. To implement them will require overcoming the power of vested interests, building strong institutions, improving knowledge, encouraging participatory decisionmaking, and building a partnership of cooperation between industrial and developing countries.

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Other (unpublished) papers in the series are available direct from the World Development Report Office, room T7-101, extension 31393. For a complete list of titles, consult pages 182-3 of the World Development Report. The World Development Report was prepared by a team led by Andrew Steer; the background papers were edited by Will Wade-Gery.

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I. Introduction

The economic effects of carbon dioxide emissions restrictions have, 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. If those costs are relatively small, then the case for such restrictions is considerably strengthened, even in the absence of a reasonable degree of scientific agreement as to their effects. On the other hand, if the costs are relatively large, it is reasonable to require more scientific evidence. Either way, policy decisions about emissions restrictions should be made with as much insight as possible.

This paper is intended as a contribution to these debates. Like all of the other work that has been done, it is an exemplification of some of the economic possibilities; it is not 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.[1]

The model is also used to assess the sensitivity of these effects 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 accumulated emissions of carbon dioxide. Because the model has a time horizon of 100 years, with detailed accounting every five years, it is also possible to be quite specific 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 differ in the constraints under which they operate: physical resources (including capital), human resources, technologies, access to markets and foreign debt. They differ further in their industrial structure and in their use of energy sources, chemicals and the various processes that contribute to greenhouse warming. All of this means that countries will also differ in their levels, and achievable future goals, of per capita income and consumption. As a result, constraints on carbon emissions will have differential impacts across countries, and even the same impact on output and income will have different welfare effects. In the final

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[1] For a similar analysis of India see Blitzer et al. "The Effects of Restrictions on Carbon Dioxide and Methane on the Indian Economy," Background Paper prepared for the World Development Report 1992, World Bank.

analysis, therefore, emissions policies will 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 must be done at a country level.

However, most existing studies of the effects of carbon emissions restrictions 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, calling, in consequence, for a global assessment. Global and regional models have served the very useful purpose of illustrating the nature of the economic problems caused by adjustment to emissions restrictions. However, there needs to be a clear recognition of the limits of their usefulness.

Furthermore, experience with developing countries emphasizes 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. Agriculture, for example, is much more important; 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. Analyzing the future effects of emissions restrictions from simple projections of growth rates, either in the aggregate or on a sectoral basis, would therefore tend to generate misleading results. Models driven by growth rate projections do not allow for any 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. There are grounds for legitimate differences of opinion as to the usefulness of the steady state growth assumption for industrialized countries, but it is clearly quite contrary to the intentions and growth prospects of developing countries.

Moreover, while countries may move into new steady state growth conditions after the imposition of emissions constraints, the adjustment process 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 reflect reality. While the assumption of perfect capital mobility among sectors, for example, facilitates the building and computation of models, it is an assumption that will certainly make adjustment appear easier than is actually the case.

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

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

The model presented below is an intertemporal optimizing model and is thus in the same spirit as approaches by Manne and Richels (1989) and Nordhaus (1987). 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 country-specific features that affect adjustment processes. Moreover, the effectiveness of international agreements will ultimately depend on decisions that reflect national priorities. 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 welfare 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 relative to fuel consumption are calculated and subjected to alternative constraint specifications in order 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 is presented in an appendix and only those features particularly relevant to 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 energy sector, which, as noted above, is one of the primary sources of environmental offense.

The model 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 from fuel use, although it is adaptable to other types of emissions associated with the use of any input or to the output of particular goods with specific technologies. 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. In the present context, it should be noted that environmental conditions do not enter directly into the consumer's utility function or production functions. However, the consumer's choice of goods in a consumption basket will depend on relative prices and income levels, which are determined within the model and will be affected by environmental policies.

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

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 production from each of the technologies. Thus, there is the possibility of substitution among inputs to production processes. The substitution is endogenously determined in response to the relative prices of inputs and outputs, also determined endogenously. This is important for the analysis of environmental policies that directly or indirectly affect the cost of inputs.

The alternative requirements for production in each sector are, with one exception, specified exogenously - as if 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 and will depend on relative prices and any constraints affecting those prices.

In addition to hydropower, only two primary hydrocarbon energy sources are distinguished, crude oil and natural gas; Egypt uses virtually no coal. Production of each fuel is constrained by availability. Crude oil is produced from petroleum reserves; the creation and use of these and of natural gas reserves is modeled so as to reflect the fact that reserve levels are a function of the rate, as well as the quantity, of resource use and of 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 carbon emissions. The back-up technologies in question 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 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 to the particular technology 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 and 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 tradeable 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 the real difficulties of these changes not otherwise caught in the model. No constraints are placed on the import or export of non-competitive goods.

The overall balance of payments constraint limits imports to what can be paid for from exports and foreign exchange resources. 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 in a relatively harmless manner. In the initial period, sectoral levels of investment are constrained below those actually achieved in 1987. In the terminal period of the model, 2087, sectoral levels of investment are determined by the condition that they be adequate to sustain an exogenously specified rate of output growth in the relevant sector during 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 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 $V_{i,j,k,t}$. So the total amount of carbon generated by the use of a particular fuel in the sector is obtained by summing over all technologies:

$$V_{i,j,t} = \Sigma_k V_{i,j,k,t}$$

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

$$V_{i,t} = \Sigma_j V_{i,j,t}$$

The generation of carbon is related to the use of the particular fuel in the sector by a coefficient, $v_{i,j,k,t}$. Thus:

$$V_{i,j,k,t} = v_{i,j,k,t} X_{j,k,t}$$

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, and all interactions are taken into account.

IV. Data base and parameterization

The data requirements 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 is based on a 37 sector transactions matrix for 1983/84 obtained from CAPMAS.[2] The original matrix is aggregated

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[2] Central Agency for Public Mobilization and Statistics.

into a ten sector classification, then adjusted and updated.

The specific number of production technologies provided as alternatives to those implicit in the transactions matrix in 1986/87 varies across sectors. In general, these alternatives allow for substitution between fuels, electricity, labor, and capital. They are 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, labor and energy, capital and energy, and electricity and fuels. The model also takes the unit demand for fuels as fixed for each technology; 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 are 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 are 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 is used for the econometric estimates. The database for estimating these parameters is constructed by pooling cross-section family budget data, which are available for two time periods, 1974/75 and 1980/81. On the whole, the estimated expenditure elasticities are within conventional ranges. However, since the estimates for the energy sectors seem somewhat unrealistic, elasticity estimates from other sources are relied upon. A Frisch parameter of -2 is 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 are based on an examination of the readily available literature. The figures chosen reflect a cautious optimism as to what is feasible. However, the authors would not attempt a vigorous defense for any of their guesses, but, as noted, would 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 both advantages and disadvantages in the kind of application to which it is put here. In analyzing the application of a particular policy to an economy, questions are always asked regarding assumptions made about adjustment to the policy. Is adjustment efficient, 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 carried out with perfect foresight over the model's time horizon. The implicit assumption is that economic agents will not wait until crisis is upon them, but instead anticipate the necessary economic adjustments before events overtake them and thus act efficiently to maximize their welfare.

As is customary in such modeling, a single solution is less interesting than comparisons among solutions; these latter provide insight into the problems of - and opportunities in - adjusting to new constraints. In the application reported here, economic outcomes with alternative patterns of carbon emission controls are compared to those without. In all cases the solutions are dynamically efficient with respect to the objective function. It is less clear in this case, therefore, 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 this sort. 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.

If additional restrictions in the form of lower emissions are imposed, then, even without actually solving the model, we know what the general nature of the results must be. If the constraints are binding, and it is expected that they will be, economic performance measured in terms of the objective function and 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.[3] Moreover, such changes would be once-and-for-all modifications whose effects would be 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 scenarios A, B and C, listed below. Scenario D extends several of the solutions from the previous scenarios, but without discounting the utility generated in each period; this is designed to help isolate the effects of such discounting in the various solutions. Scenario E investigates the consequences of making "backstop" and "renewables" technologies available for power generation.

The reference for presentation of the results of these various scenarios is the Base Solution, in which emissions are not constrained. It should be emphasized that this is different

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[3] The case is made in National Academy of Sciences (1991); but the evidence on costs is too sparse to inspire much confidence.

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.

A. To test effects of increasing required rate of emissions reductions with alternative beginning dates

A.1. 20% reduction in CO_2 emissions starting in 1997
A.2. 30% reduction in CO_2 emissions starting in 1997
A.3. 40% reduction in CO_2 emissions starting in 1997
A.4. 50% reduction in CO_2 emissions starting in 1997
A.5. 20% reduction in CO_2 emissions starting in 2007
A.6. 30% reduction in CO_2 emissions starting in 2007
A.7. 40% reduction in CO_2 emissions starting in 2007
A.8. 50% reduction in CO_2 emissions starting in 2007

B. To test effects of postponing beginning of emissions reductions

B.1. 20% reduction in CO_2 emissions starting in 1992
B.2. 20% reduction in CO_2 emissions starting in 1997
B.3. 20% reduction in CO_2 emissions starting in 2007
B.4. 20% reduction in CO_2 emissions starting in 2012
B.5. 30% reduction in CO_2 emissions starting in 1992
B.6. 30% reduction in CO_2 emissions starting in 1997
B.7. 30% reduction in CO_2 emissions starting in 2007
B.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 of more fundamental environmental interest. Scenario C focuses on this variable.

C. To test effects of reductions in accumulated emissions over entire time horizon

C.1. 10% reduction in accumulated emissions over the reported time horizon
C.2. 20% reduction in accumulated emissions over the reported time horizon
C.3. 30% reduction in accumulated emissions over the reported time horizon
C.4. 40% reduction in accumulated emissions over the reported time horizon
C.5. 50% reduction in accumulated emissions over the reported time horizon

The role of discounting in the analysis of greenhouse warming's effects has been the subject of some controversy. What are the consequences of discounting the results of emissions restrictions intended to ameliorate global warming? The set of scenarios under D aim to elucidate these issues by computing solutions for several of the previous specifications, but with the discount rate set at zero. Comparison with the results from cases involving discounted utility, then permit isolation of the effects of discounting.

D. To investigate the consequences of discounting of utility in the objective function

D.1. Base solution with no discounting of utility
D.2. 30% annual reduction in CO_2 emissions starting in 1992 with no discounting of utility
D.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 adopting 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.

E. To test effects of conventional backstop technologies

E.1. Co-generation, nuclear and gas-transport and A.1.
E.2. Co-generation, nuclear and gas-transport and A.2.
E.3. Co-generation, nuclear and gas-transport and A.3
E.4. Co-generation, nuclear and gas-transport and C.3.

F. To test effects of conventional and renewables backstop technologies

F.1. Original renewables technology with low insolation levels and A.3.
F.2. Original renewables technology with medium insolation levels and A.3.
F.3. Original renewables technology with high insolation levels and A.3.
F.4. Renewables technology with lowest marginal cost in 2032 with high insolation levels and A.3.
F.5. Renewables technology with lowest marginal cost in 2042 with high insolation levels and A.3.
F.6. Renewables technology with lowest marginal cost in 2052 with high insolation levels and A.3.

Not all of these alternative specifications will be reported upon; they are listed to illustrate the variety of policy alternatives 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 than is of interest. The emphasis in the results reported will be on the associated changes in welfare, 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 serves as the reference to which all alternative scenario solutions are compared, is computed with the structure and parameters described above. It is not intended to be a projection of what would actually happen in Egypt, if no carbon emissions restriction were imposed. Nor does it necessarily represent a set of policies that Egypt should follow. Instead, it should be regarded as the outline of a path of development that is potentially consistent, feasible and desirable in terms of satisfying consumer demands.

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

As can be seen in Table 1, the Basic Solution generates plausible growth rates of 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 international borrowing constraints. GDP growth rates accelerate slowly to 2042 after which they decline somewhat, as a result of declining reserves of crude oil and natural gas. The initial high rate of investment growth reflects the model's internal decision to carry out a substantial restructuring of the economy. The model reacts to real relative scarcities reflected in the data and parameters that represent the economy, rather than the distorted prices which characterize the initial conditions.

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

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

Year	GDP	Private Consumption	Investment	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

Table 2 shows the substantial changes in the structure of the model economy which occur over time. While during the first fifteen years there is a growth in the relative share of the agricultural sector, this share declines steadily after 2002. This initial growth in agriculture is the result of the relatively high initial demand for manufactured goods to supply desired investment. 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.[4]

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; thus its share declines. The long term decline in agriculture and the expansion of manufacturing sectors reflects the relative productivity of resources in the two sectors and their relative earnings from exports.

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

Year	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; it 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 insufficient to keep up with growing demand. A similar pattern exists for natural gas, which also declines relative to the economy as a whole. The same forces are also evident in 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.

The declining share of the electricity sector should be noted. The high initial level in 1987 reflects, to a considerable extent, the artificially low price in that sector. As real relative scarcity increases, relative demand falls 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 later result, namely 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 the sector.

There is an initial fall and a subsequent increase in emissions from the electricity sector; this is the net consequence of two factors. In the model solution the scarcity price of electricity is higher than it was in the data for the base year, when it was kept at an artificially low level.

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[4] 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.

Table 3 Structure Of The Energy Sectors in Base Solution Shares in GDP (percent)

Year	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

As a result of the higher scarcity price, private consumption substitution away from electric power use begins to occur immediately. 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, which both reduces emissions and conserves petroleum for other uses. Natural gas has fewer carbon emissions than petroleum, and this further 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 initially due to slower growth of output from the sector as increasing real prices constrain demand. The increases from 2017 onward reflect, in particular, increasing producer demands.

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

Table 4 Sectoral Contributions to Total Carbon Emissions (per cent)

Year	Agriculture	Manufacturing	Petroleum products	Electricity	Construction	Transport	Services	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

VII. Insights from alternative scenarios

The alternative scenarios provide a rich set of insights about the consequences of different forms of emissions restrictions. The macroeconomic consequences result from intricate and extensive underlying microeconomic adjustments. In this survey, major consequences are described together with a short explanation for their occurrence. In general, as pointed out above, it should not be surprising that with additional constraints, the performance of the economy deteriorates. Significantly from a practical point of view, the form and timing of the constraints have important consequences for their impact.

In the base case model solution's first period, 1992, there are many readjustments in the structure of the economy, as compared to the initial conditions, even though carbon emissions restrictions have yet to be imposed. 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 adjusting initial capital stocks and preparing for the imposition of carbon emissions. By 2007 there have been twenty years of adjustment and preparation; by 2012, twenty-five years.

Effects of increasingly restrictive limits on annual emissions

Scenario A imposes on emissions different levels of constraint with different starting points. Conventional modeling of the economic effects of imposing emissions restrictions tends to report resultant losses in GDP. While there is doubt as to whether these are the most relevant set of observations, here they are taken as a starting point for analysis of the results.

Chart 1 reports the reductions in 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 growth rates achieved; lower rates are associated with higher levels of emissions restrictions and earlier starting dates. Perhaps even more striking are the relatively small differences in GDP growth rates.

The percentage reduction in GDP is virtually the same for each specified rate of reduction in carbon emissions, whenever 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, again regardless of the restrictions' beginning date. 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 is simply unable to identify a feasible solution when the required rate of reduction in emissions is 40 per cent beginning in 1987. It should come as no surprise that there are some emissions reduction requirements that cannot be met, even in this optimizing model, with perfect foresight and efficiency in the allocation of resources.

The low sensitivity of GDP growth to restrictions on carbon emissions would seem to be consistent with results from other models that find relatively small losses in GDP resulting 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 is the very long run horizon of the model. The emissions constraints begin at different times, but all start in the early years of the model horizon. The later years dominate in terms of GDP growth over the entire horizon of the model. The second determinant is the fact that, after some initial adjustments in the capital stock and labor force, this model uses all available resources. So differences in GDP are due only to small differences in relative prices.

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

On further reflection, this convergence is unsurprising. 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. Economic theory suggests that steady state growth conditions are not much affected by constraints such as those imposed here; they can be interpreted as a kind of tax.

These results show how long run growth rates can be misleading as indicators of the burdens imposed by carbon emissions restrictions. Charts 3A and 3B, which present the time paths of GDP levels for Scenario A's alternatives, further demonstrate this same point. 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 emissions constraints. The difference between projected and achieved GDP levels ranges 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.

Chart 1

GDP Growth Effects of CO2 Reductions

With Alternative Beginning Dates

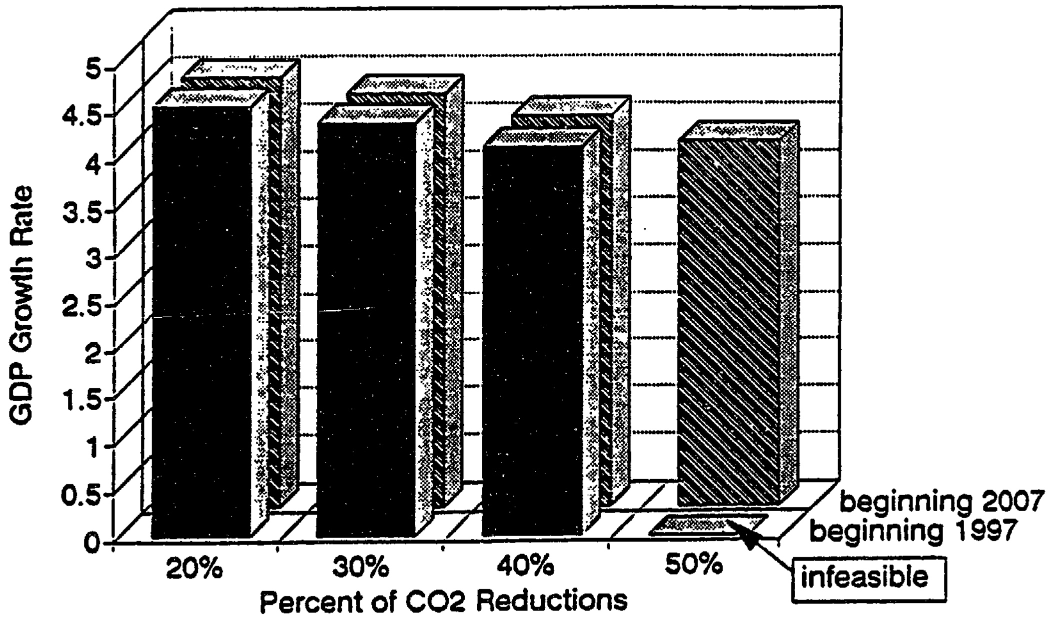


Chart 2A

Time Path of GDP Growth Rates

With Reductions in CO2 beginning 1997

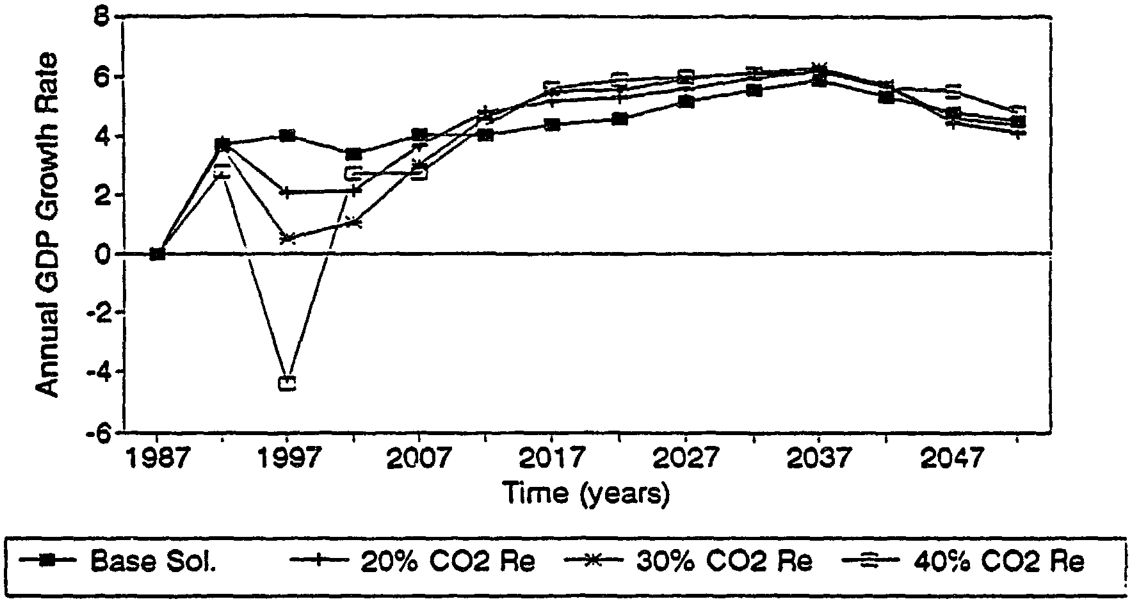


Chart 2B

Time Path of GDP Growth Rates

Of Reductions in CO2 beginning 2007

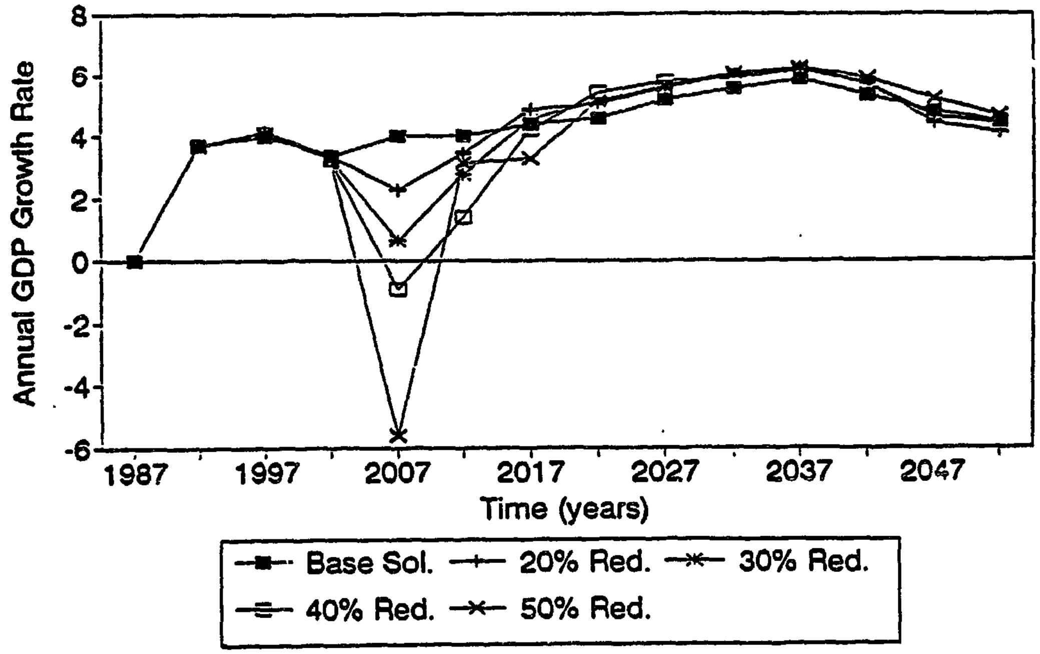


Chart 3A

GDP Reductions Due to Emissions Limits

Constraints Beginning in 1997

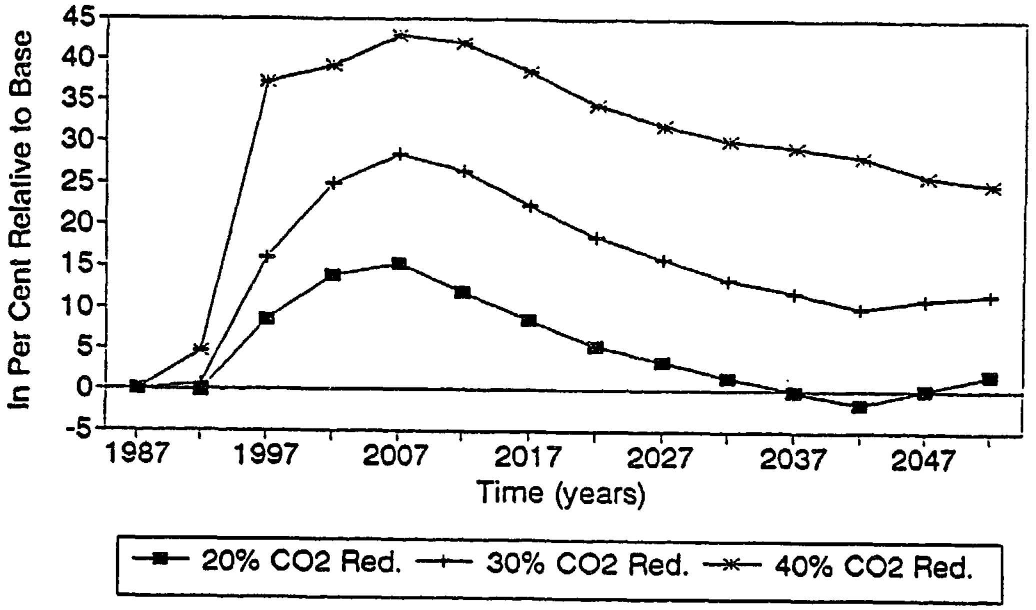
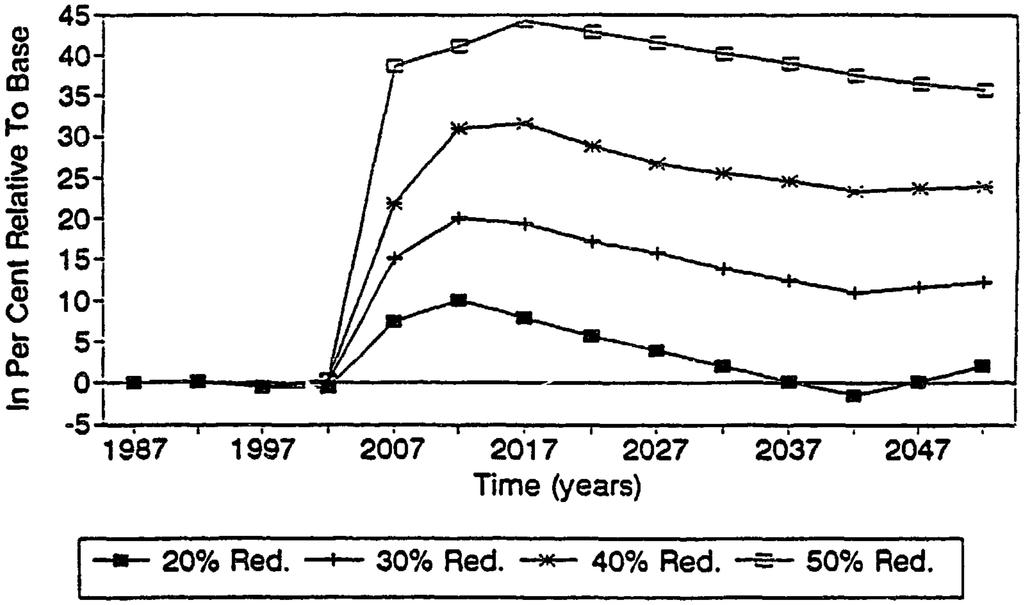


Chart 3B

GDP Reductions Due to Emissions Limits

Constraints Beginning in 2007



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 in the absence of 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 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 compared to other models used for the same purpose. That implies less substitutability, since the implicit assumption of aggregation is that all output and resources within a sectoral aggregate are perfect substitutes.

Third, Egypt uses petroleum products and natural gas as fuels, but virtually no coal. Substitution of petroleum products and, in particular, natural gas for coal, which can be a major form of adjustment to lower carbon emissions in other economies, is already an essential feature of the Egyptian economy. Requiring uniform rates of emissions reductions across economies would therefore 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, because of resource shortages and a substantial international debt, which limits 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. The welfare function that is maximized in this model is "synthetic" in several senses. Certainly it is not deduced from first principles. Second, data limitations restrict the potential of the econometric methods used to estimate the consumption parameters. Third, the welfare function leaves out possible 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. Indirect benefits would include the avoidance of the additional real production and infrastructural costs necessary to counter the effects of any global warming.

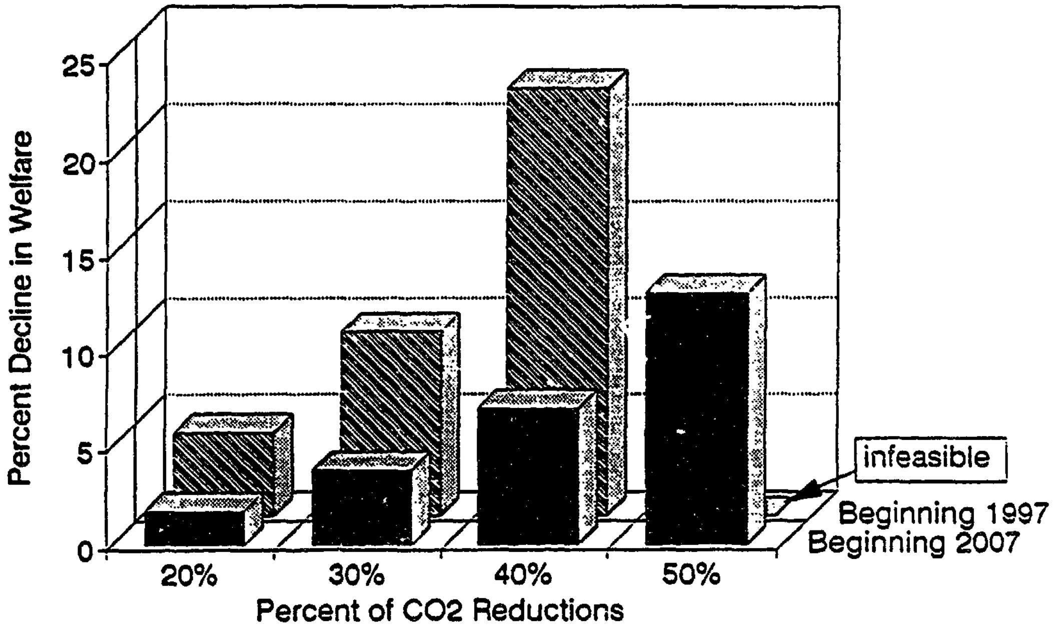
Natural skepticism may be offset by thinking of the maximand simply as a weighted index of discounted consumption, rather than as a welfare function. The particular index chosen is a plausible one, but subject to many disclaimers.

The welfare losses (relative to the base solution) of imposing different rates of carbon

Chart 4

Welfare Effects of CO2 Reductions

With Alternative Beginning Dates



emissions reductions with alternative beginning dates, are shown in Chart 4.[5] If the reductions must begin in 1992, then welfare losses are 4.3 per cent for twenty per cent reductions in CO_2 emission rates, 9.5 per cent for 30 per cent reductions, and 22 per cent for 40 per cent reductions.

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

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 losses by more than two-thirds; and a 25 year delay, by almost 80 per cent, to less than two per cent of the base year total welfare.

As Chart 4 reveals, effects are relatively nonlinear both with respect to the magnitudes of required reductions in carbon emissions and with respect to timing. The elasticity of welfare

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[5] The welfare losses shown are computed for the period to 2030 only.

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 available resources, 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. William Nordhaus, for example, in discussing projections of relatively high short run emission reduction costs, notes that "the short run gradually turns into the long run so that the high short run costs of a surprise increase in prices soon become the lower long run costs."[6] That is, of course, true. But, as indicated in Charts 3 and 4 above, the high short run costs create high welfare losses that do not go away.

The losses are not simply the result of a "surprise" increase in prices, since in none of solutions described above do the emissions constraints arise unexpectedly. 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 less efficient than those without the constraints. That is not to say that the benefits of future climate conditions will more than offset their costs; the present game is simply the calculation of costs.

Turning to other aspects of the Scenario A 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, since these have relatively high carbon emissions ratios. The model solution compensates in two ways: first, by substituting, when possible, the output of other sectors for the output of these high emitting sectors, in response to the endogenous increase in the prices of these two sectors; second, by increasing manufacturing imports, noting that imports of transport and electricity are not possible.

In the Base Solution, the model shifts resources out of agriculture. In the solutions shown in Chart 5, when emissions reductions are 20 percent, there is an increase in domestic agricultural production, as compared to the base solution. That is one aspect of the substitution mentioned above. Since agriculture has relatively low emissions, the model increases its domestic production. The foreign exchange resources earlier used to import agricultural goods are now used to import manufactures. These adjustments demonstrate the effect of the emissions restrictions in changing comparative advantage. They also show the natural tendency of following a "dirty thy neighbor" policy by importing products whose production generates a relatively large quantity of unwanted emissions, and by producing relatively clean products at home.

Chart 5 also indicates that when the rate of emission reduction is increased to 30 per cent

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[6] W. Nordhaus, (1991).

Chart 5A

Sectoral Growth Effects of Reductions in CO2 beginning 1997

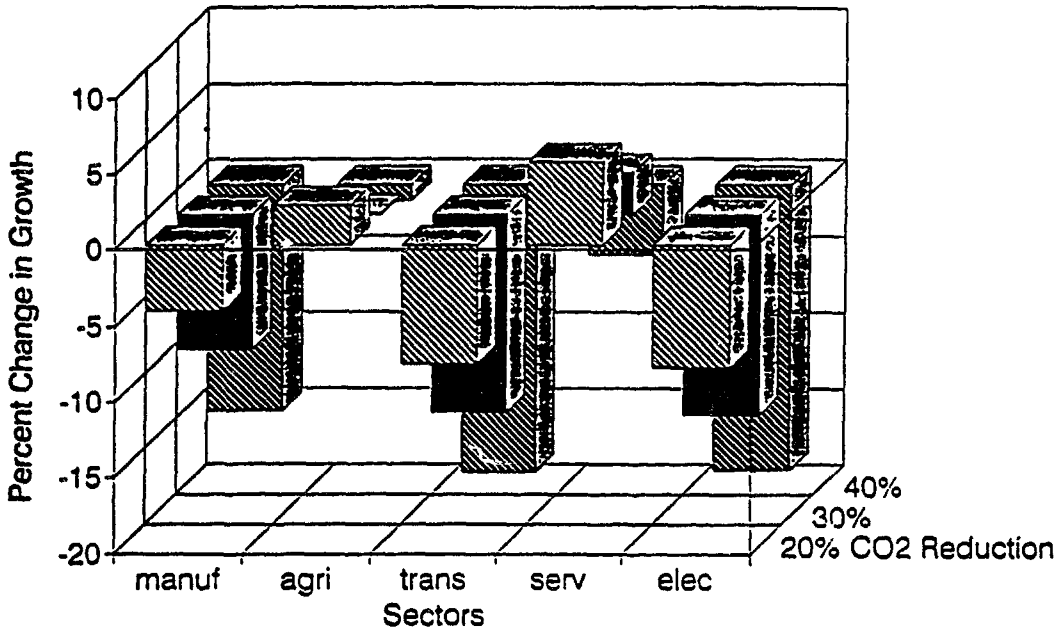
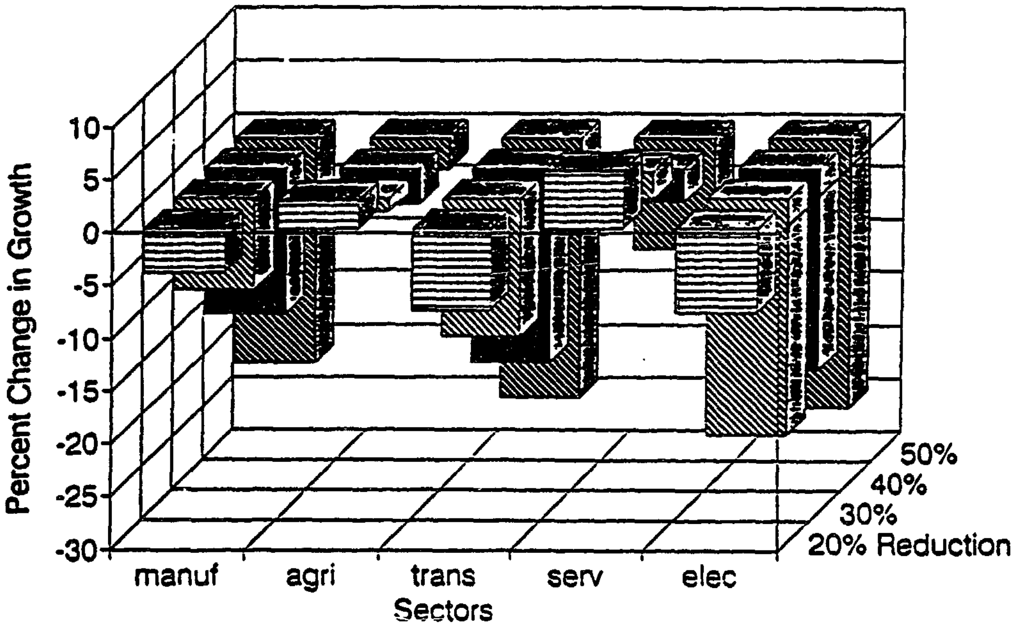


Chart 5B

Sectoral Growth Effects of Reductions in CO2 beginning 2007



and above, the increase in agricultural production is much less than at 20 percent emission reductions. This is the result of the increased difficulty 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 being incidental to the main points made above.

Effects of postponing constraints on annual CO_2 emissions

Scenario B is designed to explore further the effects of postponing the beginning of emissions restrictions. The time paths of GDP associated with alternative rates of emissions restrictions and alternative beginning dates, 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 B. Again, welfare losses are reduced by postponement.

There are three major reasons for these results. Postponing the beginning of the emissions restrictions allows the model more time to adjust technologies and capital structure. This 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, which means there can be more consumption in its earlier years. 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 of utility being discounted. (The effects of discounting are explored in Scenario D.)

Effects of constraints on accumulated emissions

Although the scenarios listed under C may seem similar to those specified previously, they imply a major shift in policy. Rather than stipulating changed emissions rates, they mandate changes in accumulated emissions over the entire model horizon, relative to the level of (unconstrained) accumulated emissions in the base solution. Such a policy is to be preferred for several reasons. Control of accumulated emissions is more closely identified with the total amount of greenhouse gases in the environment, which is the actual source of global warming. The effectiveness of emissions control policies should therefore be judged in terms of accumulated emissions over the policy horizon, rather than in terms of the emissions rate in any particular period. Imposing the constraint on accumulated emissions also provides an important additional degree of policy flexibility, since it allows a country to optimize degree and timing of emissions reductions, consistent with meeting a target for reduction of total emissions over a specified period.

Chart 6A

Time Path of GDP Reductions

Due to a 20% Reduction in CO2

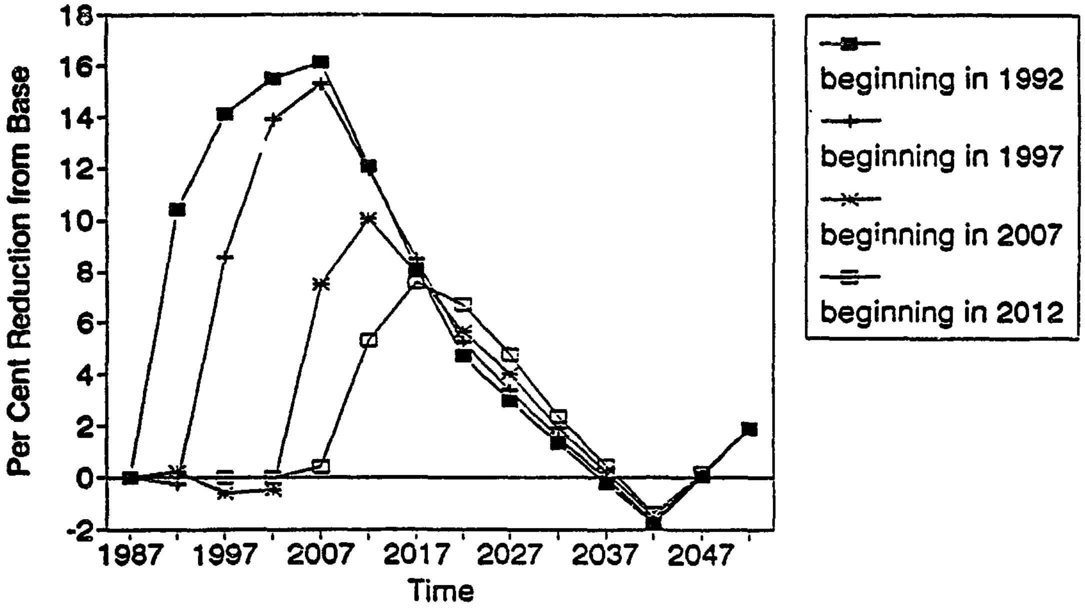


Chart 6B

Time Path of GDP Reductions

Due to a 30% Reduction in CO2

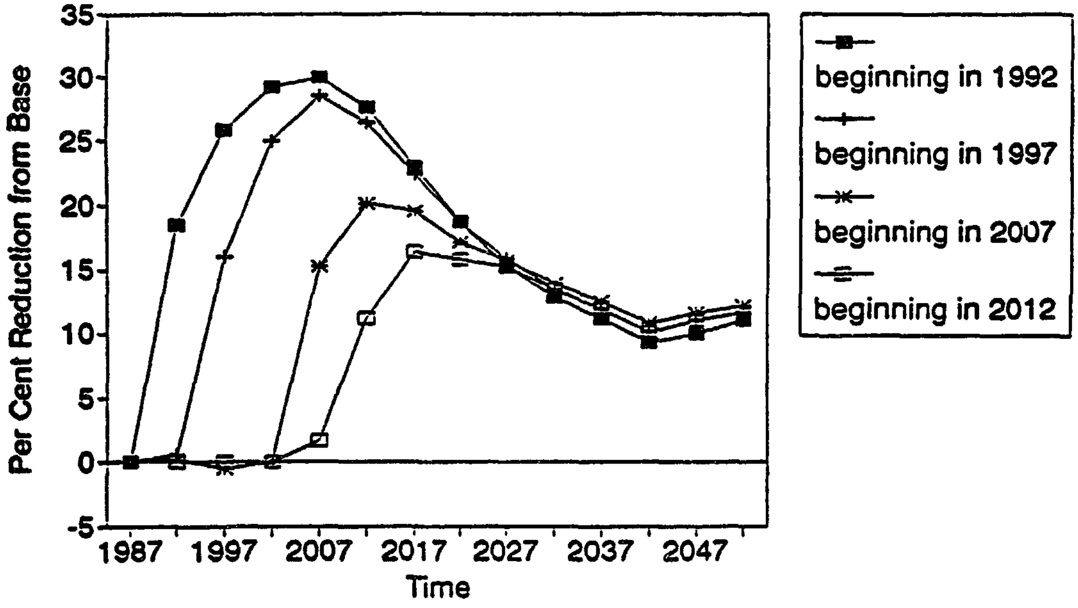


Chart 6C

Time Path of GDP Reductions

Due to a 40% Reduction in CO2

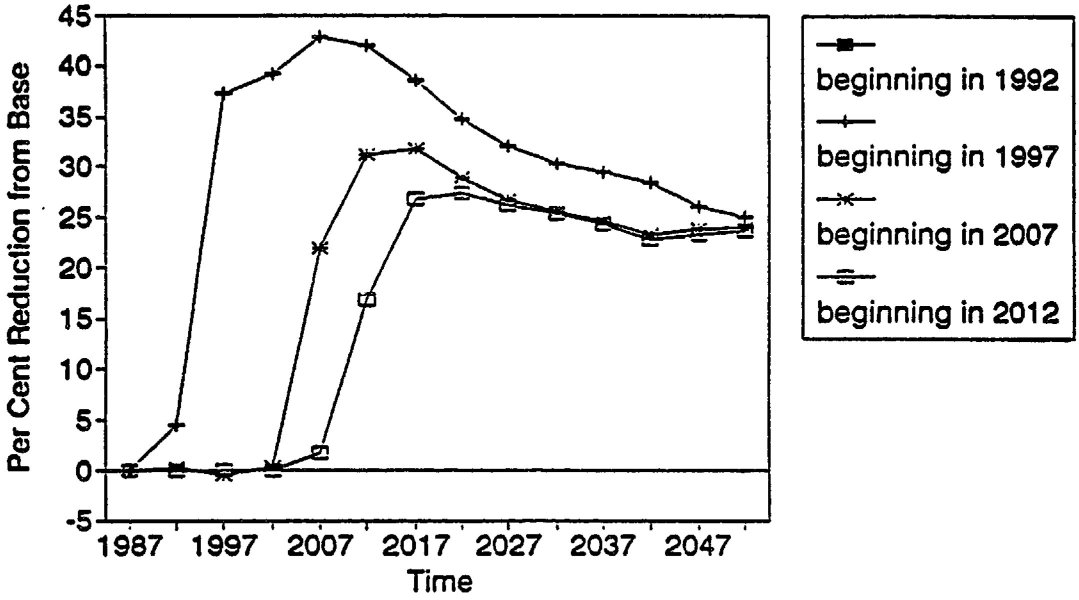
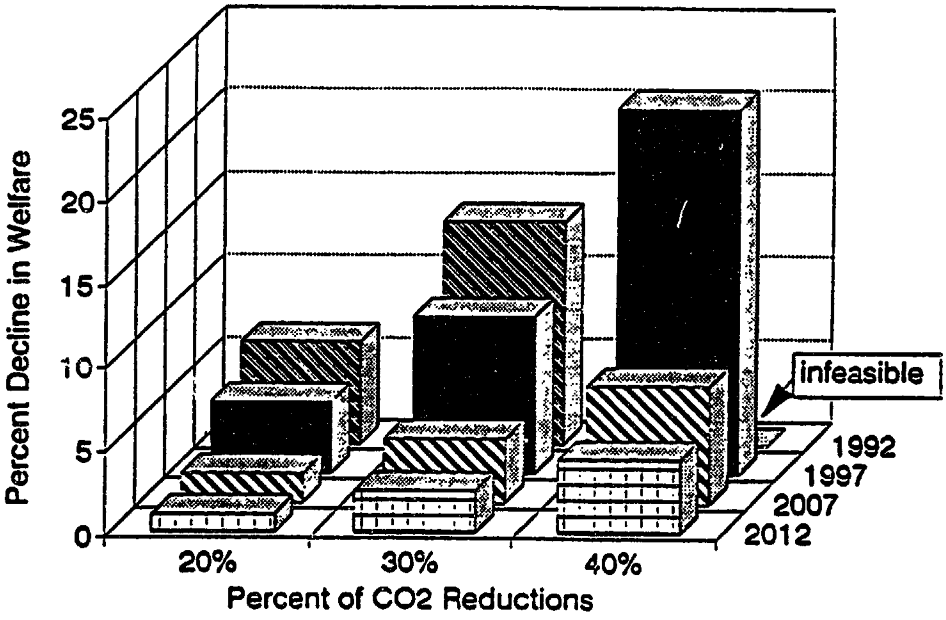


Chart 7

Welfare Effects of CO2 Reductions

With Alternative Beginning Dates



The consequences of stipulating reductions in accumulated emissions over the model's horizon are best shown by comparing results with the outcomes generated when annual rates of emissions reduction are specified. These consequences are shown in Charts 8A, 8B and 8C, which compare 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 time for adjustments to the expected emissions constraint. Second, there is always a welfare gain from postponing reductions in consumption, since the welfare function incorporates discounting considerations.

The manner in which the model utilizes the additional flexibility noted above 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 Base Solution. In each case, with a modest exception in the 50 per cent reduction scenario, 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. Furthermore, in all cases, the maximum annual reduction rate attained is substantially above the average annual reduction rate.

Scenario C provides an important lesson: to achieve a specified reduction in the accumulation of greenhouse gases in the atmosphere, it is far better to allow for flexibility in the timing of adjustment policies, rather than imposing a particular deadline. The lesson is a general one, applicable to advanced countries as well: rigidities in the imposition of limits on emissions controls have unnecessary economic costs.

Chart 8A

GDP Reductions Due to Emissions Limits

20% CO2 Reduction Starting in 1992

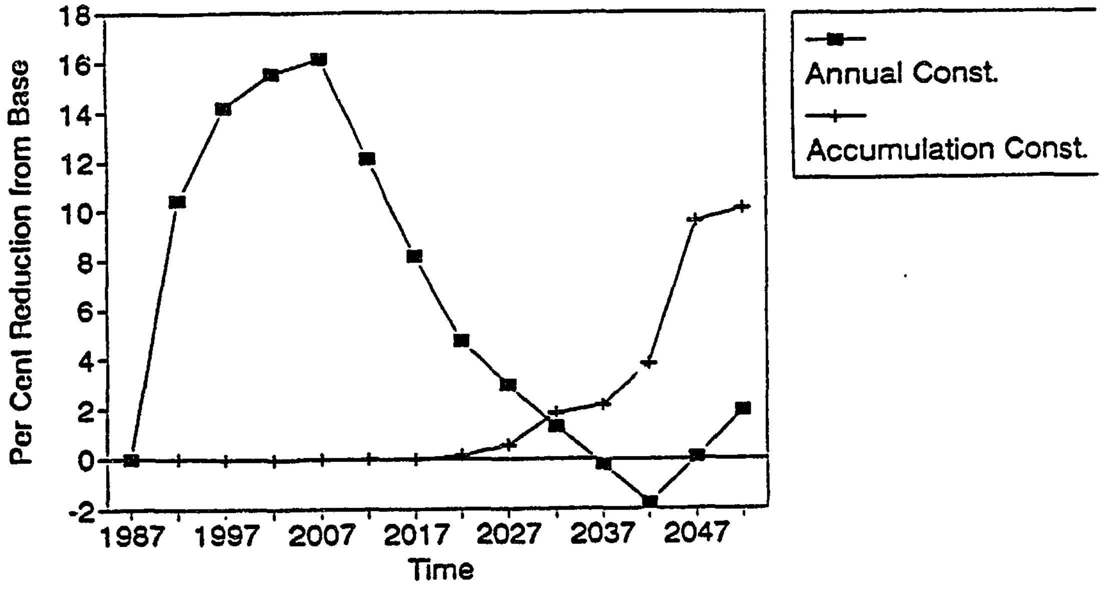


Chart 8B

GDP Reductions Due to Emissions Limits

30% CO2 Reductiion Starting in 1992

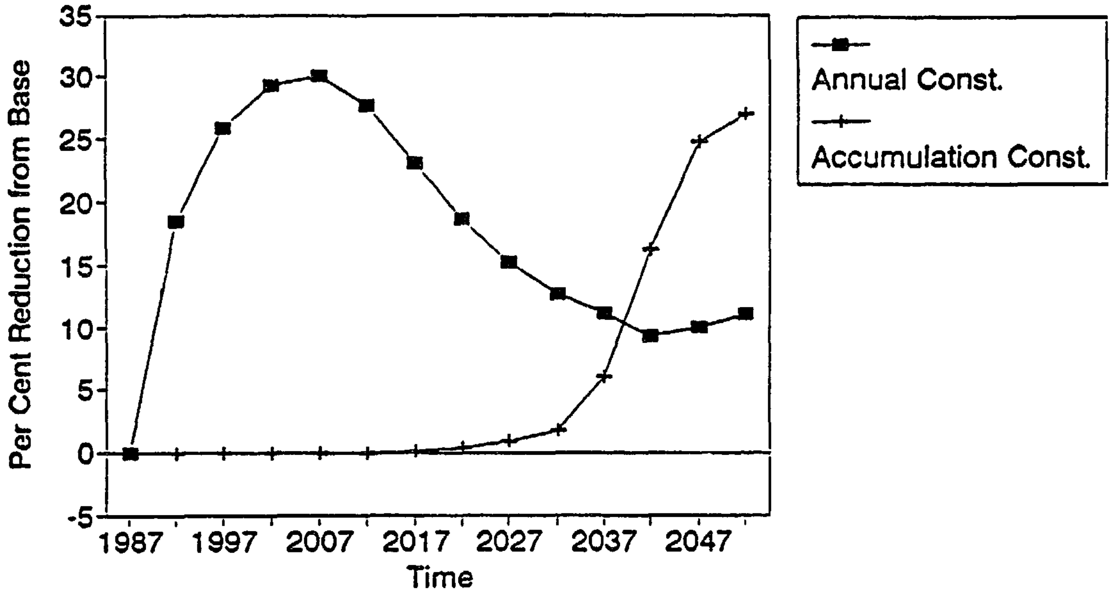


Chart 8C

GDP Reductions Due to Emissions Limits

40% CO2 Reduction Starting in 1992

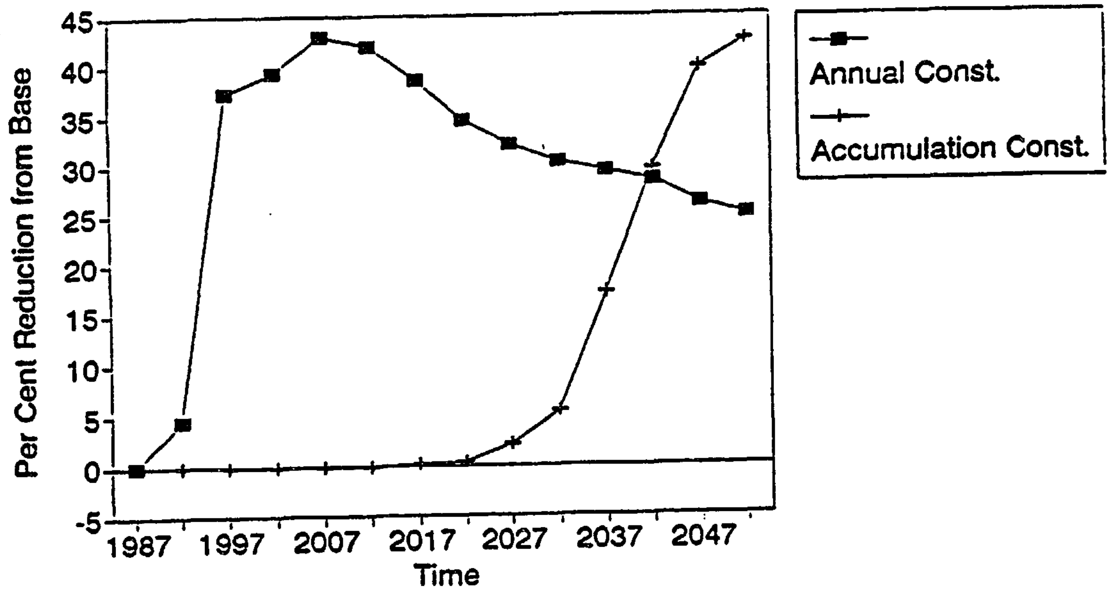


Chart 9

Welfare Effects of CO2 Reductions

With Alternative Emission Constraints

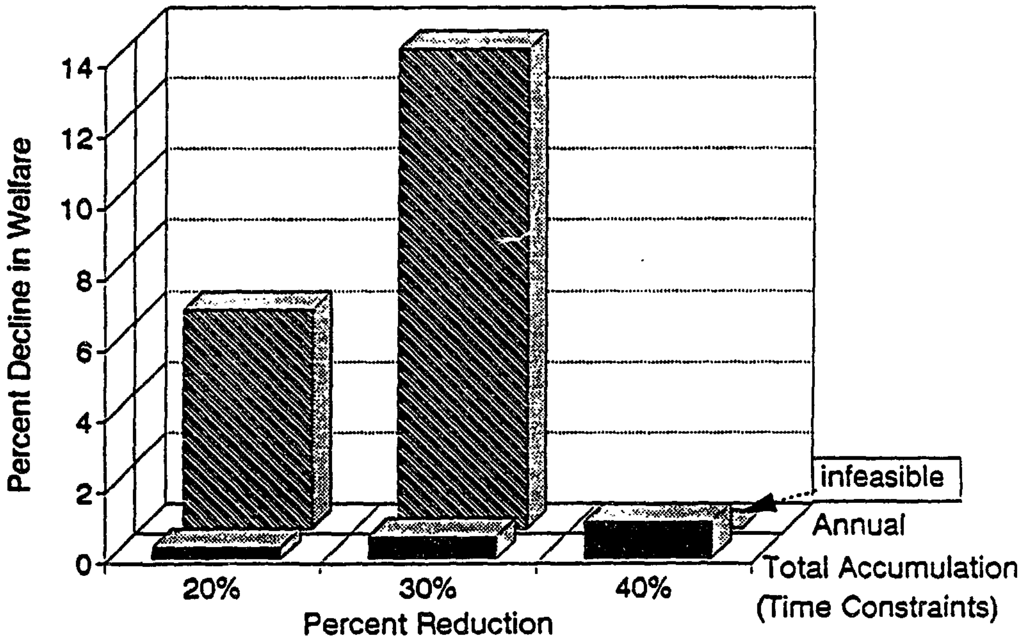
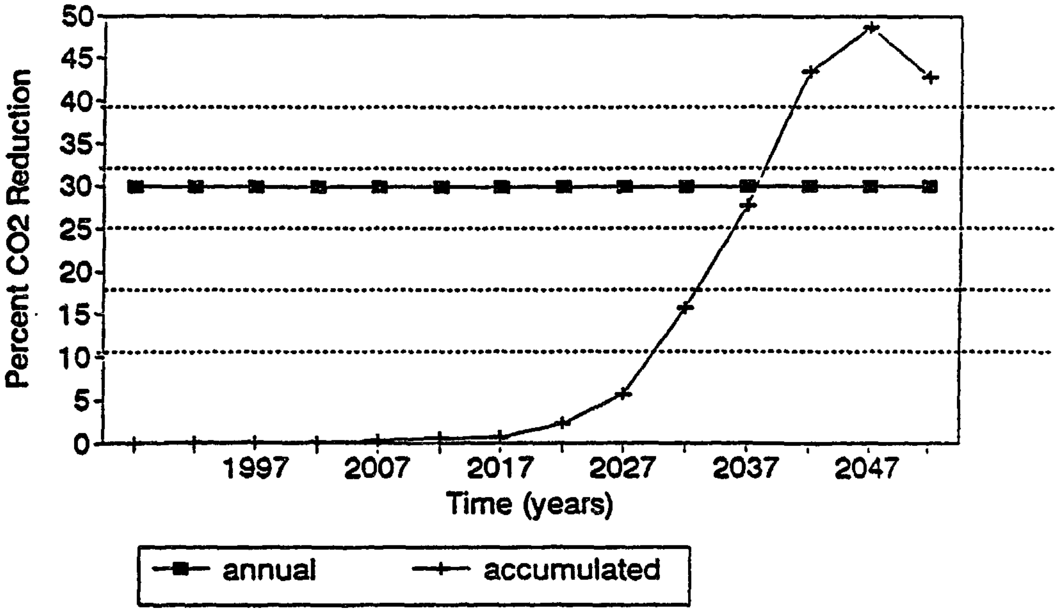


Chart 10

Time-path of CO2 Reductions

under a 30% emissions constraint



There may be an important qualification imposed by the physical processes of greenhouse warming, which is that the timing of any delay in the reduction of emissions will, itself, have consequences for the ultimate change in temperature, etc.. It has not been possible to find an analysis of this question in the literature. Analyses which do address the consequences of delaying the start of emissions restrictions, do not deal with the pattern of emissions restrictions stipulated in Scenario C. In the solutions obtained for this Scenario, although the starting date of the emissions restrictions is delayed, the total amount of reduced emissions is the same as in corresponding solutions to which comparisons are made in Charts 8 and 9 above.

There is one other significant qualification to these results. In effect, Scenario C simulates the outcome of a commitment to an allowable total accumulation of emissions. While the benefits are manifest and would be enjoyed in the relatively early years of the commitment, the costs of the commitment appear only in later years and appearing with them would be the temptation to violate its terms.

Effects of not discounting utility in the objective function

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, which 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 the ratios of GDP, consumption and investment in the undiscounted solution to the same values obtained in the solution discounted 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 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. The quirks are, 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. Subsequent and relatively larger consumption, investment and GDP levels are the payoffs from that initial difference in investment. Lower consumption in the first period in the undiscounted solution is more than offset by later increases, because the latter are not discounted.

The solutions with constraints on annual emissions and accumulated emissions show generally similar behavior in the sense that it is not discounting which accounts for the temporal patterns of consumption. There is some shifting around in the relative results, but this is insignificant when compared to 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/GDP	Consumption/ Consumption	Investment/ Investment
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 provides further confirmation. 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 flexibility of meeting constraints on accumulated emissions can be directly observed; in essence, adjustment is delayed and consumption relatively increased.

Table 6 Annual Levels of Consumption

	Discounted Solutions			Undiscounted Solutions		
Year	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 annual levels of consumption for undiscounted solutions. Despite their lack of discounting in the objective function, these solutions show essentially the same relative behavior as similar solutions in which there is discounting. When given the freedom to put off the adjustment, the model utilizes that time to effect a relative increase in consumption during the earlier periods, at the expense of later periods.

The contribution of backstop technologies

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

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 generally both substantially higher. These differences are shown in Charts 11 and 12.

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

CHART 11

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

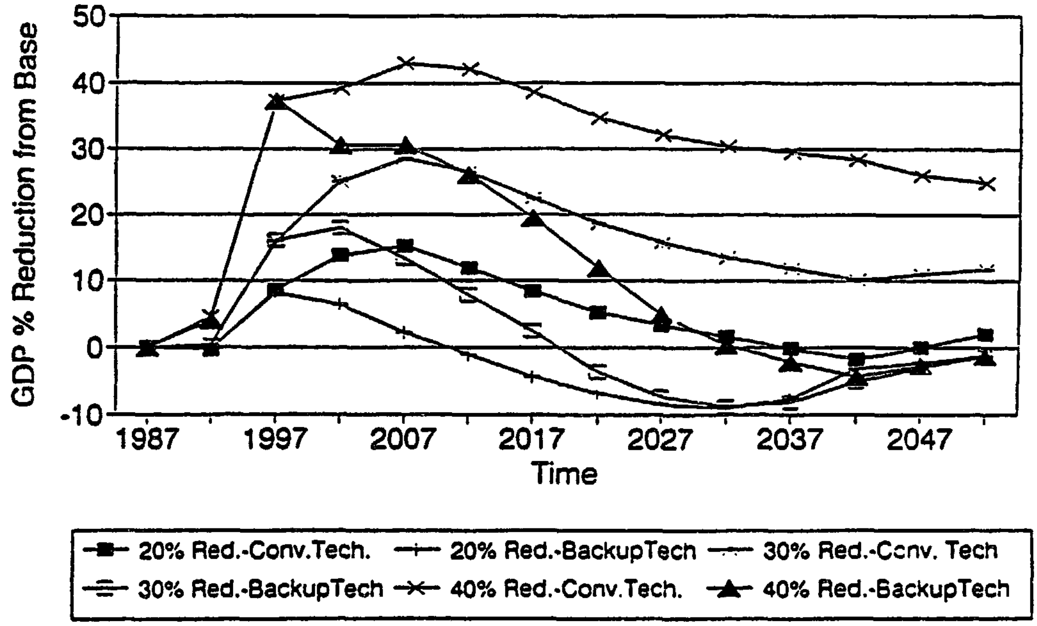
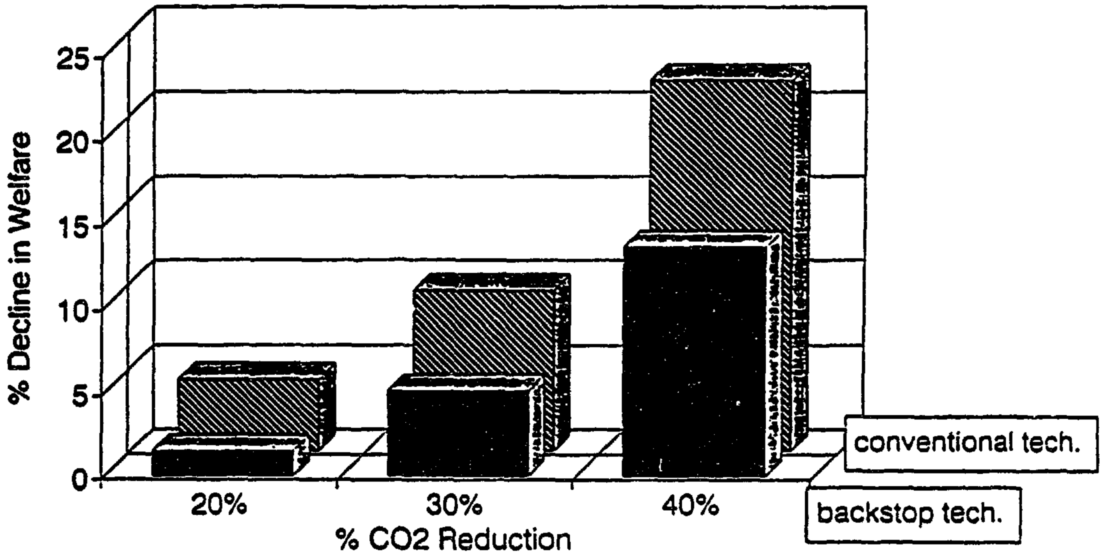


Chart 12

Welfare Effects of CO2 Reduction

With Alternative Emission Constraints



Once available, the gas-powered transport technological option is also used, until the price of natural gas rises due to depletion of domestic reserves.

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

The contribution of "renewable" technologies

Finally, in Scenario F, the experiments with the model were done with "renewable" electricity generating technologies: photovoltaic, solar-thermal, and dendroelectric power. These, together with the "backstop" technologies, are all summarized in a single representative "alternative" technology. This technology embodies different assumptions about the "renewable" technologies, including the degree of sunlight available and a time-dependent reduction in costs; this latter reflecting expectations of future technological improvements.

The lowest unit costs, for each level of insolation, are reached in 2022 in Scenarios F.1., F.2. and F.3.. In Scenarios F.4., F.5. and F.6., high insolation levels are assumed but the date at which the minimum cost is achieved is stretched to 2032, 2042 and 2052, respectively. The renewable technologies are 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

Chart 13

Time Path of GDP % Reduction from Base
30 Percent Less Accumulated Emissions

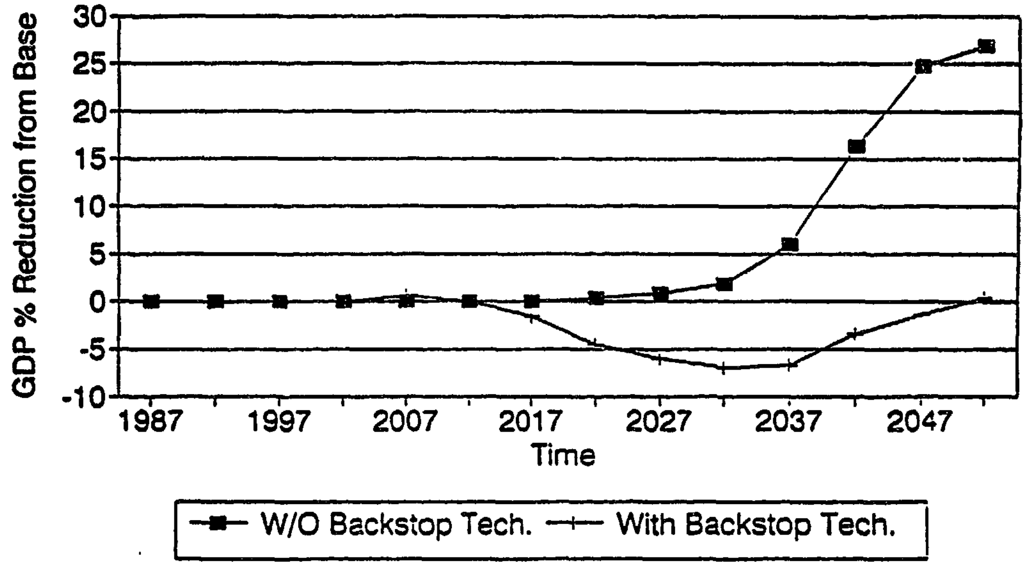
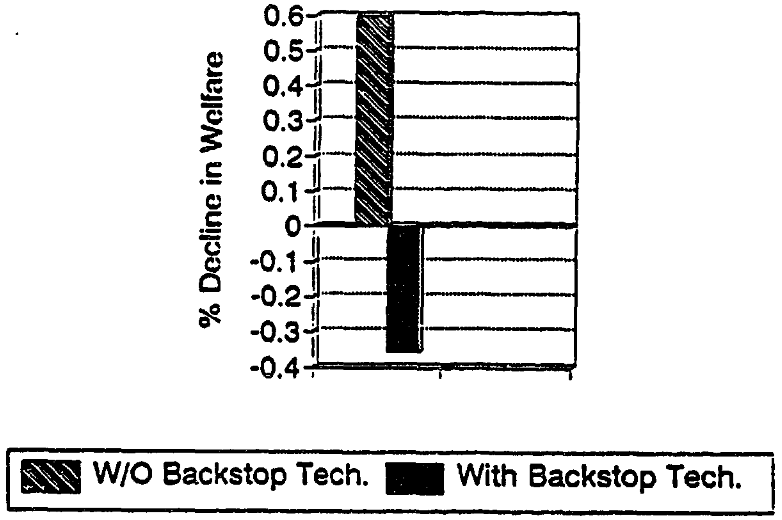


Chart 14

Welfare Effects of CO2 Reduction

With 30 % Less Accumulated Emissions



presented.

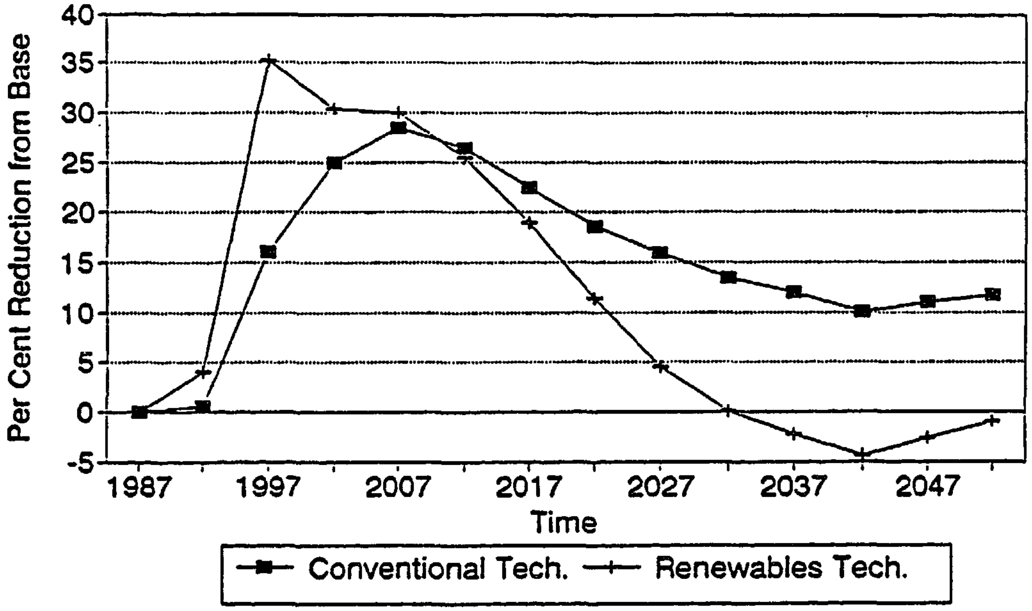
The direct and indirect costs of the renewable technologies are shown to be relatively high compared to the backstop and conventional technologies, for all except the cases in which high levels of sunlight are assumed. As a result, the solutions with the renewable and backstop technologies show improvements in performance relative to solutions with only the more conventional backstop technologies. The renewable technologies are introduced into the solution in 1997, before the date at which the backstop technologies are 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 renewable technologies and their capital is allowed to depreciate. The results of one case are illustrated in Chart 15.

The renewables technology, with assumed high insolation, is used intensively once domestic gas reserves become severely depleted and carbon emissions restrictions are severe.

Chart 15

Time Path of GDP Reduction

Due to a 30% Reduction in CO2



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 these results, and those of other models. The substantive insights indicate the comparative advantages of alternative forms of carbon emissions restrictions, as well as the particular contributions of conventional and unconventional backstop technologies to 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 depletes its hydrocarbon reserves, which are the only non-produced 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 growth rates that are much the same, with and without carbon emissions restrictions.

The differences in GDP growth results created by carbon emissions restrictions that have been reported from models of this type and, presumably, other models are, therefore, not principally the result of the particular emissions restrictions 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 restrictions make no difference to the performance of an economy. A better measure of performance than GDP growth rates is the welfare 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, although the adjustments due to carbon emissions restrictions create differences in effective productivity of the resources used. For this reason also, a measure of the consumption that the model economy can deliver is a better indicator of performance than GDP.

Welfare losses due to the imposition of annual restrictions on the rate of carbon emissions are quite substantial, ranging from 4.5 per cent 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 relatively nonlinear.

The results show that the timing of the emissions restrictions is also significant. 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.

Furthermore, the form of the emissions restrictions is important. Although all other models and nearly all accompanying debate focus on the effect of annual rates of emissions, the more critical issue is the total addition to the accumulation of greenhouse gases in the environment. When the emissions constraint is imposed 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; moreover, the model further delays the reduction in emissions restrictions in order to provide consumption goods relatively early in its horizon, when 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 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 a set of unconventional "renewable" technologies. The latter cannot effectively 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 as a means of comparing the results of generic, "What if...?" questions. While there may be further questions of this sort to examine, the results thus far justify the efforts involved.

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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

Table 7 (cont.)

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
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 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

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

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

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

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

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

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

Balance of Payments and Trade Constraints

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

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

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

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

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

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

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