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How Restricting Carbon Dioxide and Methane Emissions Would Affect the Indian Economy

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The economic effects on India of restricting carbon dioxide and methane emissions would be profound. Would compliance with international agreements for emission restrictions be more likely if they required annual, rather than cumulative, reductions?

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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 (September 1992, 40 pages).

India and China between them contain about 40 percent of the earth's people. They are at an early stage of economic development, and their increasingly massive energy requirements will depend heavily on coal, a potent source of carbon dioxide, a powerful and long-lasting greenhouse gas.

India also has important sources and uses of hydroelectric and nuclear power, petroleum, and natural gas. Agriculture still produces about 30 percent of its gross domestic product, and about 72 percent of the population lives in rural areas — with their large animal populations and substantial forest acreage. India has vast cities and an industrial sector that is large in absolute terms, although it represents only 30 percent of the economy.

The model developed to analyze the economic effects of constraints on greenhouse gas emissions is a multisectoral, intertemporal linear programming model, driven by the optimization of the welfare of a representative consumer. A comprehensive model was built not to project the future at a single stroke but to begin to answer questions of a "What if?" form.

The results strongly suggest that the economic effects on India of such constraints would be profound.

The implications of different forms of emissions restrictions — annual, cumulative, and radiative forcing — deserve more attention. Cumulative restrictions — or better still, restrictions on radiative forcing — are closely related to public policy on greenhouse effects. Such restrictions also provide significant additional degrees of freedom for the economic adjustments required. They do this, in part, by allowing the postponement of emissions restrictions, which is not permitted by annual constraints. Of course, the question arises whether a country, having benefited from postponing a required reduction in emissions, would then be willing to face the consequences in economic losses.

Might there be a genuine preference — albeit an irrational one — for taking the losses annually? Would compliance with international agreements for emission restrictions be more likely if they required annual, rather than cumulative, reductions? Monitoring requirements would be the same in either case; if effective monitoring were carried out, it would detect departures from cumulative or radiative forcing constraints just as easily as departures from annual constraints.

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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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I. Introduction

India and China are two of global environmentalism's great worries. As the world's world's population giants, they have between them roughly forty percent of the earth's people. They are each still at an early stage of their potential economic development and their increasingly massive energy requirements will be heavily dependent on coal, a potent source of carbon dioxide - itself a powerful and long-lasting greenhouse gas. It is thus especially important to try to understand both the potential impact that Indian and Chinese economic development might have on the global environment, and the potential economic consequences of constraining their emissions of greenhouse gases. This study focuses on India, whose data sources are relatively accessible.[1]

The authors have argued the point elsewhere that it is important that studies of the economic consequences of greenhouse gas emission restrictions be undertaken for particular countries on a relatively disaggregated basis.[2] While international negotiations on greenhouse warming proceed, participation in any agreements will effectively be decided at the country level. Individual nations will, implicitly or explicitly, make their own benefit-cost analyses, as well as assessments of the global consequences of their environmental policies; in this process they will, inevitably, take account of the manner in which greenhouse gas emission restrictions will affect their own economies. They will also take into account the likely regional effects of global warming, since present global climate forecasts suggest strong geographic variation in the effects of global warming. Assessments of the benefits, as well as the costs, of global environmental policies therefore require a focus at the national level.[3] Country level studies will also have a more reliable data base and, in order to catch the special features of each country, disaggregation becomes essential.

India is an especially interesting subject of study, not only for its size, but also for its diversity. Although heavily reliant on coal, it has important sources and uses of hydroelectric as well as nuclear power, petroleum and natural gas. Agriculture still produces about 30 percent of its gross domestic product and rural areas contain about 72 percent of its total population. Of significance for greenhouse gas emissions and carbon dioxide fixing, it has a large animal population and substantial forest acreage. It also has vast cities and an industrial sector that, although still relatively small at 30 percent of the economy, is large in absolute terms.

These features call for at least a moderate degree of sectoral disaggregation in order to identify the significance of different sectors for both growth and greenhouse gas emissions. The analytical structure should also be able to demonstrate the consequences of growth and change over time: for example, in the availability of fuel reserves, and use of alternative sources of

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[1] For a similar analysis of carbon emissions restrictions in Egypt, see Blitzer, Eckaus, Lahiri and Meeaus, Growth and Welfare Losses from Carbon Emissions Restrictions: A General Equilibrium Analysis for Egypt, Policy Research Working Paper Series, World Bank, 1992.

[2] Op. cit.

[3] In fact, India is so large, that greenhouse effects might well be expected to vary across its regions.

energy.

The model constructed and used below to analyze the economic effects of constraints on greenhouse gas emissions is similar to other models that have been used by the authors and other economists for the same purpose. It is a multisectoral, intertemporal linear programming model, driven by the optimization of the welfare of a representative consumer.[4] There are natural resource, capital formation, capital use, foreign exchange, and international borrowing constraints. For each sector, there are alternative technologies that embody relationships both of complementarity and substitution among labor, capital and energy inputs. However, the substitution possibilities are limited; for example, it is never possible to produce electric power with only labor and capital.

The economic consequences of constraints on emission rates, cumulative emission amounts and their radiative forcing effects are examined for alternative solutions. The constraints are applied at different rates and times in order to illustrate the potential consequences of different policies.

The model has some important new features that, we believe, place it in the second generation of such analyses. Methane as well as carbon dioxide emissions are identified and accounted for, permitting the investigation of interactions between constraints on these two greenhouse gases. The cumulative amounts of both types of emissions are calculated with a rudimentary adjustment for the decay or disappearance of these gases. In some of the alternative scenarios, constraints are placed on these accumulated emissions and, separately, on the total amount of radiative forcing from emissions. These formulations allow for the additional (and realistic) flexibility that might be exercised if binding commitments are made to reduce greenhouse warming.

II. The Structure of the Model

The basic structure of intertemporal optimizing of the type used here, has been made familiar by previous work. The model's structure is described here only in general terms, except for some particularly significant and distinctive features.[5]

The economic variables determined by the model are investment, sectoral capital capacity and production, household consumption by sector, energy demand and supply, imports and exports, international borrowing and relative prices, as well as emissions of carbon dioxide and methane. The interactions between these variables are endogenous and subject to the various constraints of technology, foreign exchange and foreign reserves, and rules for capital formation and labor mobility.

The model has a 71 year time horizon; the first period is 6 years long; thereafter, they are 5 years each. Long periods are used to avoid the additional computation required by a more detailed year-by-year formulation. While this creates a somewhat artificial pacing, it still

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[4] See pp 33-35 for the relevant equations and constraints.

[5] For further details, see pp 33-40.

provides a reasonably close temporal approximation of growth conditions. The long time horizon provides an ample term for adjustments.[6]

The objective or welfare function which is optimized 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 their consumption of each type of good and a parametrically fixed, minimum consumption level. Individual utility is then 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. The representative consumer's choice of goods in the consumption basket will depend on relative prices and income levels, which are determined within the model. While these conditions will be affected by environmental policies, environmental conditions do not enter directly into the consumer's utility function.

The material balance constraints require, in each period, that aggregate output use can be no greater than aggregate output availability. The availability of output in each sector depends on domestic production and, where feasible, on imports.

Intermediate inputs, with the exception of energy inputs, are determined by an input-output matrix. The set of alternative technologies or, "activities," for the use of labor, capital and energy in each sector is specified exogenously for different input patterns. The choice among alternative technologies in each sector is determined endogenously, in response to relative prices of inputs and outputs, also determined endogenously and reflective of real relative scarcities. The total output of each sector is the sum of production from each technology. The endogenous technological choices within each sector are one of the most significant features of the model for the purposes both of assessing the environmental impacts of economic activity and of adjustment to greenhouse gas emission constraints.

An exception to the exogenous specification of technological alternatives is made for petroleum products and natural gas fuels. In effect, the BTU requirements from petroleum products or natural gas per unit of output are specified, but can be met by using either input. The choice will be made endogenously, and will depend on relative prices and any constraints that affect those prices.

Coal, hydropower and wood are also fuels and, in alternative scenarios, nuclear power, gas-powered transport and a set of "renewable" power generation technologies are made available as "backstop" methods.

The initial population of India is taken as 749.6 million and is assumed to grow at an annual rate of 1.9 per cent. The base year reserves of crude oil, natural gas and coal are estimated at 4.5 billion barrels, 21 trillion cubic feet and 34 billion metric tons, respectively. It is assumed that there are initially 74.8 million hectares of forest and 379 million head of cattle with growth rates of xx and 10 per cent per year, respectively. The initial level of foreign debt is estimated at $23 billion and is assumed to grow at 4 per cent per year; the foreign exchange rate is set at 11.88 rupees per dollar.

The composition of capital varies in each sector; consistent with this variation, capital

[6] In general, results are reported only to 2040; the simple method of imposing terminal conditions contaminates the solutions in subsequent periods.

is specific to each sector and also to the particular technology that it embodies. This specificity creates "adjustment costs" that are an essential aspect of those major policy changes that are envisaged in the imposition of emission constraints. Capital formation in each period in each sector requires that investment be undertaken in the previous five year 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. Exports are chosen endogenously by the model, but are subject to constraints that limit their growth rates in particular sectors. Non-competitive imports are required in some sectors, in fixed ratios to output, and competitive imports are distributed as an optimal substitution for domestic production, insofar as foreign exchange availabilities allow. As an approximate way of recognizing limited flexibility in the response of exports and imports to changes in relative prices, the rate of change of each of these is constrained, although within wide bounds.

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 not to exceed those actually achieved in 1990. 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 growth of output in the relevant sector during the post terminal period. These terminal conditions create some anomalies in the final periods of the model's time horizon; these are not important for the essential characteristics of the solutions. Results are reported only for the period from 1990 to 2050.

III. Calculation of emissions and formulation of emission constraints

Greenhouse gas emissions have three different source types in this model: (1) the use of hydrocarbon fuels, (2) certain production processes, and (3) as by-products of the total stocks of certain assets used in production. In the latter category, forests serve as a "negative emitter," or a means of fixing atmospheric carbon.

The emissions of carbon dioxide and methane from hydrocarbon fuels are determined by simple ratios to the amounts of the fuels. Since different amounts of the fuels are used in each of the alternative technologies in each sector, there will be differences in emissions of the two greenhouse gases by sector and technology.

The quantity of the greenhouse gas of type, V^p, that is generated by the use of a particular fuel, i, in production with technology, k, in a particular sector, j, in period, t, is $V^p_{i,j,k,r,t}$. So the total amount of gas generated by the use of a particular fuel in the sector is obtained by summing over all technologies:

$$V^p_{i,j,r,t} = \Sigma_k V^p_{i,j,k,r,t}$$

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

$$V^p_{i,r,t} = \Sigma_j V^p_{i,j,r,t}$$

The generation of the gas is related to the use of the particular fuel in the sector by a coefficient, $v^p_{i,j,k,r,t}$. Thus:

$$V^p_{i,j,k,r,t} = v^p_{i,j,k,r,t} X_{j,k,t}$$

Among the production processes that generate carbon dioxide and methane, other than the combustion of fuel, perhaps the most important is cement production, which generates carbon dioxide through burning limestone. Methane is also lost in the production, distribution and use of natural gas, as well as through its combustion. These relationships are like those above, except that the variable determining the amount of the emissions is sectoral output, rather than fuel inputs.

There are also methane emissions from rice paddies, cattle, and coal mines, which are "stocks" of natural assets. The generation of methane in paddy rice production depends on the acreage in production. Methane emissions from both rice paddies and coal mines are approximated by production relationships. Methane emissions from cattle are related to total numbers of the animals. without adjustments for the composition of their feed.

The fixing of carbon in trees is related to their total acreage; it is subtracted from the total of carbon emissions generated by other sources to obtain the total carbon emissions of the economy as a whole.

These latter emissions/stock relationships are therefore of the form:

$$V^s_{j,r,t} = v^s_{j,r,t} S_{j,t}$$

where $V^s_{j,r,t}$ is the amount of emissions of type r from stocks in sector j at time t; $v^s_{j,r,t}$ is the emission/stock ratio, for gas r in sector j at time t; and $S_{j,t}$ is the stock releasing emissions in sector j at time t.

Constraints

In order to test the effects of limitations on the contribution of the Indian economy to greenhouse warming, constraints were applied in several alternative forms. First, a Base Solution was found in which emissions of CO_2 and CH_4 were not constrained. Then, in subsequent solutions, limits were placed on the rates of carbon dioxide and methane emissions, as a proportion of the amounts of these two greenhouse gases that were generated in the Base Solution. A restriction on annual emissions is the type of limitation most frequently analyzed in previous models, including those of the present authors. It is also the emissions policy that appears to be at the center of the attention of the International Negotiating Committee of the UN.

However, there seems to be no scientific nor economic necessity in controlling annual rates of emissions. Since radiative forcing depends on the amounts of the greenhouse gases in the atmosphere, the type of constraint which deals more directly with the causes of global warming is that on increments in the accumulated amounts of each gas. The constraint is plausible only on the assumption that India is ascribed a certain quota of the increments in worldwide emissions of each gas. To implement this constraint, the total accumulated amount of each gas, $ANE_{r,t}$ must be calculated as:

$$ANE_{r,t} = ds^{o}_{r,t}\, ANE_{r,t} + (ds^{n}_{r,t}/2)\,(TE_{r,t} + TE_{r,t-1}),$$

where $ds^{o}_{r,t}$ is defined as the rate of "radioactive" decay or absorption of "old" emissions, and $ds^{n}_{r,t}$ is the rate of decay of new emissions of type r. $TE_{r,t}$ are total annual emissions of type r in period t, net of absorption by forests.

The third type of constraint considered deals even more directly with the central issue: limits are placed on the additional radiative forcing that results from the accumulation of both gases over the model's time horizon. Again, this constraint is plausible only on the assumption that there is a rational world policy of allocating every country a quota of contributions over time to total radiative forcing. The constraint is employed by a simple translation of methane emissions into "equivalent" carbon dioxide emissions. This is done using the relative radiative forcing estimates that are available.[7] Thus, the additional radiative forcing, RFC_t, is:

$$RFC_t = \Sigma_r rf_r\, ANE_{rt}$$

where rf_r is the radiative forcing rate relative to carbon dioxide.

IV. Description of the database

Data needs can be classified into four broad categories, which are then discussed separately:

- national accounting components;
- behavioral relationships;
- technological relationships including emission of pollutants;
- certain exogenous or predetermined variables.

Transactions Matrix

The first task is to obtain a consistent set of data, including interindustry flows and final demand transactions, for a particular base year.[8] The 1984-85 national accounts data from

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[7] See K.P. Shine, R.G. Derwent, D.J. Wuebbles and J.J. Morcrete, "Radiative Forcing of Climate," in, "Climate Change: The IPCC Scientific Assessment," J.T. Houghton, G.J. Jenkins and J.J. Ephraums, eds., Cambridge U. Press, Cambridge, 1990, p. 58.

[8] "A Technical Note on the Seventh Plan of India (1985-90): Perspective Planning Division, Planning Commission, Government of India, June 1986.

World Bank sources are used to generate a 50 sector flow matrix based on the 1984-85 input/output coefficients of the Seventh Five Year Plan.[9] Given final demand figures and 1984-85 input-output coefficients, gross output is generated using the standard formula:

$$X = (I-A)^{-1} F$$

where X is a 50-sector column vector of gross output levels, A is the 50 x 50 matrix of input-output coefficients, and F is a column vector of final demand. These sectoral gross output totals support the intermediate and final demands of each sector.

The 50 sector transactions flow matrix is modified by separating petroleum and natural gas extraction. Data from energy balance tables are used for this purpose.[10] The matrix is then aggregated into an 18 producing sector transactions matrix with the composition of the sectors as shown in Table 1.

The transactions matrix does not distinguish between competitive and noncompetitive imports, a distinction which is essential for modeling purposes. However, the imported input use coefficient for the 50 sector matrix, as well as for the structure of final demand for 1984-85, is also available. This is used to generate a 50 sector import flow matrix by using the above coefficients and the Leontief inverse matrix procedure described earlier.

TABLE 1 Aggregation of 50 Sector Table to 18 Sectors

18 Sectors		50 Sectors	
Sector No.	Sector Name	Sector No.	Sector Name
1	Food, Fiber, and Fishing	1	Paddy
		2	Wheat
		3	Other Cereals (Jow,Baj,Maize)
		4	Pulses
		5	Fiber Crops (Cotton,Jute)
		6	Tea & Coffee (Plantation)
		7	Other Crops
		10	Fishing
2	Forestry	9	Forestry and Logging
3	Coal	11	Coal and Lignite
4	Petroleum Extraction	12	Petroleum and Natural Gas
5	Natural Gas		
6	Mining	13	Iron Ore
		14	Other Metallic Minerals
		15	Non-Metallic & Minor Minerals
7	Chemicals	24	Paper and Paper Based Industry
		25	Leather and Leather Products
		26	Rubber Products
		27	Plastics
		29	Coal Tar Products
		30	Fertilizers
		31	Pesticides
		32	Synthetic Fiber Resin
		33	Other Chemicals

9 World Bank data.

10 The data sources were "Energy Indicators - Developing Member Countries," Asian Development Bank, and "Indian Petroleum and Petrochemical Statistics."

Table 1 (cont.)

8	Cement and Glass	34	Cement
		35	Other Non-Metal Mineral Products
9	Light Manufacturing	16	Sugar
		17	Khandsari And Boora
		18	Other Food and Beverage Industries
		19	Cotton Textile
		20	Art Silk & Synthetic Fiber Textiles
		21	Woolen Textiles
		22	Other Textiles
		23	Wood Based Industries
		42	Other Transport Equipment
		43	Communication & Electronic Equipment
		44	Other Manufacturing
10	Heavy Manufacturing	36	Iron and Steel
		38	Non-Electrical Machinery
		39	Electrical Machinery
		40	Rail Equipments
		41	Motor Vehicles
11	Rail Transport Service	45	Rail Transport Service
12	Other Transport Service	46	Other Transport Service
13	Electricity	47	Electricity
14	Construction	48	Construction
15	Services	49	Communication
		50	Other Services
16	Non-Ferrous Metals	37	Non-Ferrous Metals
17	Animal Husbandry	8	Animal Husbandry
18	Petroleum Products	28	Petroleum Products

The import flows in this aggregated import flow matrix are then divided into competitive and noncompetitive imports. Three noncompetitive sectors are added: Heavy Manufacturing, Chemicals and Non-Ferrous Metals.

Parameters of the utility function

The parameters of the utility function are based on several econometric studies which have been done for India. Price and expenditure elasticity values are available for certain broad groups of commodities for rural and urban households. Weighted averages for these elasticity values are calculated using urban rural population and gross sector outputs as weights.

These parameters are then adjusted to match the consumption vector generated by our 18 sector transaction matrix. A Frisch parameter of -2.0 is assumed to generate the subsistence parameter of the utility function.

Estimation of Incremental Capital Output Ratios

Incremental capital output ratios are estimated from time series data for the period 1975-1984. Values of net capital formation are regressed on incremental moving average values of sectoral GDP at factor cost. The outputs of the railway and electric power sectors are corrected to include implicit subsidies. In several cases this procedure generates implausible numbers and data from other sources are used.

Technological Alternatives in the Production Process

The production processes in the model provide for substitution among labor, capital, energy and other intermediate inputs. In general, in a separate subfunction nested within the original production function, the aggregate energy input is made up of inputs from fuel, coal and electric power, which in turn are substitutable. In some sectors, however, such as rail transport, the substitution is limited. Alternative shares of aggregate energy in terms of fuel, coal and electricity are calculated by assuming specific values for the own and cross price elasticities with varying prices for the energy inputs.

Alternative input combinations of capital and total energy are generated by assuming that the sum of the price elasticities of each input with respect to the prices of each of the other inputs should sum to zero. Calculation of shares of alternative inputs along an isoquant is then computed by varying the prices of inputs from their original level. The elasticity estimates are based on various production function studies.

V. Characteristics of the Base Solution

Tables 2 and 3 present the macroeconomic variables generated in the base solution of the model, with estimates of the actual levels achieved in 1984 and 1989 shown in Table 2. It can be seen that, on the whole, the model produces overall results that are consistent with the performance of the Indian economy through 1989, although they do imply a slowdown in the 1984-1989 overall growth rate; the actual growth rate was high relative to previous experience.

The share of investment is often around 25 per cent of GDP, growing to roughly 30 per cent in the second and third decades of the next century before falling back to about 20 per cent again. This compares with the reality of a roughly 20 per cent rate of saving. However, it is not an implausible feature of a model with relatively high growth rates, since high savings are both a cause and effect of the high growth.

TABLE 2 Base Case: Macroeconomic Variables (billions of 1984 Rupees)

Year	GDP	Private Consumption	Investment	Government Consumption	Imports	Exports
1984	2044	1360	538	237	199	143
1989	2903	1904	708	344	(-)53	
1990	2945	1977	731	274	210	172
1995	3960	2732	935	310	250	233
2000	5129	3533	1235	351	310	319
2005	6653	4538	1681	397	405	442
2010	8690	5817	2350	450	543	617
2015	11645	7738	3276	509	743	866
2020	15828	10486	4577	576	1032	1221
2025	21779	14437	6409	651	1446	1729
2030	30133	19865	9120	737	2041	2453
2035	42679	28762	12513	834	2846	3416
2040	61409	44649	15082	943	4085	4819
2045	86732	76036	8706	1067	5954	6878
2050	83297	64854	15935	1207	7324	8625

TABLE 3 Base Case: Growth Rates of Macroeconomic Variables (average annual rates in per cent)

Year	GDP	Private Consumption	Investment	Government Consumption	Imports	Exports
1990	6.27	6.44	5.23	2.50	0.88	3.11
1995	6.10	6.68	5.03	2.50	3.57	6.24
2000	5.31	5.28	5.74	2.50	4.41	6.52
2005	5.34	5.13	6.35	2.50	5.45	6.73
2010	5.49	5.09	6.93	2.50	6.05	6.90
2015	6.03	5.87	6.87	2.50	6.48	7.03
2020	6.33	6.27	6.92	2.50	6.80	7.12
2025	6.59	6.60	6.97	2.50	6.98	7.20
2030	6.71	6.59	7.31	2.50	7.14	7.25
2035	7.21	7.68	6.53	2.50	6.87	6.84
2040	7.55	9.19	3.81	2.50	7.50	7.13
2045	7.15	11.24	-10.41	2.50	7.83	7.37

The changes in the sectoral shares are shown in Table 4. On the whole, they are characteristic of the patterns that would be expected in the course of development. They are slow and seldom dramatic, as would also be expected in a large and already diversified economy. The modest decline in the agricultural sector reflects mainly the continuing pressure of consumer demand, as represented in the assumed income elasticities. The decline in forestry's share indicates the limitations of the resource as demand continues to expand.

Table 4 Sectoral Shares in Total Output (Per cent)

Sector	1990	2000	2010	2020	2030	2040
Agriculture	0.1854	0.1921	0.1813	0.1694	0.1659	0.1705
Forestry	0.0029	0.0017	0.0011	0.0006	0.0003	0.0002
Animal Husbandry	0.0493	0.0576	0.0565	0.0555	0.0554	0.0575
Mining	0.0038	0.0052	0.0061	0.0066	0.0068	0.0032
Crude Oil	0.0060	0.0026	0.0013	0.0006	0.0003	0.0001
GAS	0.0032	0.0033	0.0036	0.0019	0.0007	0.0003
Petroleum Product	0.0212	0.0197	0.0194	0.0196	0.0204	0.0210
Coal	0.0062	0.0055	0.0075	0.0099	0.0109	0.0090
Electric Power	0.0202	0.0193	0.0193	0.0193	0.0190	0.0180
Heavy Mfg.	0.0909	0.0921	0.1022	0.1076	0.1104	0.0954
Light Mfg.	0.1391	0.1368	0.1384	0.1417	0.1421	0.1496
Nonferrous Met.	0.0038	0.0041	0.0045	0.0047	0.0049	0.0046
Chemicals	0.0697	0.0697	0.0703	0.0718	0.0725	0.0776
Cement, Glass	0.0172	0.0165	0.0174	0.0180	0.0185	0.0162
Construction	0.0814	0.0776	0.0810	0.0835	0.0855	0.0747
Railroads	0.0143	0.0137	0.0141	0.0145	0.0145	0.0138
Other Transport	0.0324	0.0306	0.0321	0.0327	0.0342	0.0413
Services	0.2530	0.2518	0.2440	0.2422	0.2377	0.2471
	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

The changes that do occur in sectoral shares are the result of several influences. First of all, one would expect such changes in the course of development influenced by different consumer demand elasticities. Changes in the levels and composition of investment, which call for different input patterns, will also affect relative output levels. Finally, the shadow prices in the model solution reflect these changing influences, while the prices that have actually prevailed may either be controlled directly or be influenced by controlled prices. For example, the modest changes in the share of the electric power sector, in the face of increasing dependence on electric power in the course of development, are the result of the relatively high shadow price of electric power. Actual electric power prices are kept at artificially low levels.

The model solution also delineates an increasing dependency on coal and a slight decline in the share of petroleum; again, this is in reaction to real relative scarcities, although an increase in petroleum as well as coal reserves is earlier assumed.

The emissions of carbon dioxide and methane in this base case solution are shown in Table 5, measured in millions of tons. In addition, Table 5 presents the relative contribution of carbon dioxide and methane to the incremental radiative forcing generated by the two gases.

Table 5 Net Accumulated Emissions and Radiative Forcing (Millions tons)

	1990	2000	2010	2020	2030	2040	2050
Carbon Dioxide	3408	10274	23247	52754	115094	235280	411843
Methane	248	648	1151	1944	3470	6695	12628
Incremental Radiative Forcing:							
Carbon Dioxide share (%)	19.12	21.47	25.83	31.86	36.38	37.73	35.19
Methane share (%)	80.88	78.53	74.17	68.14	63.62	62.27	64.01

The dominating importance of methane as a greenhouse gas - currently and in the near future - is in striking contrast with the greater importance of carbon dioxide in industrialized countries. However, the pattern that the solution projects as India modernizes its economy is a change in the relative importance of the two greenhouse gases.

Table 6 indicates sources of carbon dioxide emissions and Table 7 indicates sources of methane emissions. With respect to both gases there are negligible amounts of absorption from economic processes, including fixing in biomass. This result requires further and deeper study; thus in Table 6 a distinction is made between emissions of carbon dioxide from hydrocarbon fuels used domestically and those from electric power generation and transport. In addition, the table identifies emissions from these fuels in other production sectors.

Table 6 Sources of Carbon Dioxide Emissions (per cent)

	1990	2000	2010	2020	2030	2040	2050
Domestic Fuels							
Petroleum Products	0.0362	0.0290	0.0191	0.0125	0.0103	0.0183	0.0294
Coal	0.0564	0.0451	0.0297	0.0194	0.0160	0	0
Gas	0.0532	0.0615	0.0535	0.0225	0.0081	0.0034	0.0023
Electric Power Generation and Transport							
Petroleum	0.1990	0.2154	0.1758	0.1518	0.1510	0.2020	0.2329
Coal	0.6447	0.6380	0.7123	0.7852	0.8063	0.7682	0.7283
Other Production Processes							
Coal	0.0015	0.0014	0.0016	0.0017	0.0017	0.0016	0.0012
Cement,Glass	0.0090	0.0095	0.0080	0.0068	0.0065	0.0064	0.0058

Table 6 confirms the conventional projection that coal is, and will be, the major source of carbon dioxide emissions; petroleum fuels, however, are a significant source as well. While part of the carbon dioxide emissions from coal, early in the time horizon, are from its use as a domestic fuel and from the direct use of coal in production processes, most of these emissions come from coal's use in electric power generation.

Table 7 Sources of Methane Emissions (per cent)

	1990	2000	2010	2020	2030	2040	2050
Domestic Fuels							
Petroleum	.00010	.00008	.00006	.00005	.00005	.00007	.00011
Coal	0	0	.00001	.00001	0	0	0
Gas	.00001	.00001	.00002	.00001	0	0	0
Electric Power Generation and Transport							
Petroleum	.00001	.00007	.00008	.00008	.00009	.00011	.00011
Coal	.00010	.00006	.00009	)0013	.00015	.00012	.00010
Other Production Processes							
Oil	.09857	.04275	.02204	.01063	.00498	.00226	.00155
Gas	.04105	.04306	.04964	.02752	.01096	.00410	.00244
Coal	.02585	.02308	.03328	.04751	.05386	.04419	.02844
Chemicals	.00046	.00045	.00048	.00053	.00056	.00059	.00062
Capital Stocks							
Agriculture	.68023	.70969	.70714	.71467	.72396	.73743	.74893
Animal Husbandry	.15360	.18075	.18717	.19886	.20538	.21112	.21770

The major source of methane emissions, as indicated in Table 7, is the agricultural sector, notably paddy rice fields. There are also substantial methane emissions from cattle. The growth in importance of methane emissions from both sectors reflects the projected increases in production from the sector, in response to consumer demands. It is assumed that these increases are achieved by more intensive use of the paddy rice fields, with consequent increases in emissions. Table 6 suggests the difficulties that would be involved in attempting substantial reductions in methane emissions; methane's major sources are sectors critical for their supply of output, provision of employment and social role.

VI. Scenarios of Emissions Reductions

The purpose of building this comprehensive model is not to project the future at a single stroke, but to begin to answer questions of a "What if ... ?" form. Answers do not consist of definite projections of what the future would be like under the "if" conditions; rather, the insights come from a comparison of the calculated consequences of alternatives. No one solution, including the Base Solution, is intended as a forecast. The model is essentially an elaborate tool for doing "comparative dynamics."

There are many "What if ..." questions that can be posed and many comparisons that can be made. Questions are posed in the form of scenarios that incorporate emissions restrictions of differing magnitudes, timing and composition. All such restrictions are made relative to the Base Solution.

This is a different comparison from that which appears most commonly. In most other exercises of this sort, the comparison is made relative to emissions levels in an initial year. This has little to recommend it, even for advanced economies, and is particularly inappropriate for developing countries that are focusing their attention on economic growth.[11]

The following set of scenarios, which appear to be of particular interest, are the first explored.

A. To test effects of annual constraints on emissions of both carbon dioxide and methane

A.1. 20% reduction in both CO_2 and CH_4 emissions starting 1990
A.2. 30% reduction in both CO_2 and CH_4 emissions starting 1990
A.3. 40% reduction in both CO_2 and CH_4 emissions starting 1990
A.4. 50% reduction in both CO_2 and CH_4 emissions starting 1990
A.5. 30% reduction in CO_2, no reduction in CH_4
A.6. 30% reduction in CH_4, no reduction in CO_2

B. To test effects of postponing reductions in emissions

B.1. 30% reduction in both CO_2 and CH_4 emissions starting 1995
B.2. 30% reduction in both CO_2 and CH_4 emissions starting 2000

C. To test effects of reductions in accumulated emissions over the entire time horizon (in each case the conditions must first be met by 2030 and maintained thereafter)

C.1. 20% reductions in accumulated emissions of both CO_2 and CH_4 emissions
C.2. 30% reductions in accumulated emissions of both CO_2 and CH_4 emissions
C.2. 30% reductions in accumulated emissions of both CO_2 and CH_4 emissions

D. To test effects of constraints on increments in radiative forcing (in each case the conditions must be met by 2030 and maintained thereafter)

D.1. 20% reduction in radiative forcing starting in 1990
D.2. 30% reduction in radiative forcing starting in 1990
D.3. 40% reduction in radiative forcing starting in 1990
D.4. 30% reduction in radiative forcing starting in 1995
D.5. 40% reduction in radiative forcing starting in 1995
D.6. 30% reduction in radiative forcing starting in 2000
D.7. 40% reduction in radiative forcing starting in 2000

E. To test effects of backstop technologies

Scenario A starts with a seemingly straightforward test of the effects of enforced reduction in emission restrictions. Inspection of the results, however, leads to other tests, some of which are designed to examine the relative sensitivity of the model economy to separate carbon dioxide and methane emission restrictions. Scenario B begins to investigate the consequences of changes in the timing of emission restrictions. While the change in the form

[11] PAS article?

of the emission restrictions in Scenario C - from annual restrictions to a restriction on accumulated emissions - may seem modest, it represents a distinct shift in policy. It is a step towards recognizing that the fundamental concern of policy should be with the total stock of greenhouse gases in the atmosphere. That recognition is carried to its logical conclusion in Scenario D, in which constraints are placed on total contributions to radiative forcing by the two greenhouse gases, as always relative to the Base Solution.

Scenario E examines the implications of adding a group of "backstop" technologies to the set of activities available for the production of electric power and, in one case, for motor transport.

The results obtained from these constraint scenarios are compared with those from the unconstrained Base Solution, and with each other.

VII. Comparisons of results of alternative scenarios

The first question asked with respect to policies of emissions reductions is, "What are the overall consequences for growth?" Other models - econometric, optimizing or computable general equilibrium - have considered only carbon dioxide emissions; in these cases, the question, though difficult to answer, is relatively straightforward. In this model, however, the question is more complex, because there are two kinds of greenhouse gas emissions, carbon dioxide and methane.

Scenario A requires that there be equal reductions in emissions of both gases, at increasing rates, as compared to the emissions produced in the Base Solution. Average GDP growth rates over the model's time horizon are affected only modestly, as shown in Chart 1. Chart 2, which illustrates percentage reductions in GDP growth rates, is slightly more revealing, but the effects still seem modest.

Chart 3 shows rates of growth over time and helps in providing an explanation for the effect of emission restrictions on growth rates. The model moves toward steady state growth rates, very much like a neo-classical growth model, in which emissions constraints do not change steady state growth conditions. This is understandable, because, in important respects, the model is like a neoclassical growth model. There are, of course, some differences; for example, in dependence on exhaustible natural resources, constraints on foreign trade and borrowing, and the presence of some exogenously specified demands. So the convergence is not exact. Moreover, in the periods beyond those pictured, when natural resource constraints become binding, there are important readjustments, which are not primarily a consequence of emission constraints.

Chart 4, shows the reductions in GDP levels associated with the emission constraints and provides further insight into their consequences. Relatively large early losses arise from the necessity of adjusting to the emission constraints. Then, within 20 years, when the systems move toward similar growth rates, the differences in levels stabilize. The diagrams show that the elasticity of the GDP loss with respect to emission reductions increases with the imposed rate of reduction.

Chart 5 demonstrates the consequences of the emissions reductions more dramatically by

CHART 1

AVERAGE GDP GROWTH RATES

WITH EQUAL REDUCTIONS IN CO2 AND CH4

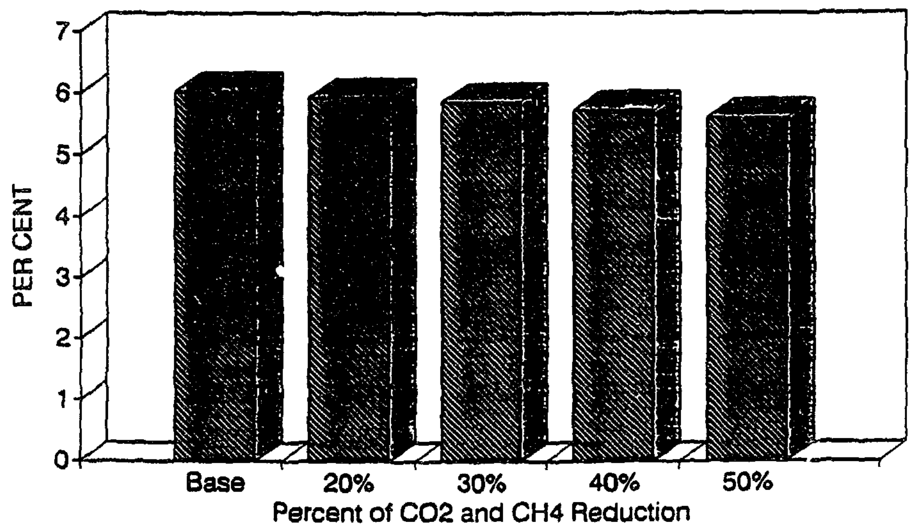
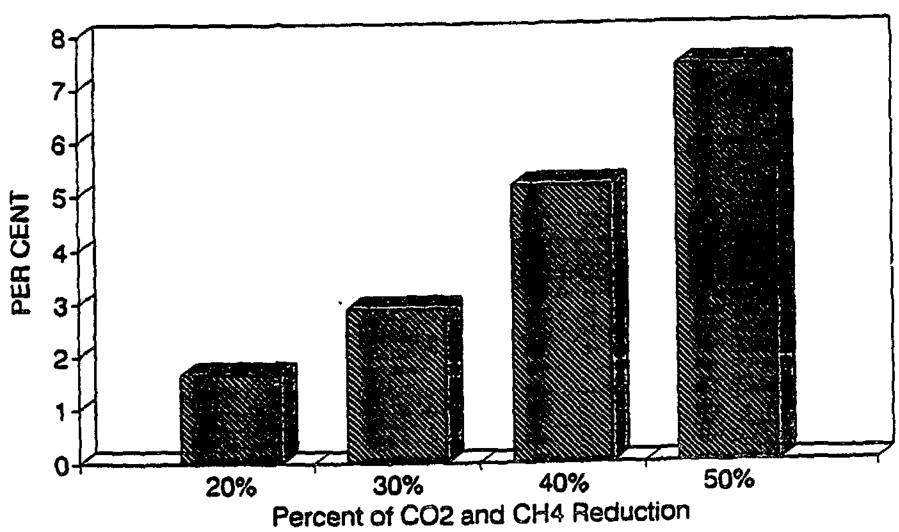


CHART 2

REDUCTION IN GDP GROWTH RATES

EQUAL REDUCTIONS IN CO2 AND CH4



Annually Starting 1990

CHART 3

GDP GROWTH RATES

WITH EQUAL REDUCTIONS IN CO_2 AND CH_4

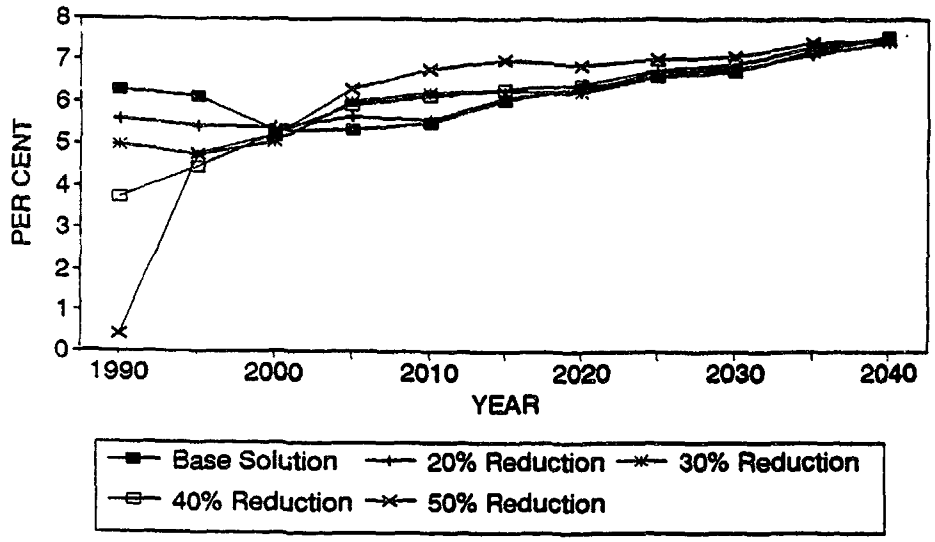


CHART 4

REDUCTIONS IN GDP LEVELS

FROM EQUAL REDUCTIONS IN CO_2 AND CH_4

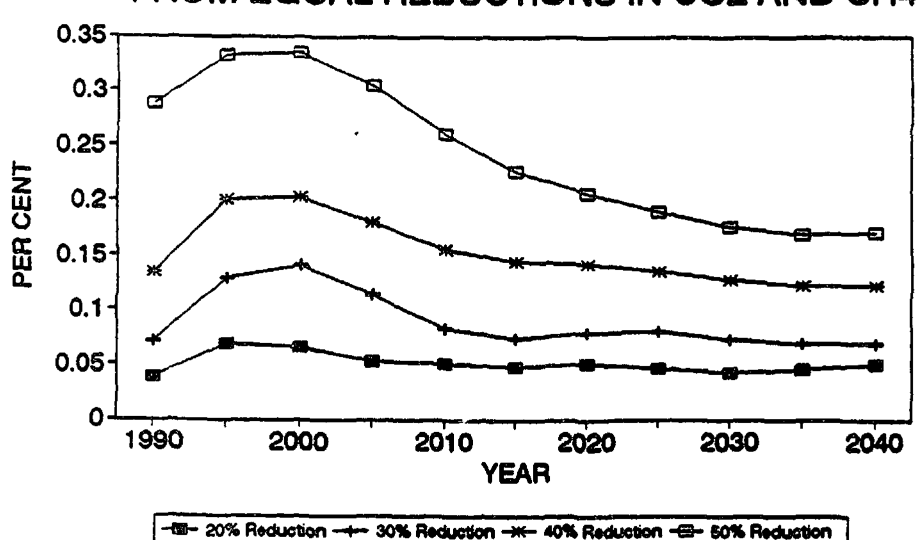
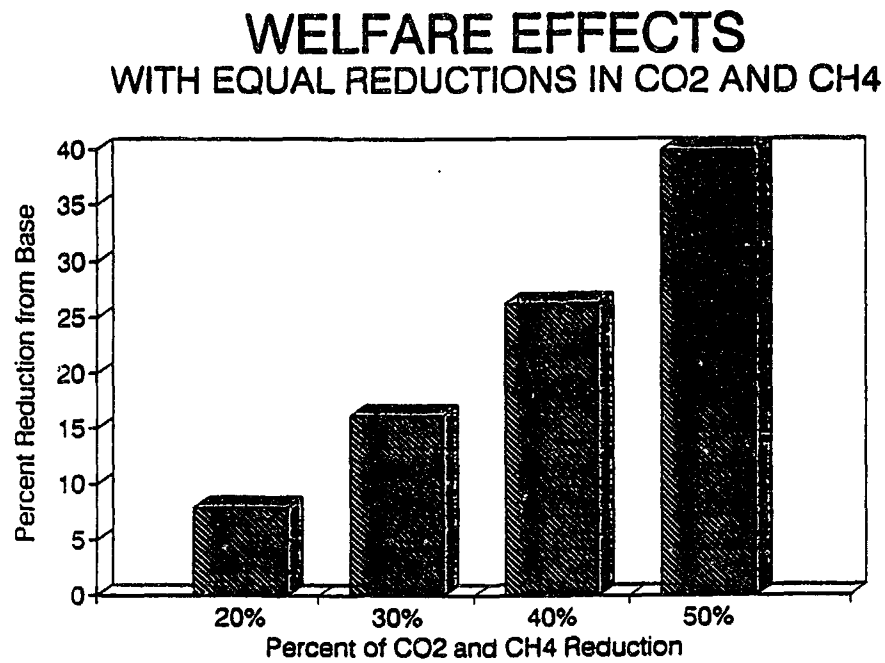


CHART 5



showing the welfare losses, as compared to the Base Solution. These welfare losses have been calculated only for the period 1984 to 2030. By any criterion, losses are substantial. Of course, the loss measurements reflect the particular form of the chosen welfare function, as do all other aspects of the solutions.

Charts 6a, 6b, 6c and 6d, show the reductions in net additional accumulated emissions that result from the imposed constraints; again, these are shown relative to the Base Solution. These results provide important new insights. Net additional accumulated emissions are calculated by summing each year's emissions and subtracting an estimate of the amounts of these emissions that "disappear" or are "reabsorbed". The net additional accumulated emissions reveal the *interactions* among emissions constraints, an area not previously investigated. In scenario A, the required emissions reductions in CO_2 and CH_4 are all equal. Clearly though, these reductions might - for one of the two gases - be excessive, since the constraint on the other gas could so limit economic activity that emissions of the first gas do not even reach the constraint level.

In interpreting Charts 6a, 6b, 6c and 6d, it should be recalled that emission reductions only begin in 1990, five years after the model run starts. Thus, initial reductions in accumulated emissions will be less than the required rate of reduction in annual emissions. Chart 6a indicates that a required 20% reduction in both carbon dioxide and methane actually forces larger reductions in CO_2 emissions in the 20 years after the constraint is first imposed, after which the emissions reductions of both gases level off at 20%. However, when the required rate of reduction is 30% or more, the picture changes radically. As shown in Charts 6b, 6c and 6d, methane emissions fall most rapidly in the initial years. After 2010, however,

CHART 6A

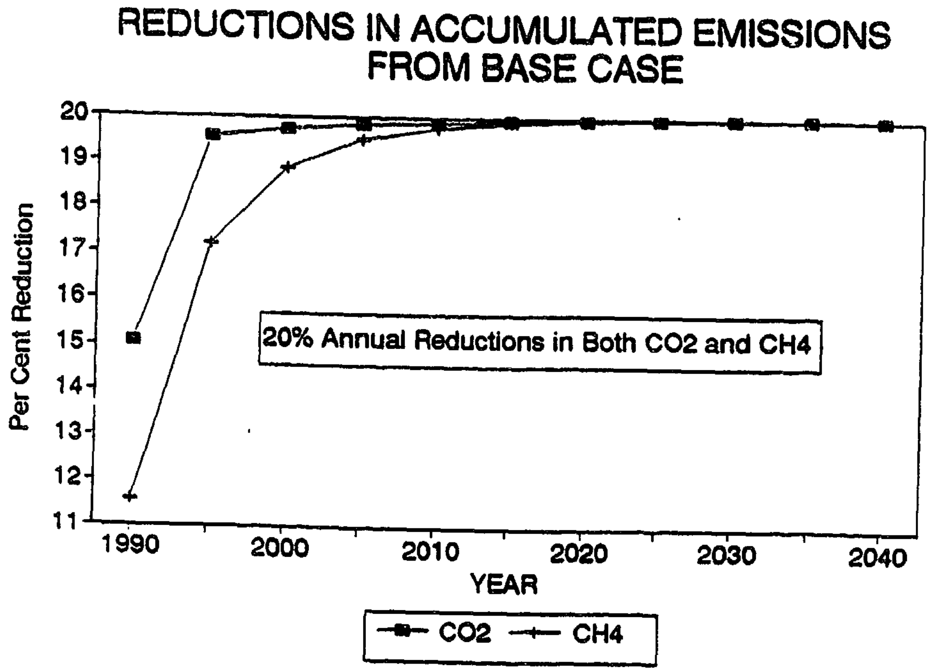


CHART 6B

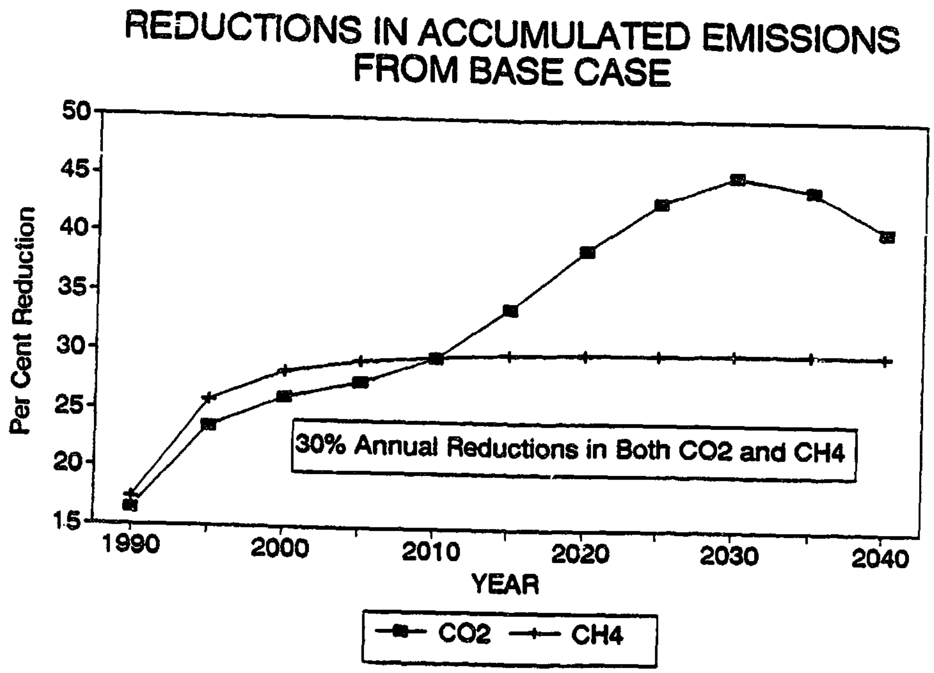


CHART 6C

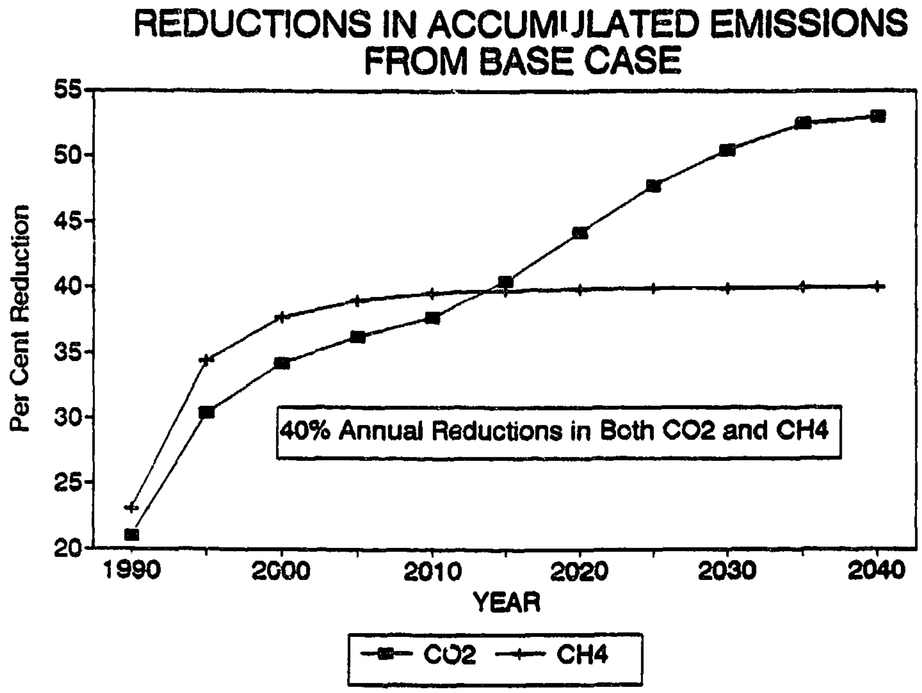
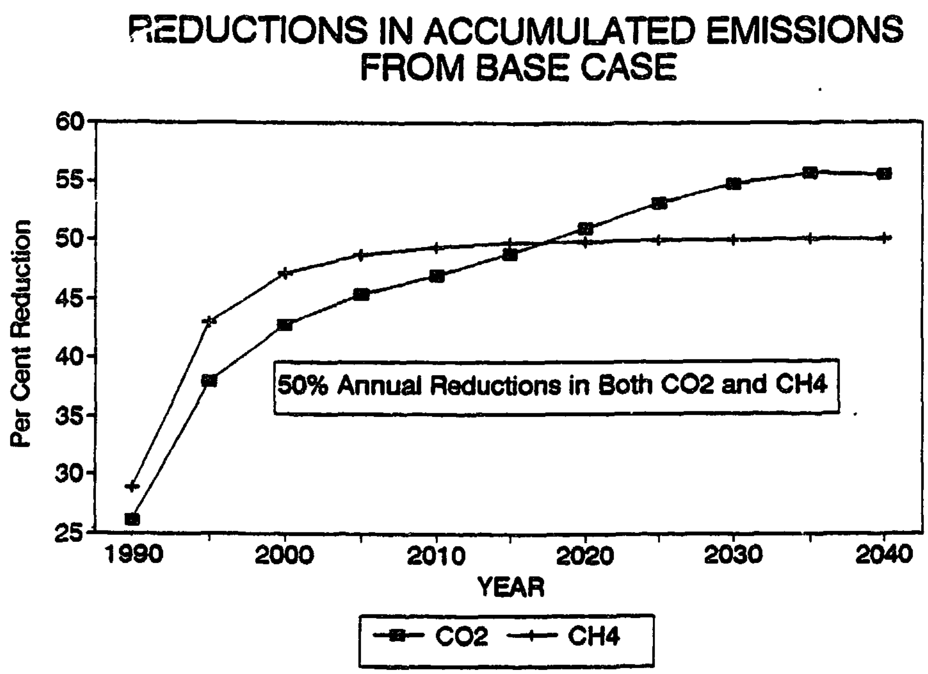


CHART 6D



for the required reduction in methane emissions to be achieved, carbon dioxide emissions must be reduced by significantly larger amounts. Charts 6a, 6b, 6c and 6d indicate that methane emission constraints generally cause substantially greater reductions to economic activity and both emission types than carbon dioxide constraints of the same general magnitude.

Scenarios A.5. and A.6. are used to explore the interactions of the emissions reductions requirements in greater detail. The effect of requiring a 30% reduction in CO_2 emissions, as compared to the base case, together with no constraints on methane emissions is shown in Chart 7A. Accumulated CO_2 emissions rise rapidly to the 30% level, but the reduction in methane emissions is 5% or less. Chart 7B presents results for Scenario A.6., in which there is no required reduction in CO_2 emissions, but methane emissions are forced to fall by 30% relative to the base case. Reductions in methane emissions rise slowly to the 30 percent level, but the reduction in accumulated CO_2 emissions becomes much larger: starting out at about 15 per cent, it stays at that level for about 15 years and then rises to 45 per cent in 2030 and 2035, after which it shows a modest decline. These charts confirm the greater sensitivity of the Indian economy to methane emissions, at least for an intermediate period.

These are striking results, with a relatively straightforward explanation. Recall a few facts. First, as noted in the description of the base case's characteristics, paddy rice fields constitute the major source of methane emissions, with cattle also being of some importance. Methane emissions from other sectors are relatively insignificant. Second, paddy rice field production uses a substantial amount of electric power, presumably for water pumps. Third, emissions of CO_2 are mainly the result of using fossil fuels, principally coal, but also petroleum products and natural gas.

CHART 7A

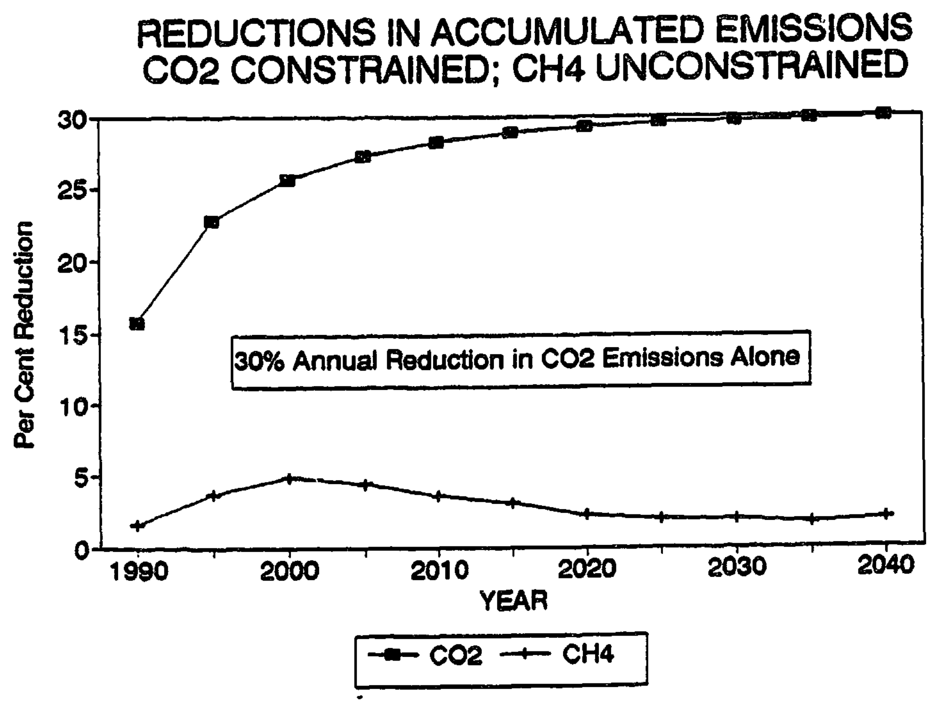
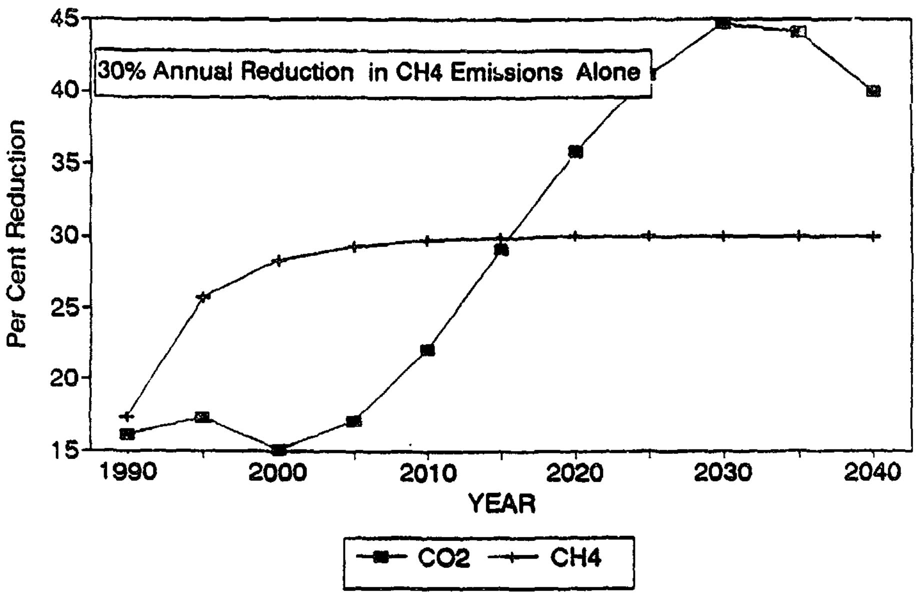


CHART 7B

REDUCTIONS IN ACCUMULATED EMISSIONS
CH4 CONSTRAINED; CO2 UNCONSTRAINED



When CO_2 emissions are restricted, the effects are spread across all sectors using these fuels; the greatest effects are in power generation and transport, both rail and road. The economy adjusts to the increased shadow prices in these sectors through technical substitution against power inputs, and by substitution in the patterns of output away from more emissions-intensive production and consumption goods. There is also a relatively modest effect on methane emissions, mainly on power use in irrigating paddy rice fields.

However, when CH_4 emissions are restricted, the impact is mostly on paddy rice production and, to some extent, animal husbandry. While there are possibilities for technical substitution in these sectors, they are relatively insignificant; rice fields need water, and animals must eat. Consumption patterns might change, but the importance of rice limits this avenue of adjustment. Thus, methane restrictions, to a greater degree than CO_2 restrictions, generally require both a squeezing of economic activity (in order to meet the emissions constraint) and substantial economic reorganization.

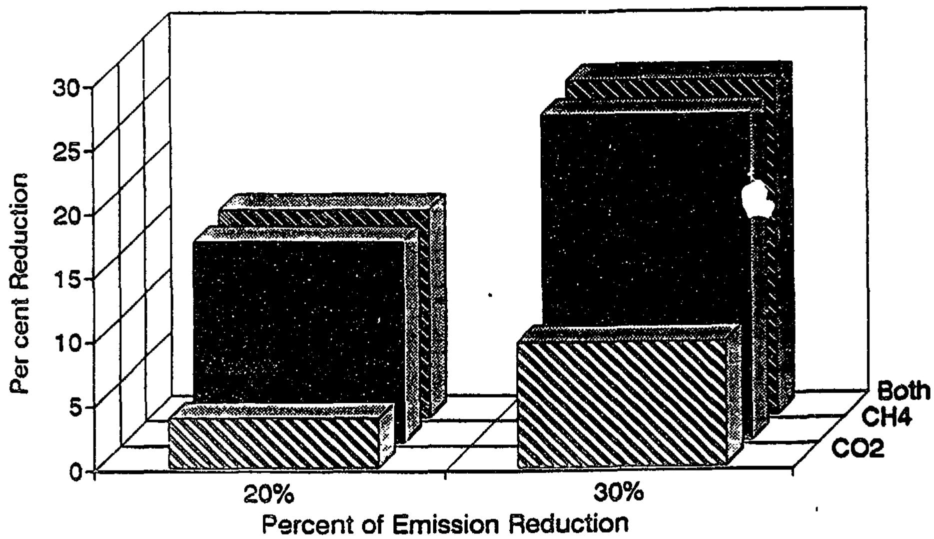
These results are not counter-intuitive, although the quantitative potential has not previously been worked out. It is well-known that in developing countries, of which India is almost the stereotypical example, the intensity of fossil fuel use - the major source of carbon dioxide emissions - is relatively low. Similarly, paddy rice fields are generally known to be relatively important sources of a basic food grain in many developing countries. In an important sense, the results reported above directly follow from these two facts.

Chart 8 provides another perspective on the consequences of interactions among different constraints. The effects on welfare are shown in three ways: first, for required reductions in carbon dioxide emissions only; second, for required reductions in methane emissions only; and third, for equal required reductions in both emission types. Methane emission reductions clearly have the greatest impact. However, it would be a mistake to conclude that constraints on carbon dioxide emissions are relatively unimportant for developing countries. What the models also show, again not counter-intuitively, is that in the course of development the use of fossil fuels increases and, therefore, there is a corresponding increase in carbon dioxide emissions, while methane emissions grow more modestly. Limitations on carbon dioxide emissions therefore become increasingly constraining for these economies.

CHART 8

WELFARE EFFECTS

WITH ALTERNATIVE REDUCTION CONSTRAINTS



Effects of delaying the imposition of emissions constraints

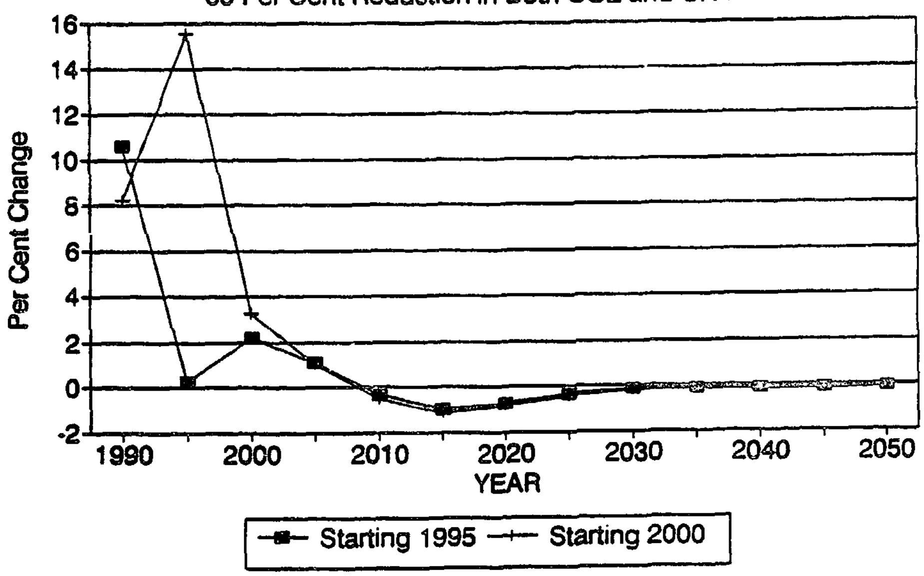
Scenario B focuses on a policy that has been widely discussed with respect to developing countries: a simple delay in the imposition of annual emissions constraints. In the two solutions for this scenario, the implementation of the constraints is delayed by 5 and 10 years, respectively. The constraints are imposed annually and are set, for both carbon dioxide and methane, at 30 per cent of the emission levels of the unconstrained base case.

Chart 9 illustrates the general nature of the results. GDP levels, relative to those that result when emissions constraints are imposed in 1990, are in both cases larger, prior to the imposition of constraints. However, what is surprising is that GDP levels for both solutions converge in 2005, only five years after the imposition of constraints in the second solution.

Moreover, GDP levels for both solutions fall slightly below that of the solution in which constraints are imposed in 1990 for a period of about 20 years. Thereafter, GDP levels for all solutions converge. The solutions of this scenario thus demonstrate that a modest delay in the implementation of emissions restrictions would not, in the best of circumstances, have a long-lasting effect on the potential economic achievements of developing countries, at least insofar as they are represented by this model.

CHART 9
COMPARATIVE REDUCTIONS IN GDP LEVELS FROM DELAYED EMISSIONS CONSTRAINTS

30 Per Cent Reduction in Both CO2 and CH4



Constraints on Accumulated Emissions

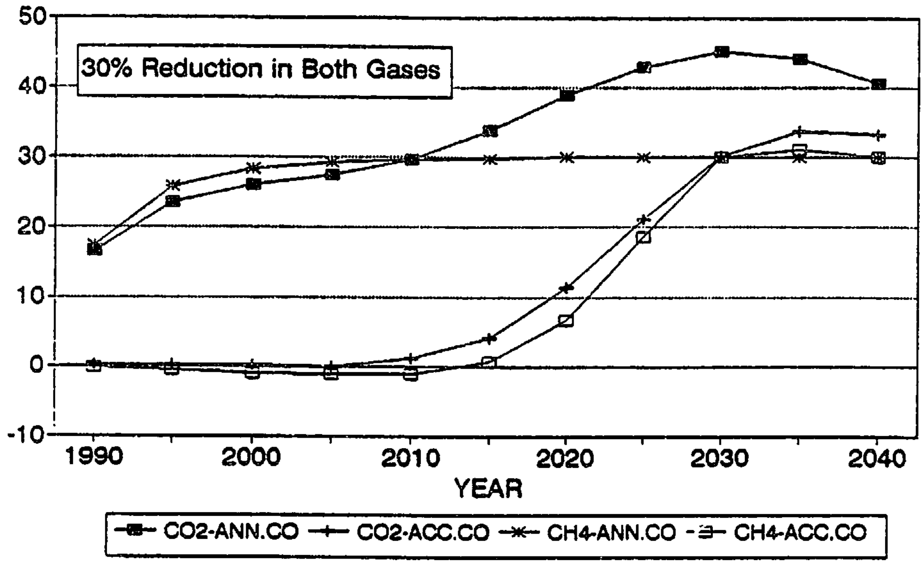
In Scenario C, constraints are placed on incremental accumulations in emissions over the time horizon, again as compared to the base case. This type of constraint comes closer to addressing the essential source of global warming: the accumulation of stocks of greenhouse gases in the atmosphere.

Chart 10 shows time paths for the changes in accumulated emissions, relative to the base case, both when constraints are imposed annually and when they are imposed on levels of accumulation. In the solutions represented in this chart, the constraints are set at 30% of the emissions of the base case. The chart, however, shows accumulated emissions for both scenarios. It is clear that, when constraints are only imposed on accumulated emissions, the

CHART 10

ACCUMULATED EMISSIONS

FOR ANNUAL AND ACCUMULATION CONSTRAINTS



model uses the extra freedom to delay emission reductions. This allows more time to accumulate productive capital as well as to adjust its composition. As pointed out above, when the constraints are imposed annually at the same level of 30 per cent less than in the base case for both carbon dioxide and methane, the emissions of methane fall by more than 30 per cent. However, when the constraints are imposed only on accumulations and not on their timing, there is relatively little difference in the reductions of the two emission types. Again, this reflects the advantages of flexibility in the constraint conditions.

Charts 11 and 12 show some of the differences in the economic effects of the different constraints. Chart 11 presents growth rates generated in Scenario C, while Chart 12 shows GDP levels achieved; again, both are in relation to the unconstrained base case. As in previous scenario comparisons, growth rates are relatively unaffected by the emission constraints; most effects come in later periods, since that is when the model determines the constraints to have maximum effect. Likewise, major reductions in GDP are postponed, but are, as expected, a function of the level of constraint.

Constraints on Radiative Forcing

The emission constraint for which there is the strongest rationale is that on net additions to radiative forcing. Radiative forcing is, after all, the source of global warming. Constraints on annual or accumulated emissions amount only to indirect means of dealing with additions to

CHART 11

EFFECTS ON GDP GROWTH RATES

OF CONSTRAINTS ON ACCUMULATED EMISSIONS

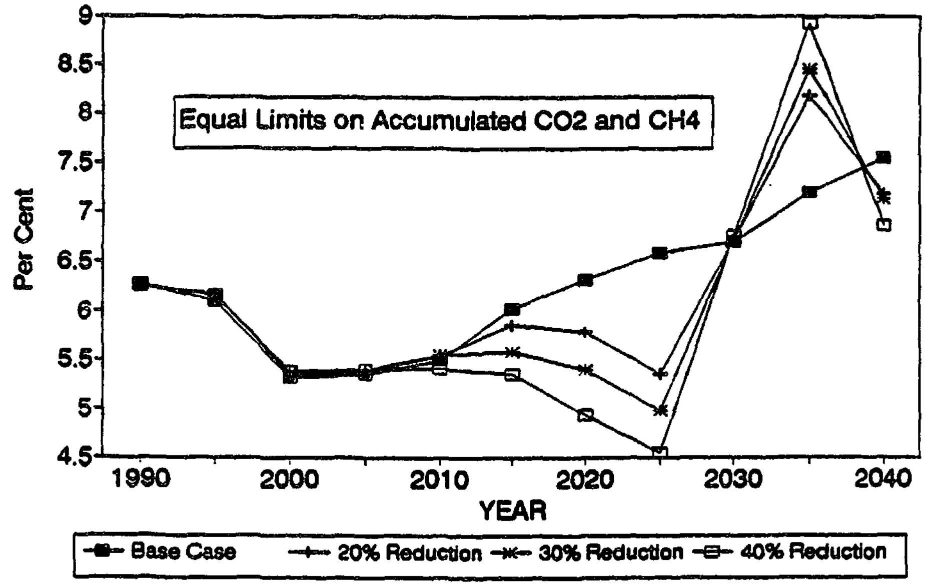
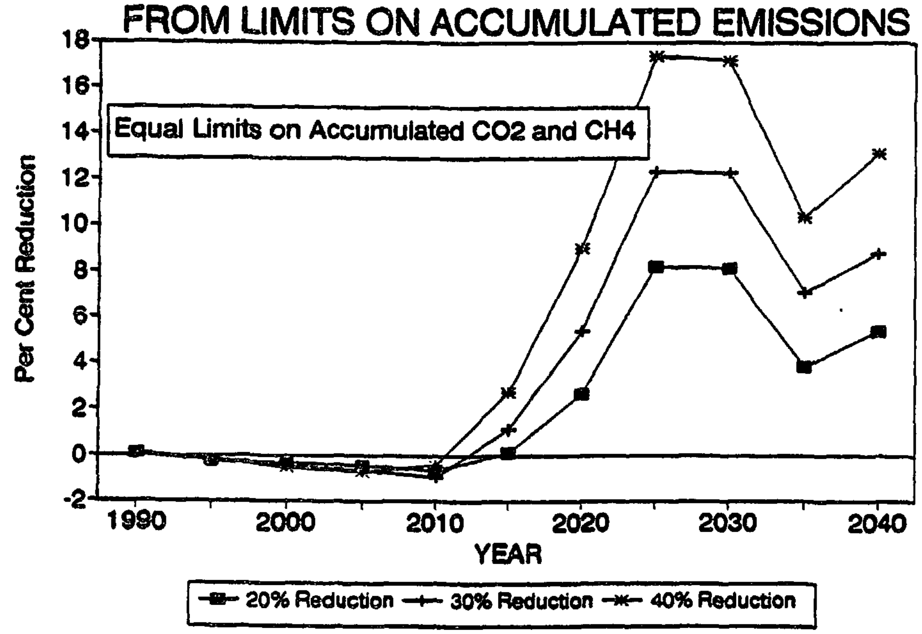


CHART 12

REDUCTIONS IN GDP LEVELS

FROM LIMITS ON ACCUMULATED EMISSIONS



radiative forcing. There is, therefore, a strong appeal in a policy that deals directly with radiative forcing or, more precisely, with increments in radiative forcing due to emissions of greenhouse gases. There are, however, serious scientific difficulties in specifying increments in radiative forcing as a simple function of accumulated emissions. In this case, these are finessed in by assuming that radiative forcing is a simple weighted sum of radiative forcing due to carbon dioxide and methane, with methane having a weight equal to its instantaneous forcing effect, relative to carbon dioxide.

While the processes of greenhouse warming provide the fundamental rationale for the constraint on radiative forcing, there are potential economic benefits in this formulation. It provides another source of flexibility in adjusting to constraints on greenhouse gas emissions, as compared to an arbitrary set of constraints on the separate greenhouse gases. It becomes possible to find the combination of gas emissions which, while meeting the radiative forcing constraint, imposes the least burden on the economic system.

Chart 13 shows the changes in radiative forcing under different types of emission constraints; again, these are relative to the base case. Of course, under all constraints there is some reduction in radiative forcing. If constraints are imposed annually, at 30% of the emissions levels of the base case, there is a much larger reduction in incremental radiative forcing during most of the model horizon, as compared to the incremental radiative forcing when constraints are imposed on accumulated emissions or on total radiative forcing. Differences are also evident in economic performance, as shown in Charts 14 and 15. The effect on growth rates is again modest, though this is consistent with significant differences in achieved GDP levels.

CHART 13

CHANGES IN RADIATIVE FORCING

UNDER ALTERNATIVE CONSTRAINTS

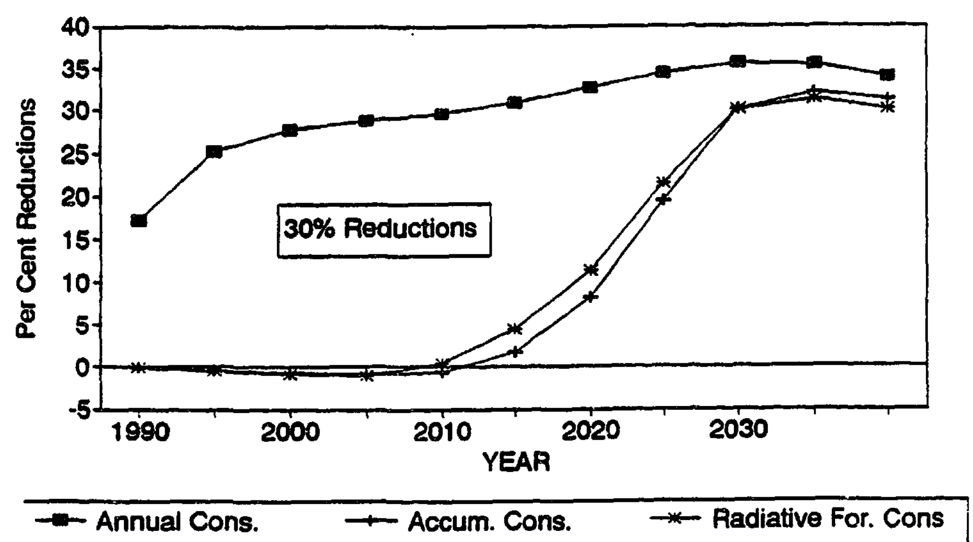


CHART 14

GDP GROWTH RATES

WITH CONSTRAINTS ON RADIATIVE FORCING

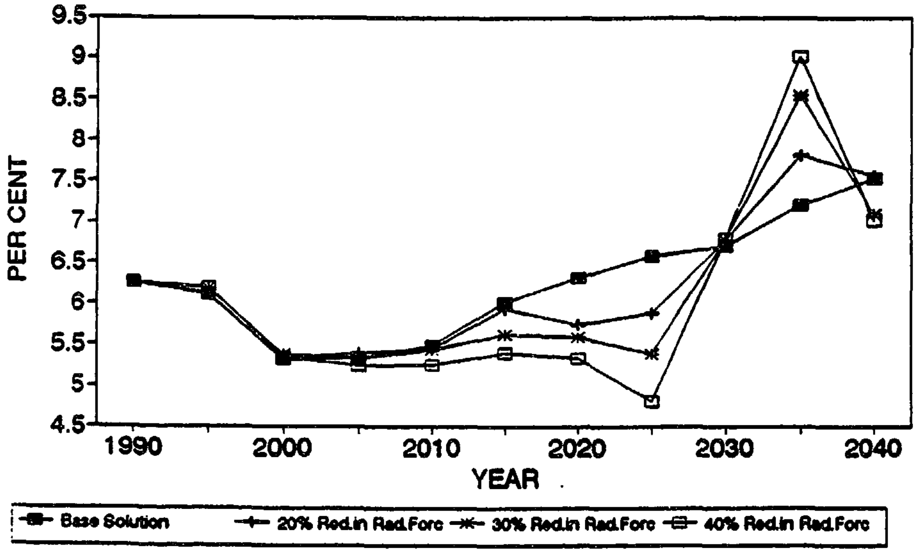
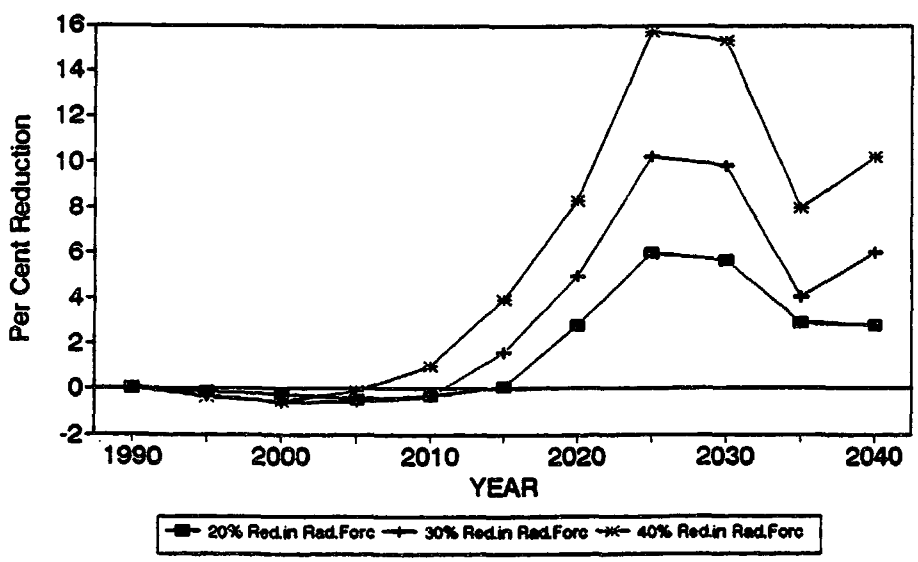


CHART 15

REDUCTIONS IN GDP LEVELS

FROM CONSTRAINTS ON RADIATIVE FORCING

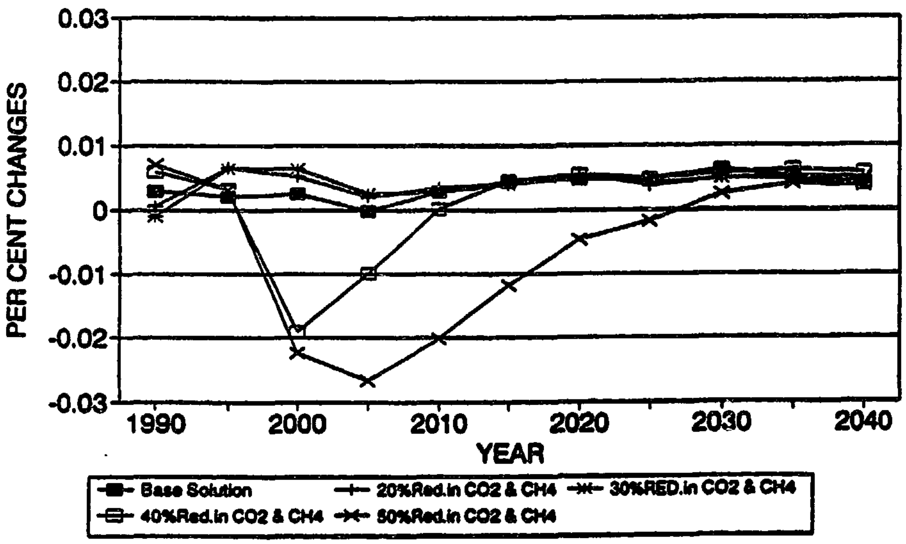


The significance of "backstop" and "alternative" technologies

Since most carbon dioxide emissions are generated in the course of using hydrocarbon fuels, the availability of technologies that substitute for such fuels (or use them more efficiently) might be expected to reduce emissions at similar levels of output. The implications of using these technologies are studied in this next set of scenarios. The effects of having additional technologies available should show up in achieved levels of economic activity. It is to be expected that such technologies would be employed in order to reduce the restrictiveness of emission constraints, even though they are, otherwise, more expensive to use. This is the sense in which they are called "backstop" technologies.[12]

Two additional types technology are added in this next scenario. The first is co-generation and gas-powered autotransportation. Co-generation economizes on all fuels used in electric power generation. Gas-powered transport substitutes a relatively low carbon dioxide emitting fuel, natural gas, for diesel or gasoline, both of which have higher carbon dioxide emissions. The second set of technologies are often called "renewables," as they do not use energy sources permanently. They include windpower and various types of solar-powered devices; both are relatively unproved, at least with respect to their costs, if used on a large scale. Assumptions are made about these that are believed to be relatively optimistic. For example, solar power technology is projected, in all cases, to operate under conditions of high insolation.

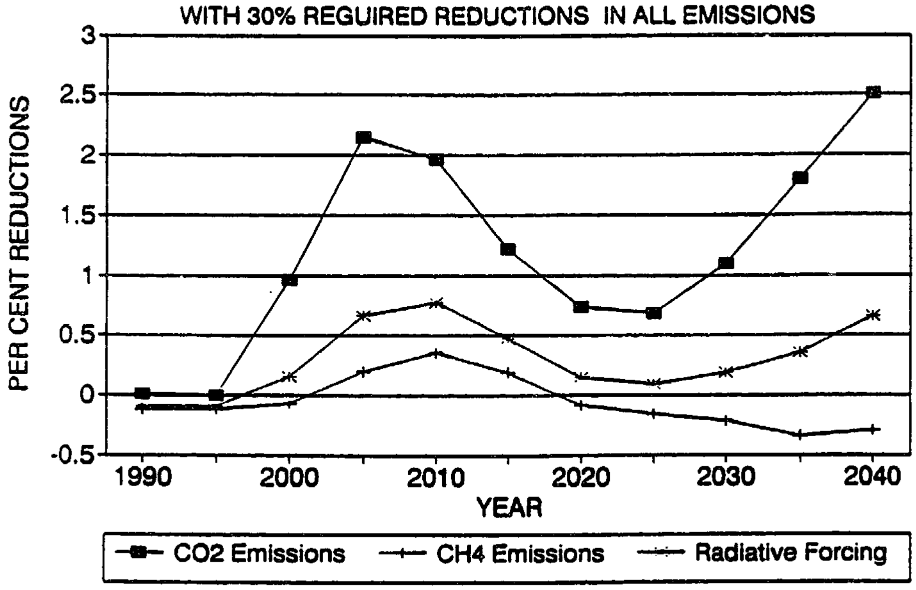
CHART 16
INCREASES IN GDP DUE TO PRESENCE
OF BACK STOP TECHNOLOGIES
WITH ALTERNATIVE RATES OF REDUCTIONS IN EMISSIONS



[12] Nuclear power is also often considered a backstop technology. However, it is already in the set of technologies currently in use in India and is therefore present in the original set of technological choices, rather than in this new set.

CHART 17
RELATIVE REDUCTIONS IN EMISSIONS & RADIATIVE FORCING DUE TO AVAILABILITY OF BACKSTOP TECHNOLOGIES

WITH 30% REGUIRED REDUCTIONS IN ALL EMISSIONS



To explore the consequences of having these alternative technologies in the available set, the model is solved with Scenario A's set of alternative emissions constraints. The striking result is that the new set of technologies are used only to a limited degree. In effect, they are much more costly than the original set, particularly compared with nuclear power, which also generates no greenhouse gas emissions. Thus, it is only when emissions constraints are extremely binding that the new set of technologies is employed to any noticeable degree. The economic consequence of their availability is also quite slight. This is shown in Chart 16, which presents the differences in GDP levels for alternative levels of carbon dioxide and methane constraints.

The effect on emissions of providing the new set of technologies is also relatively modest. Chart 17 shows the differences in emissions, with and without the ba‹ ‹stop technologies and with the same degree of emissions constraint. The increases in carbon dioxide emissions and total radiative forcing might seem somewhat paradoxical, but can be understood by recalling that, in the original scenario, reductions were actually larger than specified by the imposed constraints. (The differences were the result of the need to meet the methane emissions constraint, which forced such a large retrenchment in the economy that carbon dioxide emissions fell by a larger percentage than required.) In the present scenario, however, the availability of technologies that provide alternative sources of power, makes it possible to use less coal, which generates both carbon dioxide (in its burning) and methane (from coal mines). That, in turn, permits greater use of petroleum; consequently, more carbon dioxide is produced, although it remains below the imposed limits.

The reason for these results is straightforward. The backstop technologies are simply insufficiently efficient to replace hydrocarbon fuels and nuclear power, even if greenhouse gas emissions are constrained to these levels.

Effects of eliminating discounting in welfare function

The role of the discount rate in very long-term public decision-making has been the focus of considerable discussion, especially with regard to global warming issues. To investigate the effects of discounting, solutions are found in which the welfare function's discount rate on utility is set to zero. Chart 18 shows the *differences* in the time paths of GDP, private consumption, and increments to radiative forcing, for solutions in which 30 per cent annual reductions in both CO_2 and CH_4 emissions are required, with and without discounting. The elimination of discounting generally results in relatively small increases in GDP and private consumption. Correspondingly, there are somewhat larger increases in increments to radiative forcing, which depend on the growth in accumulated emissions.

Again, although these results may appear paradoxical, they flow directly from the structure of the model and the manner in which emission constraints are imposed. The removal of the discount rate provides slightly more freedom for arranging consumption and investment over time. The optimizing process uses this additional freedom to increase near-term investment that pays off relatively quickly in increased consumption and investment rates and therefore in GDP also. Since emission constraints are always applied relative to emissions in the base case, more emissions are actually allowed in the emission-constrained solutions without discounting.

Roughly the same pattern emerges when a comparison is made between solutions calculated with and without utility discounting, where constraints are imposed on increments in radiative forcing. Chart 18 shows that the GDP and consumption generated in the undiscounted solutions are slightly higher in the early years, slightly lower in the middle years and then substantially higher in the later years, as contrasted to solutions in which utility is discounted. The time path of the additional radiative forcing is roughly the same.

In this latter case, the solution takes advantage of the opportunity to put off reducing annual emissions in order to generate additional investment, consumption and income in the early years. Then, in the middle years, these quantities are reduced, relative to the discounted solution; emissions, therefore, are also reduced. However, in the later years of the time horizon, the payoff to earlier investment is collected in increased income and consumption, with associated increases in annual emissions.

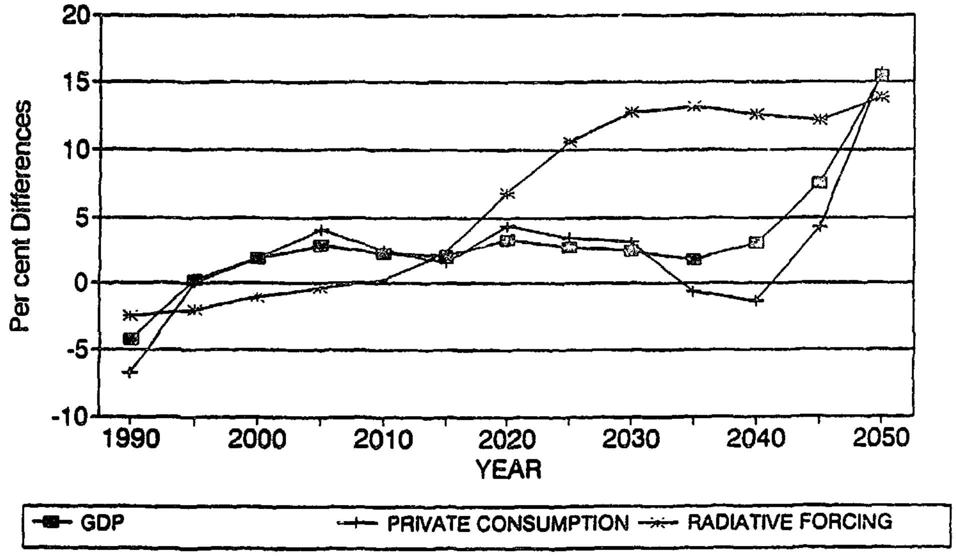
VIII. Conclusions

No model is perfect and the model used here certainly has its share of deficiencies. On the other hand, when used to understand the sectoral as well as overall economic consequences of restricting carbon dioxide and methane emissions, it provides more insight than other models. It is possible to observe both changes in the use of different fuels and changes in sectoral and aggregate output over time as the economy adjusts to emission restrictions.

The results suggest strongly that the economic effects on India of such constraints would

CHART 18

EFFECTS OF ZERO DISCOUNT RATE
REQUIRED EMISSIONS REDUCTIONS OF 20%



be quite profound. This should come as no surprise; realists, including economists, believe that free lunches are not often found. The results could be tempered, of course, by massive improvements in the efficiency with which energy is used; no doubt, improved pricing policies would be relevant in this context. Such once-and-for-all changes, however, would not modify the overall implications of emission restrictions in an economy for which rapid growth is expected.

On reflection, it is unsurprising that the model's accounting should demonstrate that methane is, for India, currently the most important greenhouse gas. There is a further important potential implication suggested, but not tested, by the model. While some carbon dioxide emissions, especially those from the burning of biomass, are not adequately accounted for in the model, intuition suggests that deficiencies in the inventory of methane emissions may be far more significant. Emissions of this gas from the decay of human and natural refuse are a particularly serious omission.

The implications of different forms of emissions restrictions - annual, cumulative and radiative forcing - deserve more attention. Cumulative restrictions, or better still, restrictions on radiative forcing are closely related to greenhouse public policy. They also provide significant additional degrees of freedom for the economic adjustments required. They do this, in part, by allowing the postponement of emissions restrictions, which is not permitted by annual constraints. Of course, the question arises of whether, in practice, a country, having benefitted from postponing a required reduction in emissions, would then be willing to face the consequences in economic losses. Might there be a genuine preference - albeit an irrational one

- for taking the losses annually? Would compliance with international agreements for emission restrictions be more likely, if they required annual, rather than cumulative, reductions? Monitoring requirements would be the same in either case; if effective monitoring were carried out, it would detect departures from cumulative or radiative forcing constraints just as easily as departures from annual constraints.

These issues have not been addressed adequately, in either analytical or policy terms. We believe that the model above, in generating important questions, helps to rectify this inadequacy.

Model Equations and Constraints

Supply-Demand Balances

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

Total Production

$$X_{i,t} = \sum_{k} X_{i,k,t} \qquad (2)$$

Intermediate Demands

$$Z_{i,t} = \sum_{j}\sum_{k} a_{i,j,k}\, X_{j,k,t} \qquad (3)$$

Foreign Exchange Balances

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

Balance of Payments and Trade Constraints

$$B_{t} \le \bar{B}_{t} \qquad (5)$$

$$M_{i,t} \ge (1 - m_{i}) M_{i,t-1} \qquad (6)$$

$$E_{i,t} \le (1 + e_{i}) E_{i,t-1} \qquad (7)$$

$$D_{t+1} = D_{t} + \frac{q}{2}(B_{t+1} + B_{t}) \qquad (8)$$

Gas and Petroleum Products Use by Industry

$$a_{gas,j,k,t} + a_{pet,j,k,t} = a_{cfuel,j,k,t} \qquad (9)$$

$$a_{gas,j,k,t} \le s_{j,k}\, a_{cfuel,j,k,t} \qquad (10)$$

Technology and Production Constraint

$$X_{i,k,t} \le K_{i,k,t} \qquad (11)$$

$$h_{i}\, X_{i,k,t} \le u_{i} R_{i,t} \qquad (12)$$

$$R_{i,t+1} = R_{i,t} + \overline{\Delta R}_{i,t+1} - \frac{np}{2}(X_{i,t+1} + X_{i,t}) \qquad (13)$$

New Capacity Formation

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

Fuel Use by Domestic Consumers

$$C_{dfuel,t} = C_{tree,t} + C_{pet,t} + C_{coal,t} \tag{15}$$

$$C_{tree,t} \leq \bar{s}_{tree} \, C_{dfuel} \tag{16}$$

$$C_{pet,t} \leq \bar{s}_{pet} \, C_{dfuel} \tag{17}$$

$$C_{coal,t} \leq \bar{s}_{coal} \, C_{dfuel} \tag{18}$$

Investment Demand

$$I_{i,t} = \sum_{j} \sum_{k} I_{i,j,k,t} \tag{19}$$

$$I_{i,j,k,t} = b_{i,j,k} \, ICOR_{j,k,t} \, \Delta K_{j,k,t+1} \tag{20}$$

$$\sum_{i} I_{i,1984} \leq \bar{I}_{1984} \tag{21}$$

Terminal Condition on Capacities

$$\sum_{k} K_{i,k,2050} \geq (1 + \bar{g}_{i}) \sum_{k} K_{i,k,2055} \tag{22}$$

Carbon Dioxide and Methane Emissions

$$V^{p}_{i,k,j,r,t} = \nu^{p}_{i,k,j,r,t} \, X_{j,k,t} \tag{23}$$

$$V^{p}_{i,j,r,t} = \sum_{k} V^{p}_{i,k,j,r,t} \tag{24}$$

$$V^{p}_{j,r,t} = \sum_{i} V^{p}_{i,j,r,t} \tag{25}$$

$$V^{c}_{i,r,t} = \nu^{c}_{i,r,t} \, C_{i,r,t} \tag{26}$$

$$V^{c}_{r,t} = \sum_{i} V^{c}_{i,r,t} \tag{27}$$

$$V^{st}_{j,r,t} = \nu^{st}_{j,r,t} \, X_{j,t} \tag{28}$$

$$V^{pp}_{j,r,t} = \nu^{pp}_{j,r,t} \, X_{j,t} \tag{29}$$

Total Gross Emissions

$$GE_{r,t} = \sum_j V^p_{j,r,t} + V^c_{r,t} + \sum_j V^{st}_{j,r,t} + \sum_j V^{pp}_{j,r,t} \tag{30}$$

Absorption by Forest Reserves

$$FA_{r,t} = a_{f,r} \; R_{tree,t} \tag{31}$$

Total Emissions Net of Absorption by Forest Reserves

$$TE_{r,t} = GE_{r,t} - FA_{r,t} \tag{32}$$

Increments in Accumulated Net Emissions

$$ANE_{r,t} = ds^o_{r,t} \; ANE_{r,t-1} + \frac{ds^n_{r,t}}{2} (TE_{r,t} + TE_{r,t-1}) \tag{33}$$

Increments to Radiative Forcing

$$RFC_t = \sum_r rf_r \; ANE_{r,t} \tag{34}$$

Alternative Emission Constraints

Annual Economy-Wide Constraints on Total Emissions

$$TE_{r,t} \leq f^{an}_{r,t} \; \overline{TE}_{r,t} \tag{35}$$

Constraint on Accumulated Net Emissions

$$ANE_{r,t} \leq f^{ac}_{r,t} \; \overline{ANE}_{r,t} \tag{37}$$

Constraint on Net Accumulated Radiative Forcing

$$SRFC_t \leq f^{ra}_t \; \overline{SRFC}_t \tag{38}$$

Objective Function

$$W = \sum_t \left\{ \frac{1}{1+p} \right\}^t \overline{N}_t \; U(C_t) \tag{39}$$

$$U(C_t) = \sum_i \beta_i \; \log\left\{ \frac{C_{i,t}}{\overline{N}_t} - \gamma_i \right\} \tag{40}$$

Endogenous Variables

$ANE_{r,t}$	Accumulated net emissions of type r in year t
B_t	Net foreign borrowing in year t
$C_{coal,t}$	Private consumption of coal in year t
$C_{dfuel,t}$	Private consumption of domestic fuel in year t
$C_{i,t}$	Private consumption of good i in year t
$C_{pet,t}$	Private consumption of petroleum in year t
$C_{tree,t}$	Private consumption of tree (fuel wood) in year t
D_t	Foreign debt in year t
$E_{i,t}$	Exports of good i in year t
$FA_{r,t}$	Amount of absorption of emissions of type r by forest reserves in year t
$GE_{r,t}$	Total quantity of emissions of type r generated 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
RFC_t	Addition to radiative forcing in year t
$R_{i,t}$	Reserves of (oil or natural gas, coal, forest reserves, hydropower) in year t
$SRFC_t$	Net accumulated radiative forcing in year t
$TE_{r,t}$	Total quantity of emissions of type r net of absorption of forest reserves in year t

$U(C_t)$	Utility of per capita consumption in year t
$V^c_{i,r,t}$	Amount of emission of type r generated by the use of a particular fuel i in private consumption in year t
$V^c_{r,t}$	Total amount of emission of type r generated in private consumption in year t
$V^p_{i,k,j,r,t}$	Amount of emission of type r generated by the use of fuel i in production using technology k in sector j in year t
$V^p_{i,j,r,t}$	Total amount of emission of type p generated by the use of a particular fuel i in production, in sector j in year t
$V^p_{j,r,t}$	Total amount of emission of type r generated by all fuels used in production in sector j in year t
$V^{pp}_{j,r,t}$	Amount of emission of type r generated from production processes in sector j in year t
$V^{at}_{j,r,t}$	Amount of emission of type r generated by existing assets in sector j (paddy, cattle, coal/mine) 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

Parameters and Exogenous Variables

$a_{i,j,k}$	Input of good i per unit of production of good j using technology k
$a_{cfuel,j,k,t}$	Input of commercial fuel per unit of production of good j using technology k in year t
af_r	Quantity of absorption of emission of type r per unit of forest reserves
$a_{gas,j,k,t}$	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
$\overline{ANE}_{rt}$	Total quantity of net accumulated emission of type r generated in year t in the optimal solution without emission constraints
$b_{i,j,k}$	Proportion of capital good i in the capital required to produce good i using technology k
$\overline{B}_t$	Maximum net foreign borrowing in year t
$d_{i,k,t}$	Rate of depreciation of capital for production of good i using technology k in year t
$ds^o_{r,t}$	Depreciation factor for old emission stock of type r in year t
$ds^n_{r,t}$	Depreciation factor for new emission stock of type r in year t
e_i	Maximum rate of increase of exports of good i between two periods
$f_{i,k}$	Capacity conversion factor for capital producing good i using technology k
f^{ac}_{rt}	Coefficient for allowable net accumulated emission of type r to be generated in year t
f^{an}_{rt}	Coefficient for allowable net emission of type r to be generated in year t
f^{ra}_{rt}	Coefficient for allowable radiative forcing to be generated in year t

$\overline{FP}_t$	Foreign firms' profit remittances in year t
$\bar{g}_i$	Minimal post-terminal growth rate of sector i
$\bar{G}_{it}$	Public consumption of good i in year t
h_i	Hydrocarbon/output conversion factor
i_t	Interest rate on foreign debt in year t
$\bar{I}_{1984}$	Aggregate investment in 1984
$\overline{TE}_{rt}$	Total quantity of net emissions of type r generated in year t in the optimal solution without emission constraints
u_i	Maximum rate of use of hydrocarbon and forest reserves
$\bar{W}_t$	Workers' remittances 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
$\nu^c_{i,r,t}$	Quantity of emission of type r, per unit use of particular fuel i, in consumption in year t
$\nu^p_{i,k,j,r,t}$	Quantity of emission of type r, per unit use of fuel i, in production, using technology k, in sector j, in year t
$\nu^{pp}_{j,r,t}$	Quantity of emission of type r, per unit of production of output in the production process in sector j, in year t
$\nu^{st}_{j,r,t}$	Quantity of emission of type r, per unit of standing stock of output in sector j, in year t

$ICOR_{j,k,t}$	Incremental capital-output ratio for production of good i using technology k in year t
$\bar{N}_t$	Population in year t
m_i	Maximum rate of fall of imports of good i between two periods
$P^e_{i,t}$	World price of exports of good i in year t
$P^m_{i,t}$	World price of imports of good in in year t
q	Number of years between two time periods t and t+1
rf_r	Coefficient of radiative forcing of emission type r
$\overline{\Delta R}_{i,t+1}$	Discoveries of resource i between year t and year t+1
$s_{j,k}$	Maximum share of natural gas in meeting commercial fuel demand of producing good j using technology k
$\bar{s}_{coal,t}$	Maximum share of coal in meeting private domestic consumption of fuel
$\bar{s}_{pet}$	Maximum share of petroleum in meeting private domestic consumption of fuel
$\bar{s}_{tree}$	Maximum share of tree (fuelwood) in meeting private domestic consumption of fuel
$\overline{SRFC}_t$	Total net accumulated radiative forcing in year t in the optimal solution without emission constraints
$\bar{T}_t$	Other foreign exchange transfers in year t

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