FOIA Number: 2017-1095-F

FOIA MARKER

This is not a textual record. This is used as an administrative marker by the William J. Clinton Presidential Library Staff.

Collection/Record Group: Clinton Presidential Records

Subgroup/Office of Origin: Council of Economic Advisers

Series/Staff Member: Judson Jaffe

Subseries:

OA/ID Number: 20747

FolderID:

Folder Title:
Climate Change - Trading Models [2]

Stack:	Row:	Section:	Shelf:	Position:
S	20	6	1	3

Pacific Northwest Laboratories
901 D St. SW, Suite 900
Washington, DC 20024

FACSIMILE TRANSMITTAL

DATE: February 11, 1998

To: Joe Aldy
Company: CEA
City/State: Washington, DC
Facsimile #: 202-395-6870
Telephone #: 202-395-1455

From: Chris MacCracken
Battelle - Washington Office
Facsimile #: (202) 646-5233
Telephone #: (202) 646-5274

Transmittal Consists of [~~25~~] Page(s) including cover page. 37

COMMENTS:

Joe –

I'm sending two papers your way. They're each 20-something pages, so I'll send them in two chunks. The "Modelling Future ..." paper was published in a book of conference proceedings. I'm including a copy of the title page of the book in front of the chapter. The other paper never got published. By the way, our "Return to 1990" paper now has an official Pacific Northwest National Laboratory document number on it, so you can cite it as "PNNL-11819 Pacific Northwest National Laboratory".

Good luck.

Chris

Note to the reader from the UNU

Future Global Change and Modelling is an ongoing programme that aims to have the United Nations University serve as a forum on the megatrend of global change and structural transformation. This programme is a response to the need to evaluate recent changes in the perception and structure of the world's politics, economics, demography, technology, ecology, and ethics. Practitioners of futures research have, over the past few decades, developed an array of systematic and powerful methodologies in an effort to understand the range and probabilities of future global scenarios. The UNU brings together this international community of scholars to undertake futures studies of global change and incorporate a wide range of variables and methodologies to increase both the early warning and longer-term planning capacities of the UN system and policy makers in general.

This book is based on the first of a series of UNU conferences on Future Global Change and Modelling held in Tokyo in October 1991. Scholars and representatives from various UN agencies and leading research institutions from 17 countries discussed immediate and long-term world problems with simulation analysis by various model systems. Subsequent UNU conferences held under this programme include Arms Reduction: Economic Implications in the Post-Cold War Era, and Global Environment, Energy, and Economic Development.

Modelling global change

Edited by Lawrence R. Klein and Fu-chen Lo

United Nations University Press
TOKYO · NEW YORK · PARIS

sterile and did not go further to exploit the potential of the simple, but differentiated enough model. Thus, for example, it might be interesting to analyse the effects of various asymmetric policies, in which various countries would face different target levels, or the potential use of compensation schemes to induce less developed countries to introduce abatement measures. For it is highly probable that concerted international measures will be hindered by the pressing needs for development and economic restructuring of the less or medium developed countries, who on the other hand are emitting a significant amount of greenhouse gases leading to global consequences.

References

Brendemoen, A., and H. Vennemo. 1991. A Climate Convention and the Norwegian Economy: A CGE Assessment. Paper presented at the Fourth IIASA Task Force meeting on AGEM. Mimeo, Research Department, Central Bureau of Statistics.

Capros, P., P. Karadeloglou, and G. Mentzas. 1990. New Developments for the MIDAS Medium-term Energy Modelling Project of the EEC: The Energy Supply Model and the Supply-Demand Pricing Linkage. IFORS 1990 Conference Paper. Mimeo, Athens.

Hare, P.G., T. Révész, and E. Zalai. 1991. Modelling an Economy in Transition: Trade Adjustment Policies for Hungary. Paper presented at the Fourth IIASA Task Force meeting on AGEM. Mimeo.

Jorgenson, D.W. ed. 1990. *General Equilibrium Modelling and Economic Policy Analysis*. Oxford: Blackwell Publishers.

Nordhaus, W.D. 1989. *The Economics of the Greenhouse Effect*. Cambridge, Mass.: Center for Energy Policy Research, MIT.

Scarf, H.E. 1973. *The Computation of Economic Equilibria, with the Collaboration of Terje Hansen*. Cowles Foundation for Research in Economics at Yale University, Monograph Series, No. 24.

Taylor, L. 1975. "Theoretical Foundations and Technical Implications." In: C. Blitzer et al., eds. *Economy-wide Models and Development Planning*. Oxford: Oxford University Press.

Zalai, E., and T. Révész. 1991. "Trade Redirection and Liberalization: Lessons from A Model Simulation." AULA: *Society and Economy*, 13(2): 69–80.

9

Modelling future greenhouse gas emissions: The second generation model description

J.A. Edmonds, H.M. Pitcher, D. Barns, R. Baron, and M.A. Wise

Introduction

The analysis of greenhouse gas emissions has made enormous progress during the course of the past decade.[1] Analysis has progressed from the use of simple time-trend extrapolations to the analysis of emissions of several greenhouse gases with parallel but independent behavioural and optimization models of energy, manufacturing, agriculture, and land-use systems. But our ability to examine potential future scenarios of greenhouse gas emissions is limited because modelling tools adequate to the task of integrating analyses of technologies and human activities on a global scale with regional detail, including energy production and consumption, agriculture, manufacture, capital formation, and land-use, along with the interdependencies between these categories, do not yet exist.

The first generation of models were specialty models which focused on a particular aspect of the emissions problem without regard to how that activity interacted with other human and natural activities. The Edmonds-Reilly model (ERM) (Edmonds and Reilly 1985), for example, is a global energy model in which the production of commercial biomass has no interaction with the agriculture sector or land-use in general. The Global 2100, Manne and Richels (1990a,b,c,d,

1991) is a computable general equilibrium model, but is limited in its applicability beyond energy-related issues. Other computable general equilibrium models such as Jorgenson and Wilcoxen (1990a,b) focus exclusively on national issues. Other modelling systems such as the Atmospheric Stabilization Framework (ASF) (Lashof and Tirpak 1989), utilize a system of models that provide global coverage of all emissions generating human activities, but do not provide a consistent analysis system in which the interaction between human activities can be analysed. The number of models in use to analyse greenhouse gas emissions reductions is large and growing, including for example: Nordhaus and Yohe (1983); Fossil2, AES (1986, 1991); GREEN, Burniaux et al. (1991), OECD (1991); CETA, Peck and Teisberg (1991); GEMINI, Scheraga et al. (1991); and IMAGE, Rotman et al. (1989).

The current state of understanding of the natural science of the global environmental change issue indicates that a variety of gases are associated with potential changes in the radiative composition of the atmosphere. These gases include: CO_2, CH_4, CO, N_2O, NO_x, SO_2, VOCs, chlorofluorocarbons (CFCs) and CFC substitutes. These gases are released in the process of a wide variety of human activities including: fossil fuel production, transfer and oxidation, land-use change, silvaculture, the application of some fertilizers to crops, the husbandry of ruminant livestock, the cultivation of wetland rice, and specific manufacturing processes such as cement manufacture, nylon manufacture, and chemical manufacture. Moreover, though local air chemistry plays an important role with regard to very short-lived[2] gases, it is the sum of all releases and absorptions of all gases by all human activities that governs the short-term[3] rate of change of the atmospheric composition of radiatively important gases, and the earth's atmospheric radiation profile. In addition, the human activities that govern emissions are interdependent. That is actions that are taken in one segment of the economy affect other segments of the economy. These interactions are likely to become extremely important if policies are undertaken to reduce potential future emissions. For example, carbon taxes raise great quantities of revenue. While the disposition of tax revenue can generally be assumed to be unimportant to the scale of macroeconomic activity, this is certainly not the case with carbon taxes (Bradley et al. 1991; Brinner et al. 1991; and Scheraga et al. 1991). Other potential policy actions such as tree planting to enhance the carbon sink and/or the extensive development of potential biomass resources to replace fossil fuel energy

stack problem

FEB 12 '98 04:58AM BATTELLE ESD

sources, can have substantial impacts on land-use, Marland (1988), Kinsman and Marland (1989), Sedjo and Solomon (1989), Moulton and Richards (1990), Adams et al. (1991), Bradley et al. (1991), and Barfield et al. (1991). Finally, it is essential that the relationship between technology, institutions, economics, and human activity be explicitly represented.

No currently existing model is capable of assessing the global emissions from all human activities and the major direct and indirect consequences of potential policies to reduce emissions. Future analysis requires a more sophisticated suite of models. The new suite of models must include both a global integrating model and compatible regional/national models. These new models must be capable of analysing the emissions of all greenhouse gases from all sources, including both those of natural and human origin, and provide an analysis of the interplay between the variety of human and natural activities responsible for greenhouse gas emissions.

The purpose of this paper is to describe the design of a model, currently under development, which is capable of addressing greenhouse gas emissions and the potential consequences of alternative policy options. We refer to this model as the *second generation model* (SGM).

Paradigms for the SGM

The development of SGMs will benefit greatly from the application of three simple principles: problem orientation, minimum modelling, and parametric modelling. The overriding design principle is that the model should be *problem oriented*. That is, the design of the model should be derived from an analysis of the underlying problem. Model design cannot begin with the set of available models and then try to make the problem fit existing model characteristics. For greenhouse gases, the issues to be addressed are: What are global emissions of greenhouse gases likely to be over the course of the next five to 100 years by region and human activity? What effect will the exercise of policy instruments to control emissions have and what will they cost? What effect will new technologies have on emissions?

Beginning with the problem and working to the design of the model allows the implementation of the second design principle, *minimum modelling*. Minimum modelling means that the model contains all of the information pertinent to answer the research question, but no extraneous information. If chemical manufacture of CFCs is an important activity in determining the rate and timing of climate

P.4/36

change it should be included. Moreover, the model should be *parametric*. That is, the model should utilize a database in which all parameters are open to examination and change by the user. In addition, the model should be an *open model*. The purpose of the model is not to provide a one-pass forecast of the future. Where complex human activities subject to public policy action are involved, the future is fundamentally unpredictable. The purpose of a formal model is to provide a consistent, reproducible framework in which to examine possible scenarios. It is important that model results be reproducible and that the model be open to public scrutiny, and criticism, and that all of the parameters be available for inspection and alteration by model users. Finally, given the complexity of the model, it is important to use a *sequential model development* process, beginning with a simple model and adding additional important behaviours in a sequential fashion.

In applying the above cited principles, it is necessary to begin by outlining the pertinent dimensions of the greenhouse gas emissions phenomenon. The critical features associated with the emissions of radiatively important gases are as follows:

1. The issue is *global*, emissions from all sources in all regions of the world determine total atmospheric change;
2. the greenhouse results from the emission of *multiple gases* including: CO_2, CH_4, CO, N_2O, NO_x, SO_2, VOCs, CFCs, and CFC substitutes;
3. emissions result from *multiple human activities* including: agriculture (including forestry), energy production and consumption, transportation, manufacture, services, and land-use;
4. emissions depend upon *multiple resources and technologies* including: managed and unmanaged ecosystems, capital stocks, and labour;
5. emissions depend on *international trade patterns*, and possibly, migration patterns;
6. factors 3, 4, and 5 depend upon *institutional arrangements*;
7. policy analysis requires both mid-term (five-year) and long-term (100-year) *time horizons*.

The second generation model

In light of the above discussion we have undertaken the design of the SGM incorporating the above-listed criteria into the model architecture. The model is global in scope, with five-year time steps and a horizon of 2100. All the major sources of greenhouse gases, as well as SO_2 will be modelled. The economic model is a member of the class referred to as computable general equilibrium models. It contains sectoral detail on households, government, agriculture, energy, and other products activities. Capital stocks are kept by vintage, with economic retirement and retrofit options available. Depletable and renewable resources are tracked in addition to land-use. Economic decision makers include households, government, and producers. The model is regionally disaggregated, with key countries represented individually. Trade between the regions occurs in energy, agriculture, and other products.

Model overview

At base the SGM is a very simple model. Figure 1 depicts the basic structure and flows of goods and services within the SGM version 0.0. At the core of the model are three productive sectors: agriculture, energy, and other products. These, as we will discuss, are disaggregated into 10 sectors in SGM version 0.0. The greatest disaggregation, eight sectors, is found in the energy sector. The central focus on energy reflects the central role energy issues play in determining the future release of radiatively important gases into the atmosphere. Agriculture is similarly handled separately due to the importance of agriculture and land-use issues in determining emissions. All other production is aggregated into a single sector, other products, in SGM version 0.0.

The three productive sectors use three primary factors of production: land, labour, and capital, in combination with produced factors: energy, agriculture, and other products, to produce final output. Note that two aspects of land-use are considered: surface land resources, and sub-surface resources, for example, energy resources.

The household sector is assumed to own land, labour, and private capital. The demographic character of the society is determined within this sector. Household supplies of land and labour are determined on the basis of the price of these factors, which in turn determine, with distributed corporate profits, taxes, and subsidies, the income of the household sector. Household savings are also determined in this sector and vary with the interest rate. This sector also determines the mix of final products to consume.

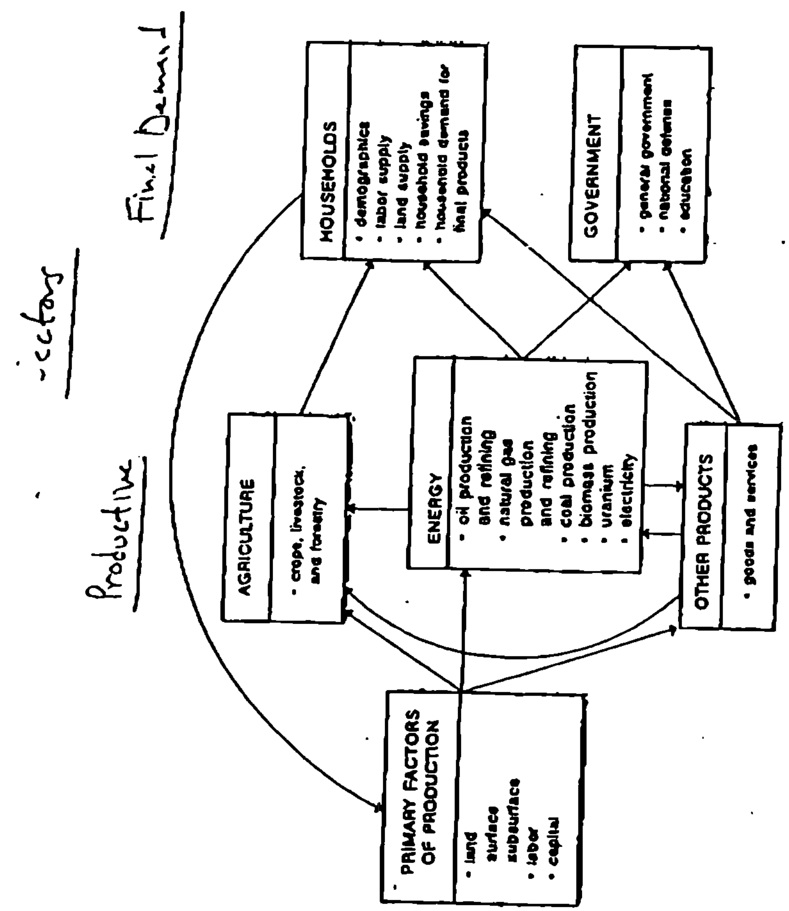


Fig. 1 The flow of goods and services in SGM version 0.0

Finally, the government sector obtains tax revenues from other parts of the economy which are either augmented by borrowing (or reduced by government savings). These revenues go to produce three government services: general government, national defence, and education.

The SGM version 0.0 is a self-consistent dynamic model of the relationship between these six general human activities.

Emissions coefficients are applied to each sector's associated subsector and technology activity rates to derive sectoral, regional, and global emissions of radiatively important gases.

Model development strategy

To reflect the current understanding of anthropogenic sources and sinks for radiatively important gases, and to anticipate the potential for new sources, the model has been designed with a generic structure. This structure allows for a flexible number of production activities, consumption activities, and markets. The implementation of this model utilizes the sequential model development principle. That is, the initial model version will be much simpler than the intended final version. Two model versions are currently identified; SGM version 0.0 and SGM version 1.0. SGM version 0.0 is intended to provide a proof in principle for the modelling system. SGM version 1.0 is intended to provide the first full implementation of the SGM system. SGM version 1.0 will be distributed to the public and have a complete documentation set including: theoretical model description, database description, software description, and user's guide.

For both SGM version 0.0 and SGM version 1.0, the energy production, transformation, and consumption activities will utilize databases developed in support of the ERM, Edmonds and Reilly (1985), Edmonds et al. (1986), Edmonds and Barns (1990; 1991). In addition to the energy structure of the ERM, two producing sectors, agriculture and other products have been added for SGM version 0.0. For SGM version 1.0, the number of sectors will be increased to include expanded government, transportation, other products, and agricultural activities. Final demand sectors for investment, government, and households have been developed. Model development is anticipated to proceed beyond SGM version 1.0, but such model designs lie beyond the present planning horizon.

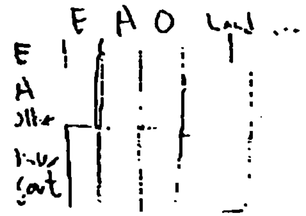
Overview of the SGM structure

Any dynamic model has two problems that it must address. It must describe where the system is at any moment in time and it must describe the process by which it evolves. The SGM is a behavioural model. That is, it attempts to describe how economic systems behave. It is not an optimizing model. The differences between these two approaches are not as great empirically as one might expect.[4] Nevertheless, we have taken the behavioural approach to developing the SGM for two reasons. First, several extremely interesting questions can be addressed in a non-optimizing, imperfect foresight analysis framework. For example, the importance of alternative expectation formation hypotheses can be tested. That is, there is no reason to believe that energy sector decision makers have perfect foresight. In fact, the immediately preceding quarter century of energy history would support the alternative hypothesis, that is that energy decision makers have very imperfect foresight about key future energy parameters such as price. In addition, the behavioural models are computationally simpler in that present behaviour is assumed to be independent of actual future events and decisions. This is of course the domain in which actual decision makers operate. However, the model and its assumed behaviour does depend on anticipated future events and decisions.[5]

Sectors, subsectors, technologies, markets, and accounting

At any moment in time a set of relationships between economic actors can be summarized in a set of accounts that are referred to as an input-output framework. *It is important to emphasize that the SGM is not a traditional static input-output model.* The use of input-output accounting identities to describe economic interrelationships at a point in time does not mean that the SGM simply uses a set of static input-output coefficients that are assumed to remain fixed for an indefinite period in the future to determine production levels and demands. Rather, the simultaneous determination of these input-output coefficients in conjunction with a consistent set of prices is the principal problem facing a computable general equilibrium model like the SGM.

An input-output table shows the relationship between the production, distribution, and use of goods and services in an economy. A row-column entry shows the quantity of a good or service associated



with a row by the sector designated by the column. If a good or service is produced in the economy, it will have both a row and column associated with it. Some sectors, for example, households, investment, and government, may be assumed to consume new final goods and services, but to provide no net output for the rest of the economy. Some factors of production, for example, land, labour, and capital, may be utilized for production in a given period, but are not produced using current flows of goods and services.

GNP accounting: The accounting framework for the SGM relies on simple economic relationships. For example, we can define GNP for any region (note we drop the regional subscript to simplify the notation) as the price-weighted sum of net production of all products,

$$\mathrm{GNP} = \sum_{i=1}^{N} P_i\left(X_i - \sum_{j=1}^{N} A_{i,j}\right) = \sum_{i=1}^{N} P_i(C_i + G_i + I_i + \mathrm{EX}_i - \mathrm{IM}_i), \tag{1}$$

where GNP is the Gross National Product; X_i is the gross domestic production of product i; A_{ij} is the domestic use of product i in the production of product j; P_i is the price of product i; N is the number of product; C_i is the domestic consumption by households of product i; G_i is the domestic consumption by government of product i; I_i is the domestic investment uses of product i; EX_i is the gross exports of product i; and IM_i is the gross imports of product i, which in turn is equal to the disposition of net output among final demand sectors. Alternatively, the GNP can be expressed as the sum of payments to the factors of production,

$$\mathrm{GNP} = \sum_{i=1}^{N}\left(P_i X_i - \sum_{j=1}^{N} P_j A_{j,i}\right) = \sum_{i=1}^{N}\left(\mathrm{TXibl}_i + \pi_i + \sum_{j=N+1}^{N+M} P_j A_{j,i}\right), \tag{2}$$

where TXibl_i is the indirect business taxes; π_i is the profits including net interest and capital consumption allowances; and M is the number of primary factors of production (e.g. labour and land).

The fundamental problem that the model must address is finding a set of prices that are consistent with demands by producers and consumers for goods, services, and primary factors of production. The major behavioural components of the model describe the relationship between prices, production, and consumption of goods and services.

Defining sectors, subsectors, technologies, and markets: For the purposes of SGM documentation we have chosen to use several terms in a specific manner.

Sectors
Sectors represent human activities that produce or consume goods and services. There are two types of sectors, producing sectors and final demand sectors;

Producing sectors
Producing sectors combine factors of production, including the products of other producing sectors and primary factors of production, to produce net output. For example, agriculture, energy, and other products are sectors in SGM version 0.0;

Final demand sectors
Final demand sectors provide final demands for final goods and services, and include households, government, investment, and net exports in SGM version 0.0;

Markets/factor inputs
Markets and factor inputs are intimately related in the SGM. A market exists in the SGM whenever production and consumption decisions are determined separately in the model. Each traded good is also potentially a factor of production, although a product may or may not be used in the production process in the implemented model. For example there may be no net demand for agricultural products by any producing sectors. Nevertheless, there will always exist a row entry in the SGM input-output accounting structure even if the element entered there is zero. Markets define the primary level of aggregation in the model. That is, all subsectors and technologies (see descriptions below) in a sector/market produce a single homogeneous commodity. Markets are defined for each producing sector plus for each primary factor of production, for example, agriculture, energy, and other products plus labour and land in SGM version 0.0;

Subsectors
A subsector exists in the SGM whenever two human activities produce the same output. All subsectors within a sector face the same

price for outputs, but would be expected to have different production functions, for example the production of electricity using oil, gas, coal, hydroelectric power, nuclear power, or solar power. Subsectors may be defined for both producing sectors and final-demand sectors;

Technologies
For some human activities an additional level of disaggregation is useful. Whereas, the number of subsectors for an individual sector in a specific region would not be expected to change from analysis to analysis, there will be times in which multiple, non-mutually exclusive, technology options should be considered. These options have the same output price as the subsectors and sector, but would have individual production functions.

SGM sectors, subsectors, technologies, and markets
For SGM version 0.0 sectors, subsectors, and markets have been identified and are listed in table 1. The technology level of the model has not been separately identified here as there is only one technology for each subsector in version 0.0.

Economic sectors

There are eight energy sectors and two non-energy production sectors in SGM version 0.0. Data for the energy sectors is largely drawn from the ERM model, Edmonds and Reilly (1985) and Edmonds et al. (1986) as updated for Edmonds and Barns (1991). The non-energy sector of the economy will be the primary focus of efforts between SGM version 0.0 and SGM version 1.0. Table 2 shows the additional sectors to be added to SGM version 0.0 to create SGM version 1.0. Producing sectors can be roughly categorized as being either agricultural, energy, or other-products related. The level of disaggregation in each area is driven by the need to understand factors affecting potential future emissions of greenhouse gases and the potential consequences of policy actions to reduce potential future greenhouse gas emissions.

Agriculture
The agriculture sector produces food, fibre, and forest products. In version 0.0, there will be only a single aggregate agricultural commodity. In version 1.0 there will be nine outputs, disaggregated primarily on the basis of greenhouse gas emissions. The three sectors

Table 1 SGM sectors, subsectors, and markets model version 0.0

Sector No.	Market No.	Sector	Subsector No.	Subsector name
1	1	Agriculture	1	Agriculture
2	2	Crude oil production	1–10	Crude oil production by grade. Each resource grade is modelled as a subsector.
3	3	Oil refining	1	Conventional oil refining
			2	Coal liquefaction
			3	Biomass liquefaction
4	4	Natural gas production	1–10	Natural gas production by grade. Each resource grade is modelled as a subsector.
5	5	Natural gas transformation	1	Conventional gas
			2	Coal gasification
			3	Biomass gasification
6	6	Coal production	1–10	Coal production by grade. Each resource grade is modelled as a subsector.
7	7	Biomass production	1	Traditional biomass
			2	Biomass waste
			3	Biomass farms
8	8	Uranium production and refinement	1–10	Uranium production and processing by grade. Each resource grade is modelled as a subsector.
9	9	Electric power generation	1	Oil
			2	Gas
			3	Coal
			4	Biomass
			5	Nuclear
			6	Solar/fusion
			7	Hydro
10	10	Other production	1	Other production
11	n.a.	Households[a]	1	Consumer demand
			2	Demographics
			3	Land supply
			4	Labour supply
			5	Savings
12	n.a.	Government	1	General government
			2	Education
			3	National defence
n.a.	11	Labour	n.a.	n.a.
n.a.	12	Land	n.a.	n.a.
n.a.	13	Savings/investment	n.a.	n.a.

a. Listed household subsectors represent major decisions made within the household sector rather than subsector as used in the other sectors. See section 'Households' below for further details.

Table 2 Sectors and subsectors added to SGM version 0.0 to create SGM version 1.0

Sector SGM version 0.0	Sectors SGM version 1.0	Subsectors
Agriculture		Rice
	Other grains	Other grains
	Ruminant livestock	Ruminant livestock
	Other livestock	Other livestock
	Other food	Other food
	Fibre	Fibre
	Forests	Forests
	Pulp and paper	Pulp and paper
	Wood and wood products	Wood and wood products
	Processed foods	Processed foods
Other production	Manufacturing	Materials intensive
		Other manufacturing
	Passenger transport	Rail
		Air
		Bus
		Other[a]
	Freight transport	Rail
		Air
		Truck
		Other
	Services	Health and other services

a. Passenger automobile in household sector.

closely associated with greenhouse gas emissions are rice (principally CH_4), ruminant livestock (principally CH_4), and forestry (principally CO_2). All sectors are associated with N_2O emissions through the application of fertilizer. Significant quantities of greenhouse gases are also associated with traditional agricultural technology, in particular the practice of slash and burn. The principal inputs in version 0.0 will be land, labour, and energy. In version 1.0 these will be expanded to include fertilizer and materials and land will potentially be disaggregated into multiple categories in accordance with soil types and climate.

Energy

There will be eight energy sectors in the model. Each of these will have subsectors as detailed in table 1 to allow the competing methods for producing the product in question to be accurately modelled.

Two types of energy technologies will be identified, those associated with depletable resources and those associated with renewable resources. All energy technologies will be associated with a resource constraint. A distinction will be made between reserves and resources. Reserves are those resources where two types of energy have been identified and whose location is known and which are known to be producible under present and anticipated economic conditions. Reserves are depleted over time as they are produced. Total reserves are augmented by additions from the resource base. The additions to reserves are determined by grade structure of resources and technologies available to extract them. Renewable resources are handled in a manner similar to depletable resources except that the capacity to produce persists beyond the point of production. Solar energy is an example of a renewable energy resource. A renewable resource may be degraded by production, however. Agriculture, for example, may deplete soils unless investments are made to maintain soil quality.

Other products

In version 0.0, the other products sector will include everything which is neither agriculture nor energy. In version 1.0, the other products sector will be broken down into manufacturing, passenger and freight transportation, and health and other services. There is the possibility of further splitting manufacturing into materials and other manufacturing. Inputs will be capital, labour, and energy in version 0.0 with materials being added in SGM version 1.0. The principal sectors are further disaggregated into subsectors on the basis of their importance to the greenhouse issue, either because they are major energy users, or because they are direct emitters or sinks for a greenhouse gas.

Regions

SGM version 0.0 has 11 regions while SGM version 1.0 will have 20 regions as shown in table 3.

Policy options

Because of the pervasive nature of activities that generate greenhouse gases, a wide variety of policy options needs to be included in the model. Making provision to model these options has had a significant impact on the structure of the model. In addition to the usual tax and regulatory options, provisions have been made in the SGM structure to model such strategies as carbon sequestration by reforestation and afforestation, and biomass energy production, and mandated technologies and practices. The SGM is also designed to explore the consequences of changes in real government expenditure patterns/or complementary reductions in non-greenhouse taxes.

Table 3 Regions in SGM model versions 0.0 and 1.0

SGM version 0.0	SGM version 1.0
1. USA	1. USA
2. Canada	2. Canada
3. Western Europe	3. European Community
4. Japan	4. Other Western Europe
5. Australia/New Zealand	5. Japan
6. Eastern Europe and Russia	6. Australia/New Zealand
7. China and other planned Asia	7. Eastern Europe
8. Mid East	8. Russia
9. Africa	9. China
10. S. & E. Asia	10. Centrally planned Asia
11. Latin America	11. Mexico
	12. Brazil
	13. Other Latin America
	14. Indonesia
	15. India
	16. Philippines
	17. South Korea
	18. Other S. & E. Asia
	19. Middle East
	20. Africa

Theoretical structure of the model

The SGM employs a generic production-cost structure to facilitate the continued development of the model with a minimum of code changes and a flexible modelling response to the wide variety of potential analyses that may be required. The core of the model is the description of production activities. These activities are described by a generic production-cost relationship. This relationship utilizes the theory of duality to describe production functions alternately in physical or financial terms.

sector → subsector → technology

The generic production/cost relationship

The generic production/cost (GPC) relationship uses information about prices, technology, and previous investments to compute levels of production and consumption of commodities as well as demands for investment in new capital stock. Productive activities are described by functional relationships in the SGM which are referred to hereafter as technologies. The term technology is used here to cover a broad array of activities including everything from the production of iron and steel to the production of rice. Technologies, as described earlier, are the fundamental unit of disaggregation in the model. Each sector contains at least one subsector and each subsector contains at least one technology. For SGM version 0.0, there is only one sector, market, subsector, and technology for the production of agricultural output. For the production of electricity, there are seven subsectors each of which can potentially utilize multiple technology options. The SGM keeps all of its information on productive capacity at the technology level of detail.

The SGM uses a vintaged description of technologies. This has a number of important implications. First, it means that history matters. When a technology is installed it remains in existence and can be operated until its retirement. New technologies affect productivity primarily at the margin. They can only affect historical decisions if they are so attractive (unattractive) that they force prices down to the point where existing technologies are retired early (undergo life extension). Another important implication is that once installed, capital stock is not malleable. It cannot be shifted around from one sector of the economy to another. In fact, once installed, capital costs no longer matter. In other words, once the technology is installed the decision to operate or idle a technology depends solely on the ability of the technology to recover its current operating expenses plus taxes and less subsidies.

A technology is described by an array of characteristics including:

1. production function parameters;
2. emissions coefficients;
3. capital investment parameters;
4. installation parameters (e.g. date of first availability, date of removal from the list of options, nominal lifetime, length of installation period); and
5. vintage.

A technology option can be described by the information contained

in parameter sets 1, 2, 3, and 4. Once installed, the operating characteristics of a technology can be described by parameter sets 1, 2, and 6.

Within the GPC relationship, the producing sectors all follow the same general structure. There are, of course, some characteristics that are specific to a sector or apply only to a subset of sectors. However, the basic model structure is sufficiently general to accommodate the production/cost and operating characteristics of the various producing sectors in its parameter set.

The sectors represent the highest level of aggregation of production characteristics in the GPC. Within the GPC framework, these production sectors are disaggregated into one or more production/cost subsectors. All sectors, subsectors, and technologies produce a common output and face a common external market price for produced output. The GPC structure allocates investment to technologies based on prior investment history and relative profitability using a logit market-share allocation scheme.

As an example of this sector-subsector hierarchy, consider an electricity production sector with subsectors for coal, oil, natural gas, biomass, nuclear, and hydroelectric power. These subsectors all produce electricity, and they all receive the same price for the electricity they generate. These subsectors do, however, have quite different operating and input requirements for producing electricity, which will in turn affect their relative profitabilities. The allocation of investment among these subsectors in the GPC will reflect these differences in profitability.

Each technology is represented by a vintage-dated, constant elasticity of substitution (CES) production/cost function (one for each vintage of capital stock in operation). For each technology, technological change through time can be captured in the model through the CES production function parameter set. In SGM version 0.0 both an initial set and a terminal set of CES coefficients or parameters is specified for each producing subsector. For any future vintage, the CES coefficients used are a time-dependent interpolation between the initial and terminal values. Different technological change scenarios can thus be modelled in each subsector by varying the terminal coefficient values and the time required to reach these terminal values.

The general execution path for the GPC is to (1) determine desired levels of investment in new capacity, (2) operate the new capacity, (3) retrofit existing capital stocks, and (4) operate or retire existing capital stocks.

The CES production/cost-function

The CES production function can be written,

$$Xs = \alpha_0\left(\sum_{i=1}^{N}\alpha_i X_i^{\rho}\right)^{1/\rho}, \tag{3}$$

where Xs is the gross output of the process; X_i is the use of input factor i; α_0 is the scale coefficient; α_i is the individual factor coefficients; and ρ is the elasticity of substitution parameter.

Profit maximization implies that,

$$P_i = P_0\frac{\partial Xs}{\partial X_i}, \qquad i = 1,\dots N-M, \tag{4}$$

where P_i is the price of ith input; P_0 is the price of output; $N-M$ is the number of variable factors; and M is the number of fixed factors.[7]

Profits can be written as,

$$\pi = P_0 Xs - \sum_{i=1}^{N-M} P_i X_i. \tag{5}$$

By judicious application of algebra, and equation (4), profits can be expressed as a function of price and the quantities of M non-variable factors of production via,

$$\pi = \alpha_0 P_0\left[1-(P_0\alpha_0)^{\mu}\left(\sum_{i=1}^{N-M}\alpha_i^{(\mu/\rho)}P_i^{-\mu}\right)\right]^{-1/\rho}\left(\sum_{i=N-M+1}^{N}\alpha_i X_i^{\rho}\right)^{1/\rho}, \tag{6}$$

where

$$\mu = \frac{\rho}{1-\rho}. \tag{7}$$

It is well known that the partial derivative of this expression with respect to the price of the ith input is the negative of the total factor demand, that is

$$\frac{\partial \pi}{\partial P_i} = -X_i. \tag{8}$$

The demand for the ith factor input to the production process can therefore be calculated directly as,

$$X_i = \left(\alpha_0 P_0\frac{\alpha_i}{P_i}\right)^{\mu/\rho}\left(\frac{Y}{Z}\right)^{1-\rho}, \qquad i = 1,\dots N-M, \tag{9}$$

where

$$Y = \sum_{i=N-M+1}^{N}\alpha_i X_i^{\rho}, \tag{10}$$

and

$$Z = 1-(\alpha_0 P_0)^{\mu}\left(\sum_{i=1}^{N-M}\alpha_i^{\mu/\rho}P_i^{-\mu}\right). \tag{11}$$

The above equations can be used to model both operational decision making and investment determination.

Expected future profits from the operation of a technology which employs

$$x_k = (X_{N-M+1},\dots,X_N)$$

fixed factors over the course of T years of operation is simply,

$$\pi_e(t_0) = \sum_{t=1}^{T}\left(\frac{\pi(x_k,t)}{1+\text{dis}}\right)^t, \tag{12}$$

where $\pi(x_k,t)$ is the profit rate consistent with expected future prices in future period t and dis is the discount rate.

Investment and operating decisions

Once a technology has been installed, operation is determined by the set of factor prices for variable factors of production, and the quantity of the fixed factor employed. The determination of factor demands is therefore a relatively simple matter. Investment decisions however are not so simple. These are determined both by the present set of factor prices and the set of expected future factor prices extending out over the expected lifetime of the investment. In the SGM, there are two types of investments, investments in new capacity and investments in existing capacity, in the form of retrofit and renovation (life extension) investments. The existence of retrofit and renovation (life extension) investment alternatives means that present operations are never simple, and that the technology chosen for an addition to new capacity may be substantially altered before its ultimate retirement. The analysis of investment alternatives requires a mechanism for the determination of expectations regarding future prices and taxes.

Future price and tax rate expectations

In each sector, investments are allocated among subsectors on the basis of their relative *expected* profitabilities. Therefore, investment decisions for each subsector require expected profit rate calculations, which require expected prices and taxes for all inputs. For an open economy the purchase price of the good produced by the ith sector in region "1" is given by:

$$P_{i,t} = \alpha_{i,t}[P_i(1 + \delta_{i,j}\mathrm{Tr}_i)\mathrm{txa}_{i,t} + \mathrm{txb}_{i,t}], \quad (13)$$

where $\alpha_{i,t}$ is an adjustment factor to reflect markups and intra-regional transport costs; Tr_i is the import transportation costs for the ith good; $\delta_{i,t}$ is a logic driven parameter whose value is 0 if the region is a net exporter, and 1 otherwise, $\mathrm{txa}_{i,t}$ is the proportional tax on the ith product in region 1; and $\mathrm{txb}_{i,t}$ is the additive tax on the ith product in region 1.

Obviously, the price received by the producer of the jth good is simply,

$$P_{i,j} = P_i(1 + \delta_{i,j}\mathrm{Tr}_i). \quad (14)$$

The direct computation of $\pi_e(t_0)$ is cumbersome. An approximation of this value can be obtained by substituting a set of present discounted prices directly into the profit function. This yields an exact solution when $\mu = 1$ (see equation [7]). The present discounted price for product j (either an input or an output), Pe_j, is calculated by,

$$Pe_{j,t}(T) = \sum_{t=1}^{T_{exp}} P_{j,t}(t_0) \cdot \left(\frac{1 + r_j}{1 + \mathrm{dis}}\right)^t. \quad (15)$$

where T_{exp} is the nominal life of the investment; r_j is the rate of expected price change; and dis_j is the discount rate for that subsector.

As noted above, the nominal life of the investment is a parameter of the technology. This parameter value may be different from the maximum potential life of the technology. The tax rate tx is an exogenous variable. Both the rate of expected price change r_j and the discount rate dis are behavioural variables. Expectations of future price and tax rate expectations are assumed to be formed in one of two ways. Either they are given exogenously, and assumed known, or they are formed on the basis of prior experience. This yields four alternative formation assumptions for future prices and taxes of inputs and outputs which can be created by combining assumptions 1, 2, 3, and 4 from the following matrix:

	Formed on the assumption that previous B periods rate of change will continue indefinitely	Given exogenously
Prices	1	3
Taxes	2	4

Note that whenever price of tax expectations are formed on the basis of prior experience, the period of prior experience, B, must also be specified. For $B = 0$, present prices or taxes are assumed to remain constant indefinitely. Furthermore, it is possible to run the model in an iterative sequence to develop a perfect foresight set of exogenously specified set of prices. This would be accomplished by specifying prior solution prices as the set of expected future prices and iterating until stability is reached.

We feel that the ability to model behaviour in which price expectations are formed on the basis of imperfect foresight is important. The period of time between 1970 and the present is marked by decision-making on the basis of flawed foresight in energy markets.

Furthermore, the effectiveness of tax and regulatory policies may in fact depend on the expectations formed with regard to long-term commitment.

The relationship between the discount and interest rates

The discount rate and the real interest rate need not be the same. A great deal of behavioural literature suggests that these rates may in fact be significantly different from each other, Lind (1983), Meier and Whittier (1983), Hausman (1979), and Gately (1980). To reflect this phenomenon, the discount rate, dis, will be linked to the interest rate calculated in the model, interest, by a constant factor of addition, fac_r. The sector-specific discount rate for retrofit investments, will therefore be given by,

$$\mathrm{dis}_r = \mathrm{interest} + \mathrm{fac}_r. \tag{16}$$

The add-on factor for retrofit investments need not be the same as the add-on factor for new investments.

The expected future profit rate for a capacity increasing technology

The expected profit rate relative to the capital cost, K, denoted as π_e, is given by,

$$\pi_e = \frac{NR_e}{K} \tag{17}$$

and

$$\frac{NR_e}{K} = \alpha_0 Pe_0 \left[1 - (Pe_0\alpha_0)^{\rho/(1-\rho)} \left(\sum_{i=1}^{N-M} \alpha_i^{1/(1-\rho)} Pe_i^{-(\rho/(1-\rho))}\right)\right]^{(1-\rho)/\rho}$$
$$\times \left(\sum_{i=N-M+1}^{N} \alpha_i x_i^{\rho}\right)^{1/\rho} (1 - tx). \tag{18}$$

where NRe is the expected net revenue, tx is the profits tax rate, there are M fixed factors, and the other $N - M$ factors are variable factors.

In version 0.0, there is only one fixed factor and the fixed factor term reduces to $\alpha_n^{(1/\rho)}$.

When investments in new capacity occur over more than one period

For most investments the decision to invest and the initiation of operation can be assumed to occur within a single five-year time step. This is not always the case. For example, the construction of nuclear electric power plants may require more than five years from start of construction to first production. Forestry similarly requires more than five years between the time of initial investment and the time of harvest. Each of these circumstances requires a somewhat different approach.

Extended construction time

When the construction time for an addition to capacity extends over $T_{\mathrm{construct}}$ periods then there is an evaluation of the investment in each of these periods under the assumption that the fraction of total investment required in each period is equal. That is, if the total investment in the new capacity is taken to be K, and the construction time is $T_{\mathrm{construct}}$, then in each period an investment of

$$K_t = K/T_{\mathrm{construct}}$$

is assumed to be made. If the investment is expected to be profitable in the first period, then construction begins. The present discounted value of the investment requirement is then,

$$K_{e,t} = \left(\frac{K}{T_{\mathrm{construct}}}\right) \sum_{tc=1}^{(T_{\mathrm{construct}}-t)} \left(\frac{1}{1+\mathrm{dis}}\right)^{tc} \qquad t = 1, \ldots T_{\mathrm{construct}}, \tag{19}$$

where, t is the investment period in which the investment decision is being made, $t = 1, \ldots T_{\mathrm{construct}}$; and tc is an index of periods of investment remaining, $t = 1, \ldots, T_{\mathrm{construct}}$. Note that as each period of construction passes, the expected profit rate will rise, other things being equal, because previous period investments become sunk costs.

Expected net revenues from operation of the investment must also be discounted by a factor,

$$\sum_{tt=1}^{(T_{construct}-1)} \left(\frac{1}{1+\text{dis}}\right)^{tc} \qquad t = 1, \ldots, T_{construct}. \tag{20}$$

The growth-harvest decision

The growth-harvest decision problem does not occur in SGM version 0.0, as all agricultural activities are aggregate. In SGM version 1.0, a forestry sector will be disaggregated and this problem will occur. In this case an investment occurs in period t_0, but no revenue is received until $T_{harvest}$. But $T_{harvest}$ is not predetermined. For growth-harvest production functions the production function given by equation (3) and

$$a_{t_0} = \alpha(C_t, C_{t-1}, \text{Atmos}_t, \text{Atmos}_{t-1}, t - t_0), \tag{21}$$

where α is now a function of a vector of climate and atmospheric state variables, and the amount of time that has elapsed between the initial investment, t_0, and the present period t. C_t is a vector of climate variables such as for example, temperature, precipitation, soil moisture, and evapotranspiration, for $t = t, t-1$; and Atmos_t is a vector of atmospheric state variables such as for example the concentration of atmospheric CO_2, for $t = t, t-1$.

The expected profit rate for an investment in a growth-harvest activity is determined by equations (18) and (21) using the expected price vector for the potential harvest $T_{harvest}$ periods in the future[8] and discounted by the value,

$$\text{discountfactor} = \sum_{t=1}^{T_{harvest}} \left(\frac{1}{1+\text{dis}}\right)^{t}. \tag{22}$$

The value of π_e can be computed for any two potential harvest periods, $T_{harvest}$ and $T_{harvest} + 1$, denoted respectively $\pi_e(T_{harvest})$ and $\pi_e(T_{harvest} + 1)$. The maximum potential value for π_e can be estimated by beginning with $T_{harvest} = 1$, and increasing the value of $T_{harvest}$ whenever,

$$\pi_e(T_{harvest} + 1) \geq \pi_e(T_{harvest}).$$

Investments with a maximum value for $\pi_e > 0$ are included in the pool of sector specific competing investments.

Resource constrained technologies

Many economic activities take place against a background of resource constraints. This is of particular interest in the field of energy economics, but is in no way limited to the energy sector. For example, the resource base for conventional oil is ultimately finite, and cumulative production from that resource base may potentially approximate the total resource over the period of analysis. Fossil fuels are an example of a depletable resource. Renewable resources, such as solar, wind, tidal, and ocean thermal energy conversion also exist. For renewable resources the resource is available in each period independent of consumption during the previous period. We will define depletable and renewable resources as follows:

- *Depletable resources*: A depletable resource is one in which the consumption of the resource in one period affects potential consumption in the next period.
- *Renewable resources*: A renewable resource is one in which the consumption of the resource in one period does not affect potential consumption of the resource in the next period.

Describing the relationship between resources and production is important for such activities.

Depletable resources

For depletable resources the total resource available for consumption over all periods is the sum of the resource available in each grade of NG grades,

$$R_i = \sum_{g=1}^{NG} R_{i,g}, \tag{23}$$

where R_i is the total amount of resource of type i which could be potentially recovered under any possible conditions; and $R_{i,g}$ is the total amount resource of type i, found in concentration c_g or higher up to c_{g-1} under any possible conditions. The resource base can be partitioned into discovered and undiscovered resources. Discovered resources are made up of extracted resources, RE, and reserves, RV. Undiscovered resources are denoted as RU. Thus,

$$R_i = RE_i + RU_i + RV_i, \tag{24}$$

$$R_{i,g} = RE_{i,g} + RU_{i,g} + RV_{i,g}. \tag{25}$$

In the model each sector that produces a depletable resource has a different subsector for each grade of the resource. For a given technology, the grade of the resource is reflected in the value of $\alpha_{ll} = \alpha_{ll,g}$ in the production function. Desired extraction from each resource grade is determined by the expected rate of profitability. The production function implicitly includes the cost of converting undiscovered resources into reserves. Production occurs out of reserves as determined by profit maximization subject to the constraint imposed by total investment in each vintage's productive capacity. The production activity occurs only from reserves, and shifts resources from the reserve category to the extracted category.

Because of the multiplicity of resource grades and the existence of substitutes, there is no guarantee that the price of a depletable resource will rise at a rate equal to the rate of interest, the 'hotelling' result.

Competition among capacity increasing investments within a sector

As discussed earlier, the sector is the highest level of aggregation in the model. Subsectors are assumed to produce an essentially homogeneous product within the sector. For example, in SGM version 1.0 it is expected that there will be four different types of freight transport: rail, air, truck, and other. Each will produce a common unit of output, tonne kilometres of freight transport. Obviously, this assumption violates physical reality. Nevertheless, it is intended to capture the essence of the system. For each subsector, there also exists an additional level of disaggregation, which we refer to as the technology level. Technologies compete within the confines of an individual subsector, and in turn determine the overall profitability of the subsector. A logit function is used to determine the share of total sectoral investment each technology obtains. That share is given by:

$$S_{i,tech} = \frac{(\pi^{\sigma}_{i,tech}/N_{tech_i}N_{ss})}{\sum_{j=1}^{NO}(\pi^{\sigma}_{j,tech}/N_{tech_j}N_{ss})}, \tag{26}$$

where $\pi_{j,tech}$ is a metric of the characteristic upon which competition is based for technology, tech, in subsector i, N_{ss} is the number of subsectors, N_{tech_i} is the number of technologies competing in subsector i, σ is a sensitivity parameter, and

$$NO = \sum_{i=1}^{N_{ss}} N_{tech_i}. \tag{27}$$

The logit function is homogeneous of degree zero. That is, any scaler change in the values of all $\pi_{i,tech}$ leaves the values of all $s_{i,tech}$ unchanged. For values of σ equal to zero, $s_i = 1/(N_{ss}N_{tech_i})$. If greater values of $\pi_{i,tech}$ enhance market share, then the value of σ is taken to be non-negative. (If greater values of $\pi_{i,tech}$ diminish market share, then the value of σ is taken to be negative.) As the value of σ approaches ∞, $s_{i,tech}$ approaches one for the largest value of $\pi_{i,tech}$.

In this model, we will use the logit function to determine the share of a sector's total investment spending that is allocated to each subsector, that is to say each competing technology option. The independent variables then are the profit rate values of π obtained earlier. In general the value of σ will be set to reflect existing market sensitivity.

Aggregate sector investment in new capacity

Aggregate regional sector investment levels are determined by using an accelerator from the previous periods total investment. Specifically,

$$K_{tot_{i,t+1}} = K_{tot_i} \cdot \text{baserate}_{t+1} \cdot f[\exp(\pi_{t+1})], \tag{28}$$

where K_{tot} is the total new investment in sector i, in period $t+1$; baserate is the base rate of growth of investment; and $f(\exp(\pi))$ is a function of the expected profit rate, $\exp(\pi)$.

We do not prejudice the determination of either baserate or the function $f(\exp(\pi))$. For present model development we use,

$$\text{baserate}_{t+1} = \frac{K_{tot_t}}{K_{tot_{t-1}}}. \tag{29}$$

The expected rate of profit is taken to be the average expected profit rate which is given by,

$$\exp(\pi_{t+1}) = \bar{\pi}_{t+1} = \left(\sum_{i=1}^{NO} \pi^{\sigma}_{i,t+1}\right)^{1/\sigma}, \tag{30}$$

where $\pi_{i,t}$ is the profit rate for the ith technology (taken over all subsectors), in period t. This derivation is given in Clarke (1991). For SGM version 0.0 we use,

$$f[\exp(\pi_{i,t+1})] = \left(\frac{\exp(\pi_{i,t+1})}{\bar{\pi}_t}\right)^{\alpha}, \tag{31}$$

where α is a sensitivity parameter.

Retrofit and renovation investment decisions and the operation of existing technology vintages

For existing technologies, or technologies with capacity already in place, there are four possible outcomes in any period:

1. *Operate* without change,
2. *Retrofit* and operate,
3. *Idle* the capacity, but do not retire,
4. *Retire* the technology.

The determination of operating mode depends upon the behavioural assumptions. Given the five-year time step in the model, it has been decided to eliminate option 3. In other words, producers will either operate a vintage in the current period or retire that vintage.

For market economies profit maximization is the behavioural paradigm. For investment decisions this means that *NR* is maximized. That is, existing technologies will continue to be operated as long as current operating costs can be covered, unless otherwise prevented from doing so. They will add retrofit technologies either if they are required or if they add to profitability. The behaviour of command economies is similar, except that (1) substantial subsidies, in both the cost of input factors and direct subsidies to total operating costs; and (2) allocation schemes where administered prices do not clear markets are an important determinant of economic behaviour.

Retrofit technologies

Retrofit technologies are the principal complicating factor in the analysis of existing technology operations. The level of operation of the technology is assumed to be identical to the parent technology. The additional capital cost, relative to the original capital cost, is a technology parameter. The presence or lack of presence of retrofit options does not affect the base production or cost functions.

New retrofit options can be incorporated into the operating structure of the technology if they either are required or are determined to be profitable. If retrofit technologies are not required, then it must be determined if the base technology will continue to be operated. If the base technology can cover current costs, it will continue to be operated, even if its present discounted expected future revenues are negative. If it cannot cover present operating costs, then the technology will be retired unless some retrofit package can produce a present discounted expected future profit.

Under some circumstances the present technology may cease to be an option because a retrofit technology must be applied. In such cases the technology will be retired unless some retrofit package can produce a present discounted expected future profit just as if the base technology had been unprofitable in the current period.

To evaluate retrofit technologies we make the following calculations. Consider an existing technology of vintage V, installed in period V, with nominal lifetime T, in existence in period t. To determine the profitability of retrofit options for that technology, we begin by computing,

$$Pe_j = P_j(t)\cdot\sum_{t=1}^{T-t}\left(\frac{1+r_j}{1+\mathrm{dis}}\right)^{t}\cdot[1+tx(t)], \qquad j=1,\ldots,N. \tag{32}$$

Note that a set of expected future prices for retrofit technologies may be different from the set of expected future prices for the base technology due to different discount rates for the two activities. That is, some firms may have a higher discount rate for retrofit technologies than for new base load investments.

Because each retrofit technology can affect the original technology is a wide variety of ways, the total technology, that is including both the base technology and a package of retrofit options, is given by a separate CES production function whose net additional capital cost is some fraction of the original capital investment, and whose lifetime is the expected lifetime remaining on the original technology.

The general formulation for profit with a fixed factor CES production function, as given by equation (6), is used to compute a value of $\pi_{retrofit}$ for each technology with a retrofit option. Note that for retrofit = 0, the expected future profit for the base technology is given. If any retrofit technology has a positive present discounted expected profit higher than the base technology, then the retrofit technology package with the highest expected future profit rate is selected. If expected profits are negative no retrofit technology is adopted, and if either the base technology is unable to cover present operating costs, or is no longer available due to mandated retrofit actions, then the technology is retired.

Renovation

Renovation is a special case of the general investment/retrofit problem. At the end of T_{exp} years of service the technology must either be retired or renovated. Renovation takes the form of a one-time capital investment, that occurs in the T_{exp}th year of service. In effect, however, the retrofit option can be thought of as competing with other new investment opportunities with the production function coefficients of the original technology, a capital cost of K_{extend}, and T_{extend} years of expected life. The profit rate is computed using equation (15) and expected future prices based on an expected technology life of T_{extend} years. Of course, more than one life-extension technology option is possible. In the case where multiple options are available, the technology with the highest expected profit rate is chosen.

The present operating profitability, *NR*, is still computed from equation (6). The operation, retirement and retrofit logic diagram is given below:

	$NR > 0$	$NR < 0$
$\pi > 0$	Operate and Retrofit	Retire
$\pi < 0$	Retire	Retire

That is, the technology will be retired unless it both can make money in the immediate period and is expected to add to the wealth of the sector over its expected lifetime.

Greenhouse gas emissions

As discussed earlier, the greenhouse issue is complicated by the fact that a wide array of gases are associated with the effect. We make no attempt to discuss either the nature or the extent of the effect various

gases have on the radiative balance of the earth/atmosphere energy balance, but simply note that the following suite of gases will be considered.

- CO_2 emissions from fossile fuel and biomass combustion processes.
- VOC emissions resulting from energy production processes, selected manufacturing processes, some combustion processes (mainly of petroleum based fuel in internal combustion engines), and from selected natural processes.
- CFC emissions from losses from refrigeration and air-conditioning equipment, foam blowing, aerosol propellants, cleaning solvents, and fire extinguishers.
- CH_4 emissions which emanate from the production and distribution of natural gas, mining of coal, from the raising of ruminant animals, the growing of rice, from sanitary landfills, and from combustion processes (principally biomass burning).
- CO emissions, most of which emanate from incomplete combustion of carbon-based fuels, principally in the transportation sector.
- N_2O emissions from combustion processes, fertilizer use, and selected natural sources.
- NO_x emissions from combustion processes – especially from electrical power generation and in internal combustion engines.
- SO_2 emissions and consequent sulphate transformations so that albedo changes can be monitored.

Greenhouse gas emissions coefficients will be included with each technology description. Emissions will be assumed to be proportional to either the scale of input utilization or output of the technology.

Emissions can be calculated simply as,

$$E_{m,1} = \sum_{i=1}^{NS} \sum_{ss=1}^{NSS(i,1)} \sum_{tech=1}^{N_{tech}(i,ss,1)} \sum_{v=V_0}^{t} \sum_{j=1}^{NI} (e_{m,i,ss,tech,j} X_{i,ss,tech,j,1,v} + f_{m,i,ss,tech,j} Xs_{i,ss}), \quad (33)$$

where, $e_{m,i,ss,tech,j}$ is the technology specific emission coefficient for emission *m*, in sector *i*, subsector *ss*, using technology tech, with input *j*; $X_{i,ss,tech,j,1,v}$ is the input demand for factor *j* by sector *i*, subsector *ss*, using technology tech, of vintage *v*, in region 1; $f_{m,i,ss,tech,j}$ is the technology specific emission coefficient for emission *m*, in sector *i*, subsector *ss*, using technology tech, producing output *j*; and

$Xs_{i,ss,tech,j,1,v}$ is the output of good j by sector i, subsector ss, using technology tech, of vintage v, in region 1.

When emissions are released costlessly into the atmosphere they have no effect on either the cost of production or the optimum demand for investment goods. Releases need not be costless. Like other inputs and outputs from the technology, emissions may be priced. Emissions coefficients have been related to individual technologies. This is because the determinants of emissions can be relatively complex. This is even the case for emissions as simple as fossil fuel combustion carbon emissions. In general the release of carbon to the atmosphere is considered to be proportional to the energy content of the specific fuel by a fixed ratio and therefore largely independent of the technology in which the fossil fuel form is combusted. This need not be the case. Emissions capture technologies exist, and the rate of release of carbon to be atmosphere per unit of fossil fuel energy combusted may therefore vary by technology.

On the presumption that emissions can be measured and therefore costs can be associated with them, emissions fees would affect the cost of production. The effect of fees will be reflected in a modification to equations (13) and (14). For consumers of the jth product in the ith sector the cost would become,

$$P_{i,ss,tech,j,1} = a_{i,1} P_i (1+\delta_{i,1} Tr_i) txa_{i,1} + txb_{i,1} + \sum_{m=1}^{EM} e_{m,i,ss,tech,j}\, tx_{m,i,ss,tech,} \tag{34}$$

where $P_{i,ss,tech,j,1}$ = the price of good j consumed in sector i, subsector ss, using technology tech, in region 1. For producers, the income from the sale of the jth product produced in sector i is,

$$P_{i,ss,tech,j,1} = P_i (1 + \delta_{i,1} Tr_i) - \sum_{m=1}^{EM} f_{m,i,ss,tech,j}\, tx_{m,i,ss,tech,j,1}. \tag{35}$$

Final demand sectors

In addition to the sectors that produce goods and services, there are three final demand sectors, households, government, and foreign. As is the case with the directly productive sectors, final demand sectors have demands for goods and services and can produce goods and services. We begin with the government sector, not because the analysis of the behaviour of the government sector is simpler than that of the household, but rather because our modelling approach to this sector is simpler than that of the household sector.

Government

Expenditures by the budget of the government sector must satisfy the following identity:

$$TX_{tot} - S_{gov} = TR_{gov} + \sum_{i=1}^{N} P_i X_{i,gov}, \tag{36}$$

where TX_{tot} is the total of all net tax revenues, where subsidies are measured S_{gov} is the net government savings, or for negative values equals net government borrowing, and TR_{gov} = is transfer payments by the government.

In SGM version 0.0, S_{gov} is assumed to be zero. In SGM Version 1.0 this assumption will be relaxed.

In SGM version 0.0 transfer payments are assumed to be a function of demographics,

$$TR_{gov} = \beta_0 POP_{tot}^{\beta_{tot}} \left(\frac{POP_{15-} + POP_{65+}}{POP_{tot}}\right)^{\beta_a} \left(\frac{POP_{25\%y}}{POP_{tot}}\right)^{\beta_b} \left(\frac{Y_{personal}}{POP_{tot}}\right)^{\beta_c}, \tag{37}$$

where POP_{tot} is the total population; POP_{15-} is the population under age 15; POP_{65+} is the population over age 65; $POP_{25\%y}$ is the population whose personal income is 25% or less than the mean; $Y_{personal}$ is the personal income; and β_i is the appropriate empirically determined coefficients.

The government is modelled as producing services. In SGM version 0.0 there are three services produced. In SGM version 1.0 this will be expanded to five. These are given in table 4.

The demand for goods and services by the government sector is modelled as a constrained optimization problem. Government max-

Table 4 SGM government subsectors version 0.0 and version 1.0

SGM version 0.0	SGM version 1.0
General, National Defence, Education	General, National Defence, Education, Infrastructure, R&D

imizes a utility function, presumed to be CES in SGM version 0.0, defined over the three subsectors (general government, national defence, and education), and subject to the net income given by equation (36). This can be represented as,

$$G = \left(\sum_{ss=1}^{NGS} \delta_{ss} G_{ss}^{\mu}\right)^{1/\mu}, \tag{38}$$

where G is the government utility, an unobservable variable; G_{ss} is the production of government service ss; δ_{ss} is a scale parameter; μ is an elasticity parameter; and NGS is the number of services produced by the government.

Government services are assumed to be produced with fixed input–output coefficients. Thus the cost of an additional unit of government service, type ss, can be computed as simply,

$$P_{g,ss} = \sum_{i=1}^{N} a_{i,g,ss} P_i, \tag{39}$$

where $P_{g,ss}$ is the cost of the next unit of government service ss, that is P_i is the price of input i in the production process; and $a_{i,g,ss}$ is the amount of input i required to produce government service from government subsector ss.

Because the cost of producing the next unit of government service is constant for any set P_i,[9] the determination of government demands for goods and services is greatly simplified. This problem can be stated as one of maximizing utility subject to a budget constraint, equation (36), maximize $G(G_1, \ldots, G_{NGS})$, subject to

$$TX_{tot} - S_{gov} - \sum_{ss=1}^{NGS} P_{g,ss} G_{ss} = 0. \tag{40}$$

This problem has a simple solution,

$$G_{ss} = (TX_{tot} - S_{gov} - TR_{gov})\beta_{ss} P_{g,ss}^{\gamma-1} \left(\sum_{ss=1}^{NGS} \beta_{ss} P_{g,ss}^{\gamma}\right)^{-1}, \tag{41}$$

where $\beta_{ss} = \delta_i^{-1/(\mu-1)}$ and $\gamma = \mu/(\mu-1)$.[10]

Households

A great number of decisions are carried out in the household sector. These include the following:

1. Demographics
2. Labour supply
3. Land supply
4. Household savings
5. Household demand for final products

In SGM version 0.0 the determination of the demographic characteristics of each region's population, and its supplies of labour, land, and savings are handled sequentially. Only the composition of demand for final goods and services is handled in a holistic utility maximization framework. Because the demographic characteristics of a region's population are an important determinant of other household behaviour we discuss this element of the model first. We then consider labour, land, and savings supplies. These factors determine disposable personal income allocated to consumption. Finally, we describe the determination of final demand for goods and services.

Demographics

The demographic component of the household sector determines population in a region by employing assumptions with regard to three characteristics: survival rates, fertility rates, and migration rates. For any period, t, total population is given by,

$$\mathrm{POP}_{tot_t} = \sum_{age=1}^{NAGE} \mathrm{POP}_{age,males} + \mathrm{POP}_{age,females}, \tag{42}$$

where $\mathrm{POP}_{age,males}$ is the males in age group age; $\mathrm{POP}_{age,females}$ is the females in age group age; and $NAGE$ is the number of age groups defined.

For the youngest age group, age = 1,

$$\mathrm{POP}_{age=1,gender,t} = \sum_{age=2}^{NAGE} g_{age,gender} f_{age,t} \mathrm{POP}_{age,female,t}, \quad gender = male, female, \qquad (43)$$

where $\mathrm{POP}_{age=1,gender,t}$ is the population in the youngest age group, age = 1, by gender, in period t; $f_{age,t}$ is the fertility rate for females in age group, age, in period t; and $g_{age,gender}$ is the fraction of births by gender, with $g_{age,1} + g_{age,2} = 1$, and for other age groups, population is determined by survival via,

$$\mathrm{POP}_{age,gender,t} = SV_{age,gender,t}\mathrm{POP}_{age-1,gender,t-1} + \mathrm{POPmig}_{age,gender,t}, \quad c = 2,\ldots,\mathrm{NAGE}. \qquad (44)$$

where $sv_{age,gender,t}$ is the survival rate by gender from age group age to age + 1; $\mathrm{POPmig}_{age=1,gender,t}$ is the net immigration of population into the region in age group, age = 1.

At this point, fertility rates, survival rates, and migration rates are determined exogenously, with the exception that net migration summed over all regions is always zero for each age and gender.

Labour supply
The supply of labour is determined by the working age population, rate of labour force participation, and the wage rate.

$$X_{labour} = \sum_{male}^{female} \sum_{age=1}^{NAGE} \alpha_{age,gender} \mathrm{POP}_{age,gender} [P_{labour}(1 - txa_{labour}) - txb_{labour}]^{\beta_{age,gender}} \qquad (45)$$

where P_{labour} is the wage rate for labour; $\alpha_{age,gender}$ is a scale coefficient for the supply of labour, by age and gender; $\beta_{age,gender}$ is the price elasticity of supply of labour by age and gender, and txa, txb are proportional and additive tax rates, respectively.

Land supply
In version 0.0, land supply is total land area in the region. All land services are sold on the domestic market. Households supply land on the basis of the rental rate via

$$X_{land} = \mathrm{LAND}_{tot}\alpha_{land}[1 - \exp(\beta_{land}P_{land})], \qquad (46)$$

where LAND_{tot} is the total surface area potentially available for allocation; α_{land} is the maximum potential share of land supplied to the market; β_{land} is a land supply price responsiveness coefficient; and P_{land} is the rental rate on a unit of land.

In SGM version 1.0, the land supply sector will become much richer. One of the potentially most important determinations is the representation of the character of land, and its potential supply and use, and the potential changes to land character as it is affected by human activity. To be most useful, the model of land must be capable of explaining both the present allocation and use of land, how that allocation and use changes with time, and the consequences of land-use for greenhouse gas emissions. Furthermore, the characterization must also be capable of providing a framework for assessing the consequences of potential changes in atmosphere and climate, and of changes in sea level. Several alternative specifications are being considered. A description of land use in SGM version 1.0 will be the subject of future model development reports.

Personal income
Personal income can be computed from the information already developed via the equation,

$$\begin{aligned} Y = {} & X_{labour\ supply}[P_{labour}(1 - txa_{labour}) - txb_{labour}] \\ & + X_{land\ supply}[P_{land}(1 - txa_{land}) - txb_{land}] \\ & + \pi_{tot}(1 - tx_{\pi} - s_{\pi}) + TR_{gov} \end{aligned} \qquad (47)$$

where Y is the disposable personal income; π_{tot} is the total net profits from the operation of all enterprises; tx_{π} is the profits tax rate; s_{π} is the rate of retained corporate earnings; and txy = income tax rate.

Savings supply
SGM version 0.0 represents savings as a function of present income and the interest rate,

$$S_{hh} = \alpha_{hhsave}Y\{1 - \exp[\beta_{hhsave}(\mathrm{interest} + \mathrm{fac}_{hh})]\} \qquad (48)$$

where S_{hh} is the total supply of savings by households; α_{hhsave} is the maximum potential household savings rate; β_{hhsave} is the price sensitivity of households to the available interest rate; and fac_{hh} is an adjustment factor linking the market interest rate to the interest rate available to households.

While it is usual for a general equilibrium model to maximize a utility function to determine household behaviour, version 0.0 does not do this. The development of a more sophisticated description of aggregate household behaviour is a development task.

Household demand for final products

Own demands for factor inputs labour and land are computed separately from demands for other goods and services.

The own demand for land is a function of the number of households,

$$\mathrm{NHH} = \left(\sum_{age=1}^{NAGE} \mathrm{POP}_{age}\right) \Big/ \alpha_{hh}, \tag{49}$$

where NHH is the number of households; and α_{hh} is the average number of people per household.

Therefore,

$$X_{land,hh} = \mathrm{NHH}\,\alpha_{land,hh} P_{land}^{\beta_{land,hh}}, \tag{50}$$

where $\alpha_{land,hh}$ is the household land intensity factor; and $\beta_{land,hh}$ is the price elasticity of demand by households for land.

The household demand for labour is a function of the price of labour,

$$X_{labour,hh} = X_{labour}\alpha_{labour,hh} P_{labour}^{\beta_{labour,hh}}, \tag{51}$$

where $\alpha_{labour,hh}$ is the household labour demand intensity factor; and $\beta_{labour,hh}$ is the price elasticity of demand by households for labour.

The total value of consumption can then be calculated by difference

$$Y_c = Y - S_{hh} - X_{land,hh}P_{land} - X_{labour,hh}P_{labour}. \tag{52}$$

Consumption of any final product can then be computed using price and income elasticities and an income expenditure normalization via,

$$xd_{i,hh} = \alpha_{i,hh} P_i^{\beta_{i,hh}} Y_c^{\gamma_{i,hh}} \left(\frac{1}{\lambda}\right), \tag{53}$$

where $Xd_{i,hh}$ is the demand for good i by the household sector; $\alpha_{i,hh}$ is the household demand intensity factor for good i; $\beta_{i,hh}$ is the price elasticity of demand by households for good i; and $\gamma_{i,hh}$ is the income elasticity of demand by households for good i, and

$$\lambda = \sum_{i=1}^{NS} \alpha_{i,hh} P_i^{\beta_{i,hh}+1} Y_c^{\gamma_{i,hh}-1}. \tag{54}$$

Each consumption good, which in version 0.0 is identical to a produced commodity in the GPC, is assumed to have an income and a price elasticity of demand.

In version 1.0, the plan is to embed the household decision making process in a cohesive intertemporal decision-making process which includes consumption, savings, and education. Education is important because, at least in the United States, it is the most important determinant of life-cycle labour-force participation. In addition, the subsector structure in the model will be used to expand the number of demographic groups. The number of such groups has not yet been determined but will reflect significant differences with respect to savings and education decisions. In version 1.0 consumption categories will probably be different from production categories, implying the need for a translation matrix from consumption to production commodities. Computationally more versatile forms for the labour and land supplies will also be explored.

General equilibrium

As noted earlier, markets are defined for each of the 10 producing sectors in SGM version 0.0 plus one for each of the three primary factors of production: land, labour, and capital.[11] There are at least 13 markets for the model to clear even when only a single region is being considered. When multiple regions are being considered simultaneously, the number of markets will expand. Land and labour markets are considered to be closed. This increases the number of markets from 13 to $11+2NL$, where NL is the number of regions. If capital markets are closed this number increases to $10+3NL$.[12] In addition, the model user can open or close any market in any

Table 5 An example of trading relationship table

Commodity	Region 1	2	3	4	5	6	7	8	9	10	11
1. Agri.	1	1	1	1	1	1	1	1	1	1	1
2. Crude oil	1	1	1	1	1	1	1	1	1	1	1
3. Oil ref.	1	1	1	1	1	1	1	1	1	1	1
4. Nat. gas	1	1	2	1	2	1	1	1	1	1	1
5. Nat. gas tr	1	1	1	1	1	1	1	1	1	1	1
6. Coal prod.	1	1	1	1	1	1	1	1	1	1	1
7. Biomass	1	1	1	1	1	1	1	1	1	1	1
8 Uranium	1	1	1	1	1	1	1	1	1	1	1
9. Elec.	1	1	2	3	0	2	3	0	0	0	0
10. Other	1	1	1	1	1	1	1	1	1	1	1
11. Labour	0	0	0	0	0	0	0	0	0	0	0
12. Land	0	0	0	0	0	0	0	0	0	0	0
13. Sav/inv	0	0	0	0	0	0	0	0	0	0	0

region relative to the rest of the world, and thus create trading groups. This is indicated through a variable, Mktlink defined over regions and commodities, where if for one of the 13 commodities and 11 regions,

Mktlink = 0 indicates that region L is permanently closed to trade in commodity IN. For example, all regions are closed to trade in land in the above matrix;

Mktlink > 0 indicates that the region trades with all other regions with similar Mktlink values for that commodity.[13]

An example of a trading relationship table is given in table 5.

The number of markets will also vary during the execution of the model. This occurs because transportation costs involved in international trade are non-trivial. It is easily possible to encounter a case in which a region would desire to export a good if the region is treated as an importing region and domestic producers are assumed to be able to obtain the world price of the commodity plus the cost of transportation. On the other hand, if the region is treated as an exporting region, in which domestic producers can obtain only the world price of the commodity, the quantity of the product demanded by the region increases and the quantity supplied decreases to the point where the region would desire to import the good. Under such

circumstances, the model will treat that region/commodity combination as if it were temporarily closed.[14]

For each region/commodity combination, an excess demand can be calculated by

$$e_{i,j} = \sum_{s=1}^{Ns} \sum_{ss=1}^{Nss_{i,s}} \sum_{tech=1}^{Ntech_{i,ss,s}} (xd_{i,s,ss,tech,j} - xs_{i,s,ss,tech,j}), \quad i = 1,\ldots N. \quad (55)$$

where $e_{i,j}$ = excess demand for commodity i in region j.

Consider for a moment the simplest case in which all commodities are traded internationally. For any period, equilibrium exists when a set of prices, $P = (P_1, \ldots P_N)$ can be found for which

$$\sum_{j=1}^{NL} e_{i,j} = 0, \qquad i = 1, \ldots, N. \quad (56)$$

This set of prices is not unique. Walras's law,

$$\sum_{i=1}^{N} \sum_{j=1}^{NL} e_{i,j} P_i = 0, \quad (57)$$

which holds as an identity, and guarantees that if an equilibrium set of prices exists, that any positive scalar multiple of those prices is also an equilibrium set of prices. Any commodity can be chosen as a numeraire and its price determined arbitrarily, set for example to one. The number of independent market prices is always one less than the number of markets.

Similarly, since the unit of measure chosen for commodities is also arbitrary, units can be chosen such that all equilibrium prices are unity in one period.

Solving the SGM

The BRM first generation model, used a Newton search procedure in an elasticity metric. Elasticities were computed numerically by perturbing each market price slightly and re-evaluating the model. This required Nmkt+1 evaluations for each search step. It also created a Nmkt[2] matrix of partial derivatives, which needed to be inverted. With 42 independent markets, this procedure requires a matrix of

1,764 elements to be inverted. The ERM also incorporated a variety of procedures to be invoked in the event that no change in a disequilibrium set of prices could be identified, through the Newton search approach, which reduced the metric of disequilibrium, the sum of squared excess demands.

Increasing the number of markets to 42 in SGM version 0.0 increases the complexity of the problem of finding numerical solutions to the model. The SGM will employ an even more diverse set of solution algorithm alternatives than the ERM. The most important addition to the set of search techniques is the Gauss-Seidel procedure. This solution algorithm begins with an initial price vector, and then updates each element of the price vector individually.[15]

Concluding remarks

This paper describes a new model under development, a second generation model of global energy and other human activities and greenhouse gas emissions. The model addresses the problem of the relationship between human activities in a wide array of domains, and their effect on the emissions of radiatively important gases, and the potential consequences of changes in the atmospheric composition and climate on those human activities. To address the extremely broad scope implied by these objectives, we have begun the development of a global, computable general equilibrium model, which provides insights not possible with linked independent market equilibrium models. It is also designed to address a specific problem. Its level of complexity and disaggregation reflects the character of that problem. Energy is the single most important human activity affecting greenhouse gas emission. It therefore receives the greatest attention in the model. Agriculture and land-use are the next most important issues and receive greater attention than, for example, their value-added contribution to GNP would indicate they warrant. Other sectors of the economy are modelled in relatively aggregate detail.

The model will be exercised for both regional/national economies independently of the world economy, and as a world model. Projects to model the United States, Chinese, and former Soviet Union are underway in partnership with sister institutions in China and Russia. These projects are anticipated to produce results during 1992. This work in turn will help inform the development of the SGM global model. Progress on these endeavours will be the subject of future reports.

Notes

1. The authors would like to express appreciation to the United States Department of Energy, Office of Energy Research and the Office of Policy, Planning, and Analysis, and to the United States Environmental Protection Agency, for support in the conduct of this research. The authors would also like to express appreciation to Yoichi Kaya, Nebojša Nakićenović, Kirit Parikh, Yuangzheng Luo, Bert Hickman, and Ken Ruffing for their thoughtful comments on an earlier draft of this paper.
2. Gases with characteristic *e*-folding or average molecular lifetime values of less than 10 years.
3. Century time scales.
4. For example, control runs using the ERM and GLOBAL 2100 models yield remarkably similar results when standard assumptions are employed in both models. This is despite the fact that the ERM is a behavioural model and GLOBAL 2100 is a dynamic optimizing model.
5. It is always possible to recast a model such as the SGM within the dynamic optimization with perfect foresight paradigm.
6. Compared to competing technologies.
7. Note that the price received by the producers, P_{ij}, is equal to the f.o.b. price. The prices paid by producers are equal to the f.o.b. price plus taxes and markups.
8. Note that in this case the period-specific expected price vector replaces the present discounted price vector given by equation (14).
9. Note that this property is characteristic of any production function which is homogeneous of degree one, such as for example the CES, and not simply the Leontief specification.
10. To see this note that first-order conditions require that

$$G_{is} = \lambda^{1/(\rho-1)} G \beta_{is} P^{\gamma}_{j,is}$$

where λ is a Lagrangian multiplier. For convenience define,

$$Y = TX_{tot} - S_{gov} - TR_{gov}$$

and note that

$$Y = \sum_{i=1}^{NGS} G_{is} P_{j,is}.$$

Subatitute (1) into (2) to yield,

$$\lambda^{1/(\rho-1)} G = Y\left(\sum_{i=1}^{NGS} \beta_{is} P^{\gamma}_{j,is}\right)^{-1}.$$

Resubstituting (3) into (1) gives the final result.

11. Recall that the capital market is a market for savings and investment. It does not allocate existing capital stocks. Those are quasi fixed as a vintaged capital stock.
12. The relaxation of the assumption that capital markets are closed requires the creation of an investment vehicle. This could be accomplished by the creation of an international bond. This bond would imply a future return flow of resources in exchange for savings. Net interest payments would be added to GNP and household disposable income, assuming households hold the bonds.
13. Note that while model logic will not be affected, there should always be at least two regions involved in a trading group for each commodity. The value of the Mktlink variable gives a reference region whose f.o.b. price of commodity *IN* determines the f.o.b. price for that commodity in all other regions in the trading group. For example, in the matrix above, all

regions, except China, use the f.o.b. price of agricultural products in the United States (region 1) as a common reference f.o.b. price.

The value used in Mktlink should *always* use the lowest region index number of any member of the trading group. For example when regions 3 and 6 form an electricity trading group, both members use the number 3 for their Mktlink values.

We note that a region cannot be open to trade in only one commodity.

14. When a region is temporarily treated as if it were closed to trade in a particular commodity, the value of Mktlink is set to the negative of the reference group number.
15. This procedure has an expected solution rate of between 5Nmkt and 10Nmkt model evaluations. It is thus computationally very efficient. The order in which the Gauss-Seidel algorithm operates may be important. For example, we may wish to solve the world market, then iterate to the regional labour and land markets, and then return to the world market. Some thought needs to be given to getting appropriate output and tracking the solution process with an eye to improving its efficiency.

References

Adams, D., R.M. Adams, J.M. Callaway, C.C. Chang, and B.A. McCarl. 1991. The Economics of Sequestering Carbon on Agricultural Land in the U.S.: A Preliminary Analysis of Social Cost and Impacts on Timber Markets. Mimeo.

Applied Energy Services, Inc. (AES). 1986. *Fossil2 Energy Policy Model Demand Sector Documentation.* 3 vols. Arlington, Va.: AES.

1991. *Fossil2 Energy Policy Model Electricity Sector Documentation.* 3 vols. Arlington, Va.: AES.

Ballard, C.L., D. Fullerton, J.B. Shoven, and J. Walley. 1985. *A General Equilibrium Model for Tax Policy Evaluation.* Chicago, Ill.: University of Chicago Press.

Hatfield, B.J., J.F. Clarke, and O.J. Loewer. 1991. *Biomass as Global Energy Source.* In: Technology Responses to Global Environmental Challenges. Proceedings of the IEA International Conference, Kyoto, p. 257.

Bradley, R. A., E.C. Watts, and E.R. Williams, eds. 1991. *Limiting Net Greenhouse Gas Emissions in the United State.* Washington D.C.: U.S. Department of Energy.

Brinner, R.E., M.G. Shelby, J.M. Yanchar, and A. Christofaro. 1991. *Optimizing Tax Strategies to Reduce Greenhouse Gases Without Curtailing Growth.* Boulder, Colo.: Energy Modeling Forum 12.

Burniaux, J.M., J.P. Martin, G. Nicoletti, and J. Oliveire Martins. 1991. *The Costs of Policies to Reduce Global Emissions of CO_2: Alternative Scenarios with GREEN.* Research report to the Policy Studies Branch, Organization for Economic Cooperation and Development, Paris.

Clarke, J.F. 1991. *The Cost and Benefit of Energy Technology in the Global Context – The Case of Fusion Power.* In: Technology Responses to Global Environmental Challenges. Proceedings of the IEA International Conference, Kyoto 1991, p. 364.

Edmonds, J., and D.W. Barns. 1990. *Estimating the Marginal Cost of Reducing Global Fossil Fuel CO_2 Emissions.* Washington, D.C.: PNL-SA-18361, Pacific Northwest Laboratory.

1991. Factors Affecting the Long-term Cost of Global Fossil Fuel CO_2 Emissions Reductions. PNL Global Studies Program Draft Working Paper.

Edmonds, J., and J.M. Reilly. 1985. *Global Energy: Assessing the Future.* New York: Oxford University Press.

Edmonds, J.A., J.M. Reilly, R.H. Gardner, and A. Brenkert. 1986. *Uncertainty in Future Global Energy Use and Fossil Fuel CO_2 Emissions 1975 to 2075.* TR036, DO3/NBB-0081 Dist. Category UC-11. National Technical Information Service. U.S. Department of Commerce: Springfield, Va.: 22161.

Edmonds, J.A., and D.B. Reister. 1982. *Characteristics of Nested CES Functions.* ORAU/IEA-82-5 (M) Oak Ridge, TN: Oak Ridge Associated Universities.

Gately, D. 1980. "Individual Discount Rates and the Purchase and Utilization of Energy Using Durables: Comment." *The Bell Journal of Economics* 11: 373–374.

Hausman, J.R. 1979. "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables." *The Bell Journal of Economics* 10: 33–54.

Henderson, J.M., and R.E. Quandt. 1958. *Microeconomic Theory: A Mathematical Approach.* New York, NY: McGraw-Hill Book Company.

Jorgenson, D.W., and P.J. Wilcoxen. 1990a. The Cost of Controlling U.S. Carbon Dioxide Emission. Presented at a Workshop on Economic Energy Environmental Modeling for Climate Policy Analysis. Washington, D.C., 22–23 October.

—— 1990b. *Global Change, Energy Prices, and U.S. Economic Growth.* Cambridge, Mass.: Department of Economics, Harvard University.

Kinsman, J.D., and G. Marland. 1989. Contribution of Deforestation to Atmospheric CO_2 and Reforestation as an Option to Control CO_2. Presented at the 82nd Annual Meeting and Exhibition of the Air and Waste Management Association, Anaheim, Calif., 25–30 June.

Lashof, Daniel A., and Dennis A. Tirpak. 1989. Policy Options for Stabilizing Global Climate. Draft Report to Congress, U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Washington, D.C.

Lind, R.C. 1983. *Discounting for Time and Risk in Energy Policy.* Resources for the Future, Washington, D.C.

Manne, A.S., and R.G. Richels. 1990a. "CO_2 Emission Limits: An Economic Cost Analysis for the USA." *The Energy Journal* 11(2): 51–75.

—— 1990b. *Global CO_2 Emissions Reductions – the Impacts of Rising Energy Costs.* Palo Alto, Calif.: Electric Power Research Institute.

—— 1990c. *Buying Greenhouse Insurance.* Palo Alto, Calif.: Electric Power Research Institute.

—— 1990d. *The Costs of Reducing U.S. CO_2 Emissions – Further Sensitivity Analysis.* Palo Alto, Calif.: Electric Power Research Institute.

—— 1991. *Estimating the Energy Conservation Parameters: An Experiment in Backcasting.* Palo Alto, Calif.: Electric Power Research Institute.

Marland, G. 1988. *The Prospect of Solving the CO_2 Problem through Global Reforestation.* DOE/NBB-0082, TR039. Springfield, Va.: National Technical Information Service, U.S. Department of Commerce.

Meier, A.K., and J. Whittier. 1983. "Consumer Discount Rates Implied by Purchases of Energy-Efficient Refrigerators." *Energy, the International Journal* 8(12): 957–962.

Moulton, J.R., and K.R. Richards. 1990. *Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States.* General Technical Report WO-58. Washington, D.C.: U.S. Department of Agriculture, Forest Service.

Nordhaus, W.D. and G.W. Yohe. 1983. "Future Carbon Dioxide Emissions from Fossil Fuels." In: *Changing Climate.* Washington D.C.: National Academy Press, pp. 87–153.

OECD (Organization for Economic Cooperation and Development) 1991. *The Costs of Policies to Reduce Global Emissions of CO_2: Three Alternative Scenarios with GREEN*. Paris, France: OECD.

Peck, S.C., and T.J. Teisberg. 1991. *CETA: A Model for Carbon Emissions Trajectory Assessment*. Palo Alto, Calif.: Electric Power Research Institute.

Rotmans, J., H. de Boois, and R. Swart. 1989. *An Integrated Model for the Assessment of the Greenhouse Effect: The Dutch Approach*. Postbus 1, 3720 BA, Bilthoven, The Netherlands: National Institute of Public Health and Environmental Protection, Rijksinstituut voor Volksgezondheid en Milieuhygiaene.

Samuelson, P.A. 1947. *Foundations of Economic Analysis*. Cambridge, Mass.: Harvard University Press.

Scheraga, J.D., D. Cohan, A. Diener, A. Gjerde, S. Haas, and A. Smith. 1991. "Reassessing the Effectiveness and Cost of Taxes to Reduce CO_2 Emissions." *Gemini Notes*. Washington, D.C.: U.S. Environmental Protection Agency.

Sedjo, R.A., and A.M. Solomon. 1989. "Climate and Forests." In: *Greenhouse Warming: Abatement and Adaptation*, N.J. Rosenberg, W.E. Easterling III, P.R. Crosson, and J. Darmstadter, eds. Washington, D.C.: Resources for the Future.

Shepherd, R.W. 1953. Cost and Production Functions. Princeton, N.J.: Princeton University Press.

Comments on chapter 9

1. Nebojša Nakićenović

The design and implementation of the "second generation" model for analysis of future greenhouse gas emissions is indeed a formidable task. Edmonds et al. (1992) set the goals of such a model well beyond the state of the art by specifying that it should be "capable of analysing the emissions of all greenhouse gases from all sources, including both those of natural and human origin, to provide an analysis of the interplay between the variety of human and natural activities responsible for greenhouse gas emission." Clearly, such models currently do not exist that are capable of "assessing emissions from all human activities and major direct and indirect consequences of potential policies to reduce emission." There are many models that already address some specific parts of the problem, e.g., carbon dioxide emissions associated with energy use or models that cover all anthropogenic sources of emissions and resulting atmospheric concentrations (e.g. EPA's Atmospheric Stabilization Framework, Lashof and Tirpak 1989). They are, of course, still very far from the comprehensive approach suggested by Edmonds et al. Hence, the development of the second generation model of the type proposed by

Edmonds et al. is certainly a most welcome effort, although a very ambitious one.

Undeniably, much could be learned by the modelling community from the exercise proposed by Edmonds et al. In particular, the efforts suggested to endogenize demographic and technological changes merit particular praise and attention. However, within a policy context there is also the issue of how such a model can help reduce the uncertainties inherent in modelling global change.

Alternatively how can the modelling exercise make more transparent and explicit the uncertainties stemming either from our insufficient understanding of natural and social phenomena or their inadequate abstraction (modelling)? Therefore, a word of caution may be in order. The policy dimension of global warming must confront simultaneously the problems of extreme uncertainty, both in the causes and consequences of global warming, and in the future contexts within which policies related to global warming will operate. Thus, there is a need for great flexibility in policy measures since the socio-economic and technological contexts within which any global change policy is situated will clearly vary and alter. We are confronting policy choices related to a global environmental issue whose effects will be measured in decades and centuries. To illustrate the difficulty of this task, imagine confronting similar issues a century before, say in 1892. At that time, electricity did not have a significant role, the motor car had just been invented, the aeroplane was unknown except as a concept, and nuclear weapons were unthinkable due to the lack of basic physics, while major urban problems were particulates from coal and dung from horses. Thus, it should be clear that it is unlikely we will forecast the future evolution of energy systems, technologies, or its social contexts over the next 100 years any more accurately today than if we had performed the same exercise a century ago. Yet, modelling and assessment of strategies for mitigation of climate change require a very long-term view, one which extends far beyond normal planning horizons.

In view of the large and still unresolved scientific uncertainty surrounding greenhouse gas emissions, their sources and sinks, the consequences such as adverse and irreversible climate change and possible response strategies, the development of the second generation model of the parametric type proposed by Edmonds et al. is a very useful effort since it will allow the testing of different hypotheses concerning future energy and greenhouse gas emissions.

In this short commentary we will discuss a few of the salient characteristics of such a model that appear to be required if it is to fulfil the expectations of its authors, but we will not raise the specific technical questions that would need to be resolved before the model can actually be built. The technical questions include, for example, the problem of integrating the global warming potential of emission and concentration of multiple greenhouse gases, or how to account for historical and current N_2O emissions from human activities and natural sources, or how to reconstruct the capital vintage structure for economies in transition and developing countries. These questions are far from being resolved but are the subject of a number of research activities and international efforts from which the proposed modelling exercise could benefit. Let us assume that these uncertainties and unknowns can be resolved by a parametric modelling approach.

We now return to the discussion of important model characteristics which (in order to be brief) we will limit to four issues: (1) population dynamics, (2) endogenization of technology, (3) socio-cultural aspects and (4) provision of energy services. They are important because they are all linked to the requirement of adopting a very long time horizon for model applications, which extends to the end of the next century. The authors are to be complimented for taking the long-term and global view. Models that focus on time-scales of two to three decades can be based on many static assumptions due to the relative stability of demographic trends, social and cultural relations, and the technology base over such periods. Conversely, extension of the time horizon well into the next century means that many of these long-term processes will become fluid and can no longer be treated as constants or "slow variables."

1. Population dynamics

In a century global population could stabilize but during the next few decades it will certainly continue to grow at rates fairly close to the current 1.7 per cent per year. In fact, the momentum behind global population growth is indeed very large. Even if we assume an abrupt change in fertility throughout the world down to or even below the replacement levels of about 2.2 children per woman, as it now prevails in most of the West European countries (and will thus result in a significant population decline), the global population would continue to grow for a few decades as illustrated in figure 1. Thus, the demographic transition is an important issue if a long time horizon is

World: Total Population in Million

	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015	2020	2025
Low Variant	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
High Variant	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Medium Variant	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

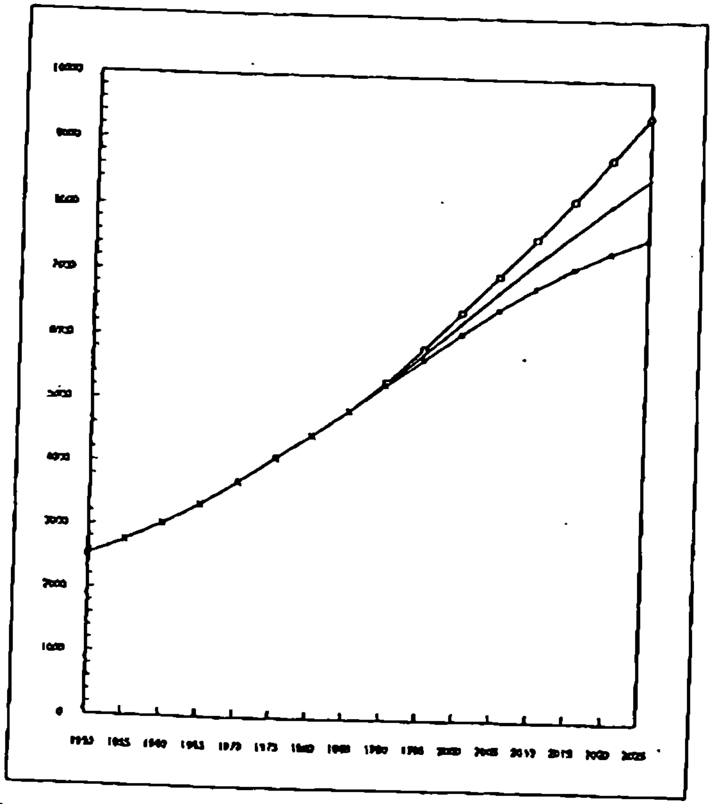


Fig. 1 World population growth, 1950 to the present and three alternative projections to the year 2025 (*UN World Population Prospects* 1990). In the case of the high variant the population is expected almost to double during the next 35 years. Despite the declining growth rates from now on, the high variant still leads to an increasing absolute population increase. By the year 2020 population increase is still about 40, 80, and 130 million per year in low, medium, and high variant respectively compared to about 100 million increase per year today (Source: Hellig 1992).

adopted. It is of paramount importance whether the global population will reach 10 billion or grow beyond. What is almost certain is that it can be expected to double during the next 100 years.

The objective to "endogenize" population growth in the next model version is to be welcomed. The actual problem is how to implement the link between development and population: is the demographic transition a prerequisite for rapid development or the other way around? How to account for the diverse experiences among countries and regions with respect to the demographic transition? A critical impasse is how to model these theoretically poorly understood linkages at the global and regional level. For the time being Edmonds et al. plan to include assumptions concerning survival, fertility, and migration rates for individual regions over the time horizon. However, increasing the number of exogenously assumed driving variables does not necessarily lead towards a better understanding of the complex issues between development and demographics. It might, therefore, be simpler and also more transparent to assume different population-growth scenarios exogenously as done by the United Nations population forecasts that are the standard reference in this field (UN 1990). Personally I see little merit in making numerous assumptions in a model without explicitly describing the linkages between the variables. The approach leaves a false impression of certainty and accuracy that does not actually exist. This critically affects particularly the treatment of migration in the proposed model. Clearly, emissions will depend on trade and migration patterns but the problem is that there is no obvious way to model international migration, especially the large movements of people that might be caused by the adverse effects of climate change. Low population growth rates and high levels of affluence in some parts of the world can also be expected to attract additional migration and, this again is a possible linkage between development and population issues.

II. Endogenization of technology

One of the important shortcomings of many energy models is that resource scarcity is one of the central driving forces of future energy development. Once the cheap and clean sources of energy are exhausted, the models "dig deeper" into dirtier and costlier options. This is close to the Malthusian concept of limited resources and has by and large been historically falsified for most factor inputs including energy, minerals, or land. It turns out that in the long run technological change leads to production of more with less rather than of less with more. And yet technological change is still a static concept entirely absent in most models. Fossil energy resources remain static, potentials for technological improvements are ignored, etc. Yet alone since the energy crises of the 1970s the discoveries of additional fossil energy reserves have outpaced their consumption. The resource base continues to increase. Table 1 shows that the known global fossil energy resources are equivalent to about 3,000 gigatons of carbon! The carbon content of the atmosphere is in comparison small with about 760 gigatons of carbon. If the current concerns regarding prospects of global warming are confirmed in the future, it is probable that most of this carbon will remain in the ground. The point here is that technological progress and development are exogenous parameters: as soon as some of these externalities are endogenized, decarbonization strategies will be economically more attractive and less costly than "dirtier" options. In retrospect, we no longer consider technologies that are hazardous to human health as "cheaper" options, but rather as non-options. Therefore, the model needs a "dynamic base" rather than the planned static concept of depletable and degradable resources.

The adoption of a capital vintage approach to endogenizing technological change by Edmonds et al. represents a significant improvement and will undoubtedly produce most valuable insights, as demonstrated by similar models for analysing economic structural change. The capital vintage approach can help to model technological change by the introduction of learning and economics-of-scale effects into new additions to the capital stock and the resource base. Nevertheless, the assumption of static resources (even if total potentially recoverable resources are subdivided into reserves and undiscovered resources) over a period of 100 years is indeed a very restrictive constraint that will, no doubt, almost "automatically" lead to high carbon emissions (since cheap and low carbon options are exhausted and renewables and nuclear limited by other "constraints"). For instance, only 10 years ago the existence of methane clathrates was largely unknown. Will they be included as a potential resource base in the model and how is the resource base going to change with the availability of new technologies?

Table 1 Fossil energy consumption, reserves and resources (Gt C)

	Coal	Oil	Gas	Total
1860-1987	114.9	58.2	24.5	197.6
1987	2.5	2.4	1.0	5.9
Reserves	391.6	92.1	58.5	542.2
Resources	2289	622	>115	3026
Additional occurrences	>3500	>1000	>700	>5200

Note: Accounting for historical, present, and potential future carbon emissions from fossil fuel use in gigatons carbon. Historical (1860–1987) and present (1987) carbon emissions from fossil fuel use by source and carbon content in identified, economically recoverable fossil fuel reserves, resources (identified quantities with uncertain prospects of economic recoverability), and additional occurrences (additional quantities inferred from geological information but with speculative technical and economic potential). Compared to historical fossil fuel use, the remaining resources in the ground represent a (perhaps even far too large) "carbon endowment" which is more than a factor 10 as large as the total carbon pool in the atmosphere of around 760 Gt C (corresponding to a present CO_2 concentration rate of about 350 ppm) (Grübler and Nakićenović 1991).

During the next century many new energy systems can also be expected to be introduced that may help avoid the astronomical levels of greenhouse emissions envisaged in many business-as-usual scenarios (e.g., see IPCC 1990). Figure 2 illustrates that even at historical diffusion rates new energy systems can be expected to reach high market shares during the next century. Such systems may include completely new technologies such as carbon removal and deposition (e.g. into the deep ocean) but they will most certainly be also based on improvements and refinements of current technologies such as the electric or hydrogen car (Nakićenović 1992; Nakićenović and John 1991). But even these more evolutionary options will need enabling systems and technologies such as new batteries and fuel cells. The diffusion of whole families of new technologies needs to be modelled both within the energy system and other sectors of the economy. It is not clear how this will be handled in the second generation model, although it is clearly crucial for the understanding of the mitigation and adoption potential offered by new, less carbon-intensive and carbon-free technologies.

III. Socio-cultural aspects

Socio-cultural determinants of future greenhouse gas emissions are also important at all scales but become especially difficult to model when the time horizon is extended to 100 years in the future. Is there cultural convergence over such long periods, especially if the world actually becomes "smaller" through more interaction, global com-

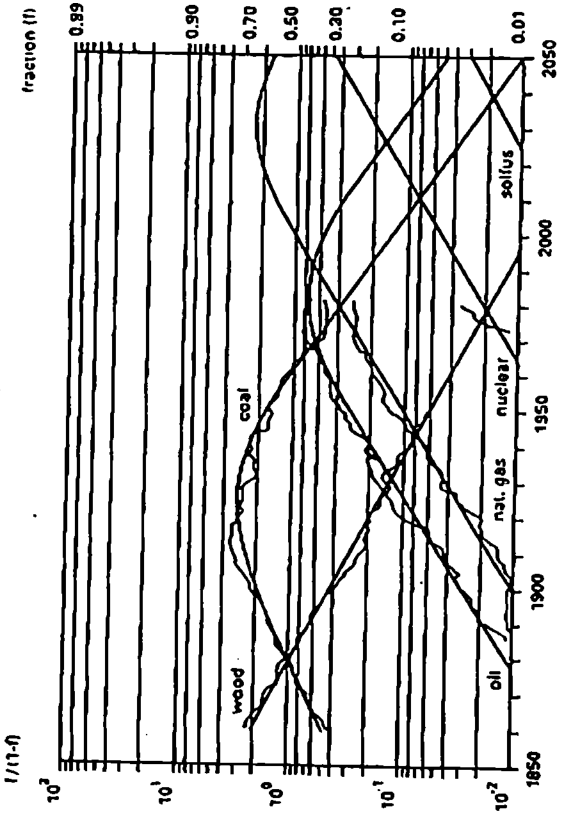


Fig. 2 World primary energy substitution. Shares of primary energy sources in global consumption. Smooth lines represent model calculations, and jagged lines are historical data. "Nat. gas" is natural gas; "solfus" is a term employed to describe a major new energy technology, for example solar or fusion (Marchetti and Nakićenović, 1979; Nakićenović 1990). It shows that the diffusion of new sources of energy is a very long process lasting many decades. Replacement of other infrastructures such as that of transport systems is also a long process.

munication, and mobility? At the other extreme, a divergence could be assumed with more heterogeneity and diversity in the world. In fact, this was the historical experience during the last century as illustrated in figure 3 for carbon intensity of value added. In contrast, many of the development strategies and scenario trajectories imply a common global path, e.g., universal adoption of technologies and their transfer despite diverse institutional and regional characteristics, and irrespective of the actual appropriateness of these systems in a given case. The second generation model can be expected to help identify some of the linkages among these issues, but the real problem occurs with the treatment of these social and cultural determinants. For the time being, socio-cultural variables have defined quantifications in most global models and at best have been included as residual values (e.g., derived from general production function approaches). Even if these variables cannot be modelled in the sense of formal abstractions from causality relations, it will be important to make explicit assumptions and scenarios in the model concerning socio-cultural development. This is a potential advantage of a parametric approach.

As another example, is it really reasonable to assume a general equilibrium approach and market-clearing mechanism for analysing the long-term future, when market-clearing mechanism imperfections and regulatory mechanisms are a prevailing characteristic of the world economy rather than an exception? Transfer of "sensitive" technologies is explicitly blocked, diffusion and adoption of technologies can be blocked by local cultures or regulations, and so on. The examples are so plentiful that it is difficult to construct a list of competitive international markets. There are, of course, many methodological reasons for adopting a general equilibrium approach, but the question is whether too much is assumed away by that approach in a model that otherwise includes so much detail. In more aggregate models this might indeed be a very viable and appropriate simplification but in a complex model such as the one proposed it is not clear how to balance detail in some areas against simplistic assumptions in others. In any case, this approach makes the analysis of major and revolutionary changes impossible. Adjustment paths to a low-emissions future is by design at best gradual and excludes socio-cultural diversity. All regions are assumed to have market-based economies and rational, utility maximizing agents (envisaged for version 1.0).

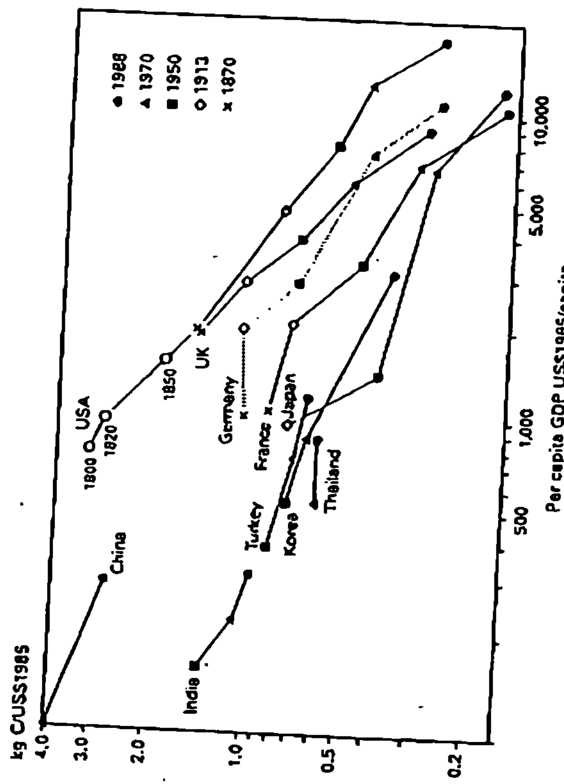


Fig. 3 Energy CO_2 emissions intensity per constant GDP in kg per constant 1985 US$ versus per capita GDP in constant 1985 US$. Energy data include also non-commercial sources such as fuelwood. In general, carbon intensity of economic activities improves as a function of differences between countries for similar per capita GDP levels. It shows that developed countries had higher specific emissions per unit GDP during early development phases that are comparable to current emission intensities of GDP in developing countries (Source: Grübler and Fujii 1991).

IV. Provision of energy services

Rationality of agents is in general a very sticky subject when it comes to describing actual energy consumption and end-use behaviours. Conservation and efficiency lag behind what appears to be rational. Often efficiency improvements are offset by increased energy services. For example, new cars are on average more efficient than the old ones in Germany, but they consume more fuel because they are larger, faster, more powerful, comfortable, and safer. Demand for more comfort at home has also increased due to older age structure, smaller family size, and larger dwellings per household, leading again to higher energy services. Figure 4 shows that longer life expectancy and shorter working time have over the last 100 years reversed the share of life spent at work compared to leisure activities from about 80 per cent to about 20 per cent today. This results in more travel, leisure activities, and time spent at home. All of these phenomena are also linked to economic structural changes, productivity increases, and evolving socio-cultural patterns. The problem arises when changes in the end use are observed at the macro-level and explained only by price mechanisms (e.g., elasticities) rather than by changes in human behaviour and social patterns. In those cases fallacies can occur. For example, the price of motor fuel increases but consumers purchase cars that consume more fuel even though they may be more efficient. Perhaps many of these considerations are marginal on a 100-year time-scale. The salient question for personal mobility in the world is rather whether car ownership will diffuse throughout the world to the degree it has in the industrialized countries. Today there are over 400 million cars in the world. Whether this number doubles or increases tenfold during the next decades will have a larger effect than any model variations in the price elasticity of motor fuels. Another example given in figure 5 shows that most of the cars are owned by the male population in Germany, while only a few, mostly young, women own automobiles. Should the ownership rates converge in the future this could almost double the fleet size.

These examples illustrate that the long-time horizon almost inherently demands an interdisciplinary approach in evaluating greenhouse-gas emission mitigation and response strategies. Economic mechanisms alone will not do nor will engineering perspectives. The complex fabric of many dimensions has to be integrated into more holistic approaches for analysing alternative development paths, those that lead to high emissions and those that are responsive to

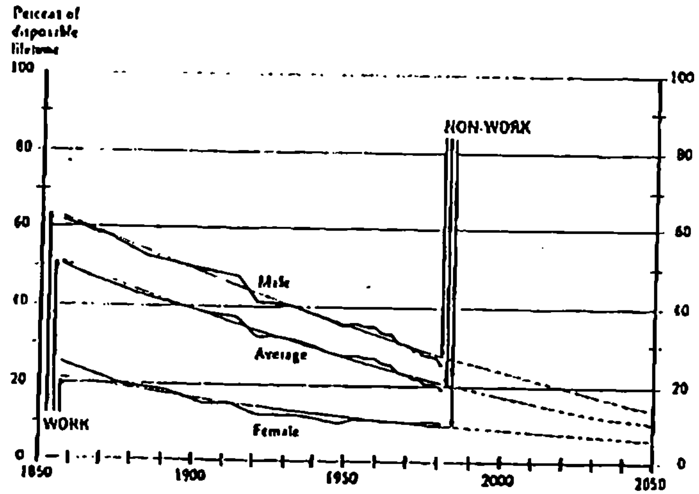


Fig. 4 Fraction of disposable lifetime spent at work and non-work of female, male, and average working population, UK 1856–1981. Figures are derived by comparing life hours of work to total disposable, active non-work hours for adults. Disposable hours are calculated by subtracting 10 years for childhood and first elementary education and also required "physiological" time, e.g., time required for sleep, eating, and personal hygiene, assumed on average to amount to 10 hours per day. For the average working population in the United Kingdom, working hours decreased from about 124,000 to 69,000 hours between 1856 and 1981, while at the same time disposable lifetime hours increased from 292,000 to 378,000 hours. Thus, non-working hours increased from about 118,000 to 287,000 hours over a lifetime. On average over 60 per cent of the disposable lifetime of male adults was spent working in 1856, this percentage has fallen to less than 20 per cent at present (Source: Ausubel and Grübler 1990).

climate change. Perhaps creative scenario writing would even further enhance the value of models such as the one proposed by Edmonds et al.

The ultimate question is what is the appropriate model scale (e.g., number of sectors, equations, variables) that is required to capture some of these characteristics? It is clearly undesirable to have a high degree of complexity in treating problems that are poorly understood such as the effect of global warming on international migration patterns. It is better instead to treat with higher accuracy those things that are well known such as the effect of urbanization, mobility, or

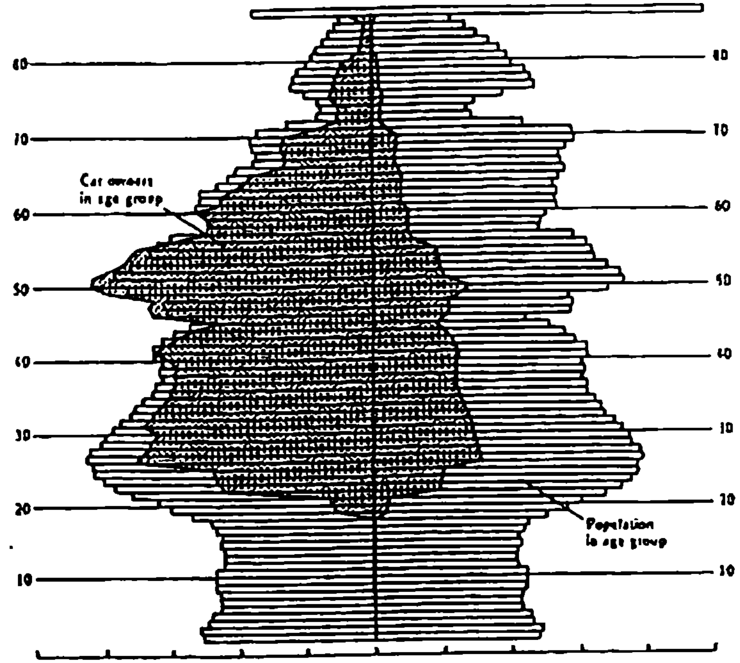


Fig. 5 Demographics of car ownership in Germany (only former FRG territory) in 1989 revealing significant intergenerational and gender differences in car ownership. Combined with demographic projections scenarios of future car ownership are developed at IIASA based on different scenarios of lifestyle changes of successive cohorts entering driving age. Conversely the ownership (or non-ownership) patterns of older generations are assumed to remain relatively stable, consistent with historical experience (Source: Büttner and Grübler 1991).

geography and climate on energy end-use patterns. It is a disbenefit to know the magnitude of the global warming potential of multiple gases if carbon dioxide effects and emissions are known with great accuracy while direct and indirect effects of methane and its emissions are very uncertain. In this case, it would be better to know the atmospheric concentrations of these two gases individually. The second generation model can help and improve the analysis of many of these issues provided it is "scaled" appropriately to answer the posed questions – to use the words of Edmonds et al., it should be problem-oriented and involve minimum modelling. I hope that they will succeed. The proof of the pudding will come in eating it – in this case we will have to be patient and wait for the first model implementation and results. In any case, the authors must be complimented on their ambitious and courageous undertaking.

References

Ausubel, J.H., and A. Grübler. 1990. *Working Less and Living Longer. Part I: Long-term Trends in Working Time and Time Budgets.* Laxenburg, Austria: International Institute for Applied Systems Analysis.

Böttner, T., and A. Grübler. 1991. *The Birth of a New "Green" Generation?* Laxenburg, Austria: International Institute for Applied Systems Analysis.

Grübler, A., and Y. Fujii. 1991. "Inter-generational and Spatial Equity Issues of Carbon Accounts." *Energy* 16(11–12): 1397–1416.

Grübler, A. and N. Nakićenović. 1991. *Energy and the Environment in the 21st Century.* Laxenburg, Austria: International Institute for Applied Systems Analysis.

Heilig, G. 1992. World Population: Trends and Prospects. Paper presented at the International Workshop on Energy/Ecology/Climate Modeling and Projections and International CHALLENGE Symposium, January 1992, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Intergovernmental Panel on Climate Change (IPCC). 1990. *Climate Change – The IPCC Scientific Assessment.* Cambridge: Cambridge University Press.

Lashof, D.A., and D.A. Tirpak. 1989. Policy Options for Stabilizing Global Climate. Draft Report to Congress, U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Washington, D.C.

Marchetti, C. and N. Nakićenović. 1979. *The Dynamics of Energy Systems and the Logistic Substitution Model,* RR 79-13. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Nakićenović, N. 1990. "Dynamics of Change and Long Waves." In: T. Vasko, R. Ayres, and L. Fontvielle, eds., *Life Cycles and Long Waves.* Berlin: Springer Verlag.

—— 1992. *Energy Strategies for Mitigating Global Change,* WP-92-1. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Nakićenović, N., and A. John. 1991. "CO_2 Reduction and Removal: Measures for the Next Century." *Energy* 16(11–12): 1347–1377.

United Nations (UN). 1990. *UN World Population Prospects.* New York: United Nations.

2. Kirit S. Parikh

At the outset, let me say that this is an extremely ambitious effort. It is even more ambitious than the one upon which we embarked at the International Institute for Applied Systems Analysis (IIASA) in 1976

in its Food and Agriculture Programme (FAP). We built what we called a Basic Linked System (BLS) of National Food and Agricultural Policy Models.[1] The national models are applied general equilibrium models with a general equilibrium linkage. The system has some 34 models, 20 referring to specific countries or groups of countries having a common agricultural policy and 14 models representing countries of the rest of the world from different regions, grouped according to the similarity of their likely behaviour on the international market. The models distinguish 10 different commodities at the international level (more domestically), of which nine were agricultural commodities and the tenth was a non-agricultural sector to close the system. The parameters of the models were empirically estimated from time-series data. Empirical estimation as opposed to benchmarking was considered essential if the model system were to describe the world with some measure of confidence. It took some 200 person years of effort. The first demonstration version of the model was ready in 1980. A usable one became available in 1984.

However, that was in 1976. Today, it is 1991 and the progress that has been made over these years in computers, algorithms, communication networks, data availability, and the experience obtained with general equilibrium modelling, should make the proposed effort of Edmonds et al. succeed within a reasonable length of time. Without the *Kitty Hawk* of the Wright brothers, 707s would not have come about when they did. With our and similar efforts on building-applied general equilibrium-based linked systems, such an ambitious effort could now be conceived and launched.

My comments on the paper are grouped under different headings. First, I would comment on its approach, then on its scope, limitations, and problem-orientation. These will be followed by some suggestions.

The approach

The approach is a bottom-up approach and the model provides enormous details. With any model that you use, the users always demand more details than what is incorporated into the model. I can confirm that from my personal experience. The model of India that we developed as a part of the IIASA Basic Linked System was one of the more detailed models of the system. I have been using this model for policy analysis and I often find that questions are asked that the model cannot answer without incorporating more details or greater articulation. All the time we keep on updating and modifying the model to address new policy issues as they come up. I am, therefore, sympathetic to the level of detail that is being sought to be incorporated into this model.

There is yet another reason for having a detailed model. A model provides scenarios and these scenarios provide consistent descriptions of a set of variables. These variables can be divided into endogenous and exogenous variables. While a model's solution provides consistency among the endogenous variables, it is not always recognized that consistency among the exogenous variables in specifying a scenario is a difficult and critical task. It does therefore help in specifying for a scenario a set of consistent values for exogenous variables, if their number is minimized. On the other hand this means that the number of parameters to be estimated becomes large. One may also note that when one is exploring long-term strategic alternatives, even empirically estimated parameters cannot be taken to be stable. Even then, the question of descriptiveness of the model cannot be dispensed with: a model scenario is an "if ... then" proposition and the "if" ought to describe the world that we live in if the "then" is to have any relevance.

A simpler CGE model, say of the Manne and Richels, or the Edmonds and Reilly type, provides a starting point for broadly defining some strategic alternatives. However, these models are already available. One should really try to build on them. Moreover, a more detailed model is indeed needed to provide guidance for policy formulations, for international agreements, or to facilitate international negotiations. For these purposes, a model is needed that tells us who gains and who pays under alternative policies and this is where I find some problems with the model.

Problem-orientation, scope, and limitations

I find the model to be what I call a "growth and greenhouse" model and not a "development and environment" model. Its emphasis is largely on loss in economic growth and on the trade-off between economic growth and greenhouse gas emissions. What is required however, is a model that treats both development and environment in a broader perspective. Questions of income distribution, questions of local versus global effects of environmental policy, questions of lifestyles of different groups of people, and questions of consumption patterns and development are very critical and not addressed by the model.

For example, the developing countries do not feel responsible for the current greenhouse problem. Their emissions of CO_2 are less than 30 per cent of the total greenhouse gas emissions in the world, even though they constitute nearly 80 per cent of the world's population. Many of these countries face severe environmental stress in their urban areas due to air pollution, poor sanitation, congestion in slums, use of dirty fuels in poorly ventilated kitchens, and crowded settlements. These environmental issues affect the welfare of their populations in a much more direct way than the consequences of the greenhouse effect. These countries, therefore, rightly feel that they should tackle these local environmental problems before they spend any resources for global environmental problems that in any case they themselves have not created. But, to explore such trade-offs, one needs to incorporate into the model the details of income distribution across different groups in rural and urban areas as mentioned earlier.

To do policy analysis with a model means to compare alternative situations. Some form of comparison of welfare in alternative situations is inescapable. The Edmonds et al. model does not stipulate an integrable demand system without which welfare comparisons would be extremely difficult to make. A consistent integrable demand system is quite essential for such a model. Here, I may also point out that to estimate a consistent demand system that remains meaningful over long periods and large changes in income levels is difficult. Recently, I had occasion to project food demand for the year 2050. When I used elasticities, or a simple linear expenditure system to project these, I got absurd results. The calorie intake implied in these projections was sometimes as high as 10,000 Kcal per day. This is clearly not a feasible intake level. One needs to find an alternative demand system. Here, what we did in the IIASA model is worth noting. We had estimated a separate demand function for each commodity as a function of income and own price. We had also estimated a separate relationship between per capita calorie intake and per capita income. This relationship was asymptotic of what one might consider the physiological limit. For a given target price vector and income level, we estimate an initial vector of demand using each of these individual demand functions. Then we find a vector point that is close to this vector and is such that it satisfies the adding up property as well as meets the aggregate calorie intake constraint. Around the new vector point we then construct a linear expenditure system. Such a procedure was repeated at each time period in IIASA's BLS models. The resulting system can be considered as a local approximation to an underlying utility function and can be shown to be consistent. Such a procedure gave sensible projections for 2050, which were also much more robust to changes in income levels. While the calorie constraint was a logical constraint to impose when dealing with food demand as we were doing in the BLS, it is not adequate for the proposed model, which has many other non-agricultural commodities. It may be necessary to impose some other natural constraint. Perhaps one could impose a constraint on the time required for alternative consumption activities and on the total time available to consume the various commodities. Such a constraint might make the demand system behave sensibly.

It is important that a model does provide insights into trade-offs between alternative development paths, between consumption patterns, between production structures, and across time. Even a long-term model must address some short-term policy issues and the issues of resulting transition costs. If a model does not provide any guidance on what we do now, the model is in some sense useless.

Some points of detail

There are some points of detail which need to be mentioned. First, it is vital to maintain common units for trade of commodities among countries. This is a critical problem and requires much care and data-grubbing work. From the description of the model, I am not sure how these problems are to be handled and how units are going to be kept consistent across different countries.

Secondly, an observation is made in the paper that capital stock data can be "relatively easy to observe." This is not so, as capital stock data are notoriously difficult to obtain. Estimates of total factor productivity growth in Indian industries based on the same data source by two different researchers arrive at two completely contrary results; one saying that factor productivity in India has grown, the other saying that it has not. The difference can be largely ascribed to the way capital stock data are put together from information on the time-series of investment at current prices by assuming certain rates of real depreciation. Unfortunately, the depreciation rates are not observed and a seemingly small change in the rate of depreciation whether it is 3 or 4 per cent per year can make a difference as to whether total factor productivity grew or not.

Thirdly, the model seems to assume that governments do not own land. However, governments can and do own land and substantial

amounts of it in many countries. Thus, questions of deforestation and land markets cannot be adequately dealt with without bringing in government behaviour in the land market. Neither do I see fishery mentioned anywhere, and consequences for oceans seem to be left out of the model, hopefully only for the moment.

Some suggestions

I would like to make a couple of suggestions. It seems to me that the agricultural sector model of IIASA's BLS would provide a very good starting point for this modelling work and the authors might explore the possibility of using this model for the agricultural sector. In addition, the algorithm development for IIASA's system has proved over the years to be robust and efficient even when dealing with policy regimes with quotas. They might also explore the possibility of using the algorithm that was developed by Michiel Keyzer[2] using the Kantarovich lemma.

Finally, I would like to emphasize that in using the model, one should keep in mind that no model can address the important question of welfare distribution and responsibilities. We have to keep this earth functioning and we must think in terms of a mechanism, a system that is fair and feasible. I suggest that we think in terms of using market-friendly approaches towards maintaining the global commons at the desired level by giving tradable emission quotas to different countries. Initial allocation of these should be consistent with the carrying capacity of the earth and should be done fairly. I suggest that the allocation based on population would be a fair way. In order not to encourage people to increase their populations, we may keep the allocations to the populations of a past year, say 1990. I hope this model would give us insights into alternative ways of preserving the global commons, of enhancing local environment, and of improving the quality of life for all persons on earth. I congratulate the modellers on their ambitious project and wish them luck.

Notes

1. Fisher, G., K. Frohberg, M.A. Keyzer, and K.S. Parikh. 1988. *Linked National Models: A Tool for International Food Policy Analysis*. Boston, Mass.: Kluwer Academic Publishers and International Institute for Applied Systems Analysis.
2. Keyzer, M.A. 1983. Computation of Fixed Points by Applied Continuation Techniques to the Kantarovich Lemma, Working Paper SOW-83-02. Amsterdam: Centre for World Food Studies.

3. **Yuangzheng Luo**

Many of the points taken up in the paper are of interest to me and I have yet to digest them. I cannot agree more with the view expressed in that paper that in the process of designing, a new model should be problem-oriented. We should not lapse into the practice of making the problem fit the model. That would be repeating the mistake of the fool in the Chinese fable who chopped off part of his feet so that they could fit the shoes.

In their reconstruction and economic development after World War II, Europe and Japan did not pay due attention to the issue of environmental pollution. Thus it went unheeded until the 1960s when it became an explosive issue. How to control environmental pollution and maintain the ecological balance became a great concern of the United Nations and governments around the world. To this end the United Nations set up the Environmental Council under the Economic and Social Council (ECOSOC). China began to take part in the Council's work in the 1970s. The developed countries have designed a number of models on environmental pollution in addition to formulating relevant policies and legislation. These have proven through practice to be effective in bringing environmental pollution under control step by step. However, from the global perspective, the problem of environmental pollution has not been solved. The global environmental issue has been aggravated as a result of the accelerated transfer by the industrialized countries since the 1980s of highly polluting and energy-guzzling labour-intensive industries to the developing countries and also as a result of the industrial development of the developing countries themselves. Moreover, the emission of greenhouse gases and the depletion of the ozone layer led to global environmental warming. People are becoming increasingly concerned about such global environmental issues. The developing countries have come to see that prevention is better than "cure." But it must be pointed out that the industrialized countries should bear the main responsibility for global environmental pollution and the degradation of the environment. While they seek to protect the environment in their own countries, the industrialized countries must transfer environmentally sound technologies to the developing countries, increase aid to them for environmental protection, and put an end to the transfer to developing countries of industries that pollute the environment.

Great strides have been made in environmental protection since

the 1960s when the problem of pollution began to catch the attention of industrialists, policy makers, and the general public. In many countries, effective measures have been taken and laws passed to keep the air and the rivers and lakes clean. Today, more and more attention is focused on the greenhouse effect. I am confident that with a common understanding of the gravity of the problem and through concerted efforts, better technologies will be developed to reduce emissions of greenhouse gases from industrial plants, vehicles, and home appliances and wiser policies adopted to control such emissions.

As a developing country, China is equally concerned about the greenhouse effect and about environmental protection. In its pursuit of a reformist policy and its opening up to the outside world, China has, in the past decade or so, made notable progress in controlling environmental pollution and preserving the ecological balance. China is fully aware of the importance of striking a proper balance between achieving economic and social progress and maintaining a sound ecological system between industrialization and environmental protection. We are ready to learn from other countries whatever is useful to us in preserving our environment. However, due to financial and technological constraints, we cannot apply the same standards of environmental protection that the developed countries use.

You may be interested to learn about China's energy picture. In 1990 China's total energy consumption amounted to 980 million tons of standard coal. The breakdown is as follows: coal, 75.6 per cent; crude oil, 17 per cent; natural gas, 2.1 per cent; and hydropower, 5.3 per cent.

You can see from these figures that coal plays a predominant role in China's energy consumption. There was a time in the 1970s and early 1980s when Chinese factories switched from coal burning to oil burning. But before long, China learnt that it could not afford to do this, since exploration of oil requires far greater capital input than the mining of coal. So we switched back to coal burning. While we continue to rely heavily on coal for energy consumption, we plan to make use of nuclear power and tap China's rich hydroelectric resources on a much larger scale. To this end, a nuclear power station is under construction at Da Ya Wan in Southern China and plans are under way for the building of more hydropower stations. Although economic development remains China's overriding concern, increasing attention is being given to environmental protection. In this regard, there is a great deal for China to learn from the advanced

Pacific Northwest Laboratories
901 D St. SW, Suite 900
Washington, DC 20024

FACSIMILE TRANSMITTAL

DATE: February 11, 1998

To:	Joe Aldy
Company:	CEA
City/State:	Washington, DC
Facsimile #:	202-395-6870
Telephone #:	202-395-1455

From:	Chris MacCracken
	Battelle - Washington Office
Facsimile #:	(202) 646-5233
Telephone #:	(202) 646-5274

Transmittal Consists of [~~26~~] Page(s) including cover page. 30

COMMENTS:

Joe – Here is paper #2!

I'm sending two papers your way. They're each 20-something pages, so I'll send them in two chunks. The "Modelling Future ..." paper was published in a book of conference proceedings. I'm including a copy of the title page of the book in front of the chapter. ~~The other paper never got published.~~ By the way, our "Return to 1990" paper ~~now has an official~~ Pacific Northwest National Laboratory document number on it, so you can cite it as "PNNL-11819 Pacific Northwest National Laboratory".

Good luck.

Chris

DRAFT

CALIBRATION OF THE SECOND GENERATION MODEL

Karen Fisher-Vanden
Richard Baron
Jae Edmonds
Hugh Pitcher
Ronald D. Sands
Marshall Wise

June 1993

Pacific Northwest National Laboratory

Washington DC

Work prepared under contract DE-AC06-76RLO1830 for the United States Department of Energy.

CALIBRATION OF THE SECOND GENERATION MODEL

Methods and tools used to calibrate specific computable general equilibrium models (CGEMs) have been extensively documented in recent years (e.g. Mansur and Whalley (1984), and Ballard et al. (1985)). Many embodiments of CGEMs have sufficiently similar properties that relatively standard techniques can be employed to implement them. When model design departs substantially from the norm, existing methods must be extended and new methods developed.

The second generation model (SGM) is a CGEM which was designed specifically to address issues associated with global change. As a consequence, the model embodies characters which are novel and interesting. A theoretical description of the model is contained in Edmonds et al (1993). Because the model must be capable of addressing major issues associated with both the emission of radiatively important gases and the potential consequences of atmosphere/-climate change, the model was designed to perform three tasks:

1. Provides estimates of environmentally important emissions associated with human activities,

2. Provides estimates of the consequences of global environmental change, with particular emphasis on human activities, and

3. Provides estimates of the economic consequences of actions to mitigate and adapt to global environmental change.

Further, the nature of the global change problem dictates that the SGM reflect the following characteristics:

1. The issue is **global**, emissions from all sources in all regions of the world determine total atmospheric change,

2. Anticipated changes in the greenhouse effect result from the emission of a **number of gases** including: CO_2, CH_4, CO, N2O, NO_x, SO_2, VOCs, CFCs, and CFC substitutes,

3. **Many human activities** are involved in both emissions and impacts including: Agriculture and Forestry, Energy Production and Consumption, Transportation, Manufacture, Services, Coastal Zone Settlement, Health Care, Water Use, and Land Use,

4. Emissions and impacts depend upon multiple **resources and technologies** including: Managed and Unmanaged Ecosystems, Capital Stocks, and Labor,

5. Emissions and impacts also depend on **international trade patterns**, and possibly, migration patterns,

6. Factors 3, 4, and 5 depend upon **institutional arrangements**,

7. Policy analysis requires both mid-term (5-year) and long-term (100 year) **time horizons**.

As a consequence, the SGM differs from other CGEMs in that it includes:

1. an energy/agriculture focus;
2. a putty-clay vintaged representation of capital;
3. land as a factor of production;
4. depletable natural resources;
5. competition among technologies; and
6. sector- and subsector-level investment decisions.

This paper provides a complete description of how the SGM was calibrated including the methods and tools from existing literature which were applied and the calibration methods which were developed to handle the unique features of the SGM. In addition, the important underlying assumptions and procedures used to produce a data set consistent with the general theoretic principles of the SGM are presented.

I. CALIBRATION VS. MACROECONOMIC PRACTICE

An essential step in applying general equilibrium analysis is the construction of a benchmark data set for the base year of simulation. Contrary to standard macroeconomic models, which are estimated econometrically from time-series data, parameters for most computable general equilibrium models (CGEMs) are not estimated with econometric techniques[1]. From a practical standpoint, this can easily be explained by the number of parameters involved. More importantly, however, is the absence of input-output time series data with satisfactory levels of disaggregation which makes econometric estimations of some model parameters virtually impossible. Although Chipman [1991] demonstrates that the number of observations does not have to be greater than the number of parameters to be estimated in a CGEM, the number of parameters requiring estimation within the SGM is too large for econometric estimation to be a feasible option. This is largely due to the SGM's requirement of 6-digit input-output tables to describe the economy in appropriate detail when, as is the case with the U.S., such data requirements are only published every 5 years[2]. In addition to the problems of data availability, parameters estimated econometrically over 5, 10, or 20 years can be questionable when used for long-term projections[3]. As a result of these data constraints, the method of calibration, described as the process of choosing model parameters to exactly reproduce observations in a given base year, is widely used by developers of CGEMs.

As with econometric estimation, calibration also has its limitations. The method of calibration not only assumes that benchmark year data reflect an economy in equilibrium, it also assumes that the benchmark equilibrium is representative of a "normal" growth path. Input-output tables and national accounts are well suited for use in general equilibrium analysis since they reflect an economy where supply equals demand (including trade). Budget constraints for the government and household sectors, however, are not explicitly reflected in input-output tables, thus requiring some work to reconcile input-output observations with these constraints.

[1] The Jorgenson/Wilcoxen [1990] model is an exception to this rule.
[2] Chipman [1991] shows that to econometrically estimate a linear approximation of a CGEM with 10,000 parameters, a minimum of 8 years of quarterly observations (25 observations) are required.
[3] Reliability, however, can be enhanced with the use of elasticities given by the literature and a comprehensive sensitivity analysis.

II. DATA REQUIREMENTS

The objective of calibration, as previously mentioned, is to choose model parameters so as to exactly reproduce data observations in the chosen base year. Essentially, the calibration process consists of translating available data into a problem-oriented data set which is used not only to reproduce observations in the benchmark years, but also to make long-term projections. A set of appropriate input-output tables (e.g., the 6-digit level 1982 benchmark tables for the US, published by the US Department of Commerce), and the national accounts are the basis for the calibration of the SGM. Other data sources include: 1) time series data on gross capital stocks and discards for each major industry and service, 2) energy data, and 3) input-output tables and national accounts for 1985, the actual benchmark year of the model. Key-parameters, such as elasticities of substitution in production, and income and price elasticities of final demand sectors, were obtained from existing literature.

II.a. Intermediate Production

In order to acquire the model parameters necessary to estimate intermediate production by SGM industry, data are required on the use of factors by industry, and input-output transactions. The "use" and "make" tables of the input-output accounts published by the Bureau of Economic Analysis (Department of Commerce, BEA 1982) provide the necessary data on factor requirements, value-added, and final demand to develop most of these model parameters. The "use" table provides the value of (1) each industry's consumption of commodities as factors of production, (2) each industry's value-added components (i.e., labor expenditures, indirect business taxes, and other value-added components), and (3) final demands for commodities.

Each column in the interindustry portion of the "use" table describes production within a specific industry while the row values pertain to the amount consumed of each commodity as input to the industry's production process. Therefore, the "use" table dimensions of commodity-by-industry. Because of joint production (i.e., multiple commodities produced in a single industry), output by industry is different than output by commodity; hence, row sums do not equal column sums in the "use" table. This presents a problem when using these data to calibrate production functions within a CGE modeling framework where single commodity production is assumed.

In order to produce an "use" table where row sums equal column sums, the construction of a commodity-by-commodity or industry-by-industry "use" table is required. A commodity-by-commodity table was constructed for the SGM since the units of output pertain to actual commodity units and not to a mix of commodities as is the case with an industry-by-industry table. This commodity-by-commodity table was constructed by combining data from the "use" table with data from the "make" table. The "make" table provides a distribution of commodity production across industries. Each row in the "make" table pertains to a single industry and gives the amount produced of each commodity within that industry. Thus, the dimensions of the "make" table are industry-by-commodity. By normalizing this "make" table and post-multiplying it with the "use" table (i.e., "use" table X normalized "make" table), a commodity-by-commodity "use" table is obtained.

Before the "use" and "make" tables can be combined, however, translation of the more disaggregate BEA industry categories to SGM categories is required. The BEA publishes two types of input-output accounts; the "benchmark" I-O accounts and the annual I-O accounts. The benchmark I-O accounts are published for economic census years and therefore include more detailed data than are available on an annual basis. Annual I-O accounts, although published more frequently, include 85 industry categories while the benchmark I-O accounts include 500 industry categories. Although the base year of the SGM is 1985, data from the 1985 annual I-O accounts are not used directly to calibrate the SGM; rather these data are used to project observations of the 1982 benchmark I-O accounts to 1985 levels. This is due to the energy sector detail required in the SGM which is only available in benchmark years.

Table 1 provides a mapping of BEA's 1982 benchmark I-O industry categories to SGM categories. Although most SGM categories are aggregations of BEA categories, a few SGM categories are actually portions of more aggregate BEA categories. In particular, the SGM Crude Oil Extraction and Natural Gas Extraction categories were created by separating the two from the more aggregate BEA category, Crude Oil and Natural Gas Extraction. To separate the two industries, it was assumed that (1) all crude oil and natural gas demand from the Oil Refining industry is actually only crude oil, and (2) all crude oil and natural gas demand from the Gas Transmission and Distribution industry is actually natural gas.

The SGM industry "Uranium Mining and Processing" also required some manipulation of the I-O accounts data. Through discussions with BEA staff, values of uranium mining and uranium processing were determined and extracted from the more aggregate BEA categories of "Nonferrous Metal Ores Mining" and "Industrial Inorganic Chemicals n.e.c".

Table 1

SGM Industry Category	BEA Category	Standard Industrial Classification	BEA Classification
Agriculture	Agriculture, Forestry and Fishing; Food and Kindred Products	01 - 09,20	01 - 04,14
Crude Oil Extraction	Crude Petroleum & Natural Gas*	13	08
Natural Gas Extraction	Crude Petroleum & Natural Gas*	13	08
Coal Mining	Coal Mining	12	07
Uranium Mining and Processing	Nonferrous Metal Ores Mining, except Copper*	1094	0602

	Industrial Inorganic Chemicals n.e.c*	2819	270104
Electricity Generation, Transmission & Distribution	Private Electric Services (Utilities)	4911	6801
	Federal Electric Utilities		7802
	State & Local Electric Utilities		7902
Oil Refining	Petroleum Refining	2911	310101
	Products of Petroleum & Coal n.e.c.	2999	310103
Gas Transmission & Distribution (utilities)	Private Gas Production	492	6802
Other Products	All other industries		

* Part of this industry category.

Upon completion of the commodity-by-commodity (CXC) "use" table, values are adjusted to 1985 levels by using data obtained from the 1985 input-output accounts. Industry output and intermediate consumption totals in 1985 for each of the SGM commodities are estimated using the 1985 I-O data. Using these totals, CXC table values are then adjusted using the RAS (row and column sum) adjustment procedure developed by Michael Bacharach [1971][4]. Other adjustments to the CXC table include industry-specific data reconciliation; for example, splitting crude oil from natural gas and ensuring that uranium is only consumed by the electric generation and defense industries.

II.b. Industry Value Added

Once completed, this CXC table provides the necessary information on the use of produced commodities in the production of other commodities which will be used in the computation of each industry's production function coefficients. Before these coefficients can be estimated, however, information on the use of non-produced factors of production (i.e., land and labor) is required. Each industry's land and labor expenditures are included in the value added portion of the I-O accounts. For benchmark years (e.g., 1982), the value added portion of the I-O accounts included the following components: (1) "compensation of employees" (labor expenditures), (2) "indirect business taxes" (e.g., sales taxes, excise taxes, property taxes, import taxes (duties)), (3)

[4] This procedure adjusts the values within the matrix so that the row and column sums equal the 1985 estimated totals.

"other value added" (e.g., profits, land rents). In order to obtain information on land and labor expenditures in the form required by the SGM, some adjustments to the data provided in the I-O accounts are necessary.

Land

In the I-O accounts, the real estate industry includes rents for buildings but not for land. Land rents paid by each industry is included in the "other value added" component of value added in the I-O accounts. A separate land component is imperative for the SGM to study the effects of greenhouse gas emissions on land use; particularly for the Agriculture sector. The land component for each SGM industry was separated from the "other value added" component by estimating each industry's expenditures on land. Land rents by SGM industry were estimated by applying an average cost of agricultural land (based on data obtained from the U.S. Department of Agriculture) to land use data from the "Statistical Abstract of the U.S." published by the Department of Commerce[5]. These estimates of land rents for each SGM industry are added as a separate component to each industry's value added and accounted for by subtracting an equal value from the "other value added" component of value added.

Labor

Industry labor expenditures are given in the "use" table of the I-O accounts as a component of value added called "compensation of employees". These data are aggregated to SGM industries at the same time as intermediate production. The only adjustment to the industry labor component is the extraction of labor used for government services from the "Other Products" industry sector. Prior to SGM industry aggregation, the industrial production component of the I-O accounts includes a "Government Industry" which contains labor as its only input to production. (This industry was added to the "Other Products" industry during SGM industry aggregation). Since the calibration of the government services' utility function (discussed in Section III.d. below) is conducted separately from industrial production, government labor expenditures need to be included with other government expenditures in the final demand portion of the I-O accounts. Therefore, government services labor expenditures are extracted from the "Other Products" sector and added as another component of the government's final demand.

Corporate Retained Earnings

Included in the total amount of savings available for investment is corporate retained earnings; the amount of corporate profits retained for investment purposes. The SGM estimates the corporate retained earnings rate (the percentage of corporate profits retained) for each sector as follows:

$$RE_i = \alpha_i \, (1 - e^{r \cdot \beta_i}) \qquad (1)$$

where

[5] An average agricultural land rental price was used on the assumption that (1) agricultural land makes up the majority of total usable land area and (2) the differential from urban land prices will be reflected in the constant term of the production function.

RE_i	=	corporate retained earnings rate of sector i;
α_i	=	the maximum potential retained earnings rate;
r	=	the real market interest rate; and
β_i	=	the retained earnings sensitivity to the real interest rate.

Although separate retained earnings rates are defined for each sector, an average retained earnings rate over all sectors was applied to each. To calibrate equation (1) to the 1985 base year it is necessary to first calculate an actual retained earnings rate over all sectors for 1985 by dividing 1985 total corporate retained earnings by 1985 total corporate profits obtained from the "Economic Report of the President, 1992". Next, the maximum potential retained earnings rate was estimated from historical data to be 0.60 (i.e., the percentage of corporate profits retained would never expect to be higher than 60%). Last, assuming a real market interest rate of 3%, the sensitivity parameter (bi) can be directly calculated from equation (1).

II.c. Capital Inputs

In addition to the factor inputs described in the I-O accounts, data on the underlying capital stock used in production are also required to compute each industry's production function coefficients. The SGM requires productive capital stock of each industry to be divided into "vintages" corresponding to the 5-year period in which the capital was initially purchased. "Vintaged" capital stock allows for improvements in production efficiency (e.g., as a result of technological change) within an industry. The SGM also assumes capital to be a fixed factor of production and to be completely productive until its average lifetime is reached[6]. The SGM assumes that at any period of time, an industry produces using capital stock from the number of vintages equal to the average lifetime of capital in that industry divided by 5 (length of a SGM time step (period)). For example, in period 1 (which includes the years 1986 to 1990) an industry with an average capital lifetime of 20 years would have four vintages of capital stock: (1) capital stock purchased during the period 1971-1975, (2) capital stock purchased during the period 1976-1980, (3) capital stock purchased during the period 1981-1985, and (4) capital stock purchased in the current period 1986-1990. Each of these capital stocks would be used to produce output in period 1.

Annual equipment and structures capital stock data were obtained from the "Fixed Reproducible Tangible Wealth in the United States" published by the BEA and are consistent with the national income and product accounts (NIPA). These data include annual values by BEA industry category for gross capital stock, capital inputs, net capital stock, depreciation, and discards. As with the I-O tables, these data require conversion from BEA industries to SGM industries.

To calculate capital stock by vintage for each SGM industry, it is necessary to first calculate annual investment by industry as the difference between the industry's current year's gross capital stock and last year's gross capital stock plus the current year's discards. Capital stock by vintage is calculated by taking the sum of investment over the vintage's corresponding 5-year period and subtracting the "vintage" discards which are calculated on the basis of lifetimes of equipment and structures, and annual investment numbers[7].

---

[6] This differs from typical accounting methods in which capital is depreciated over time.

[7] Note: Since the BEA capital stock data includes actual discards which do not always occur at the exact end of the capital's lifetime (some capital could have been discarded before or after the capital's average

As discussed previously, the production function for each industry is the sum of separate CES production functions for each vintage. For example, an industry with an average capital lifetime of 20 years would have the following production function in Period 0:

$$Q_{0,s} = q_{0,s} + q_{-1,s} + q_{-2,s} + q_{-3,s} \qquad (2)$$

where

$Q_{0,s}$	=	total production of commodity s in period 0; and
$q_{v,s}$	=	output of commodity s produced with vintage v capital stock (based on a CES production function).

This specification allows for improvements in productivity (e.g., technological change) over time. This improvement in productivity is based on the Hicks-neutral technological change rate which consists of a percentage rate of change in production efficiency incorporated into the scale factor (a0) of each vintage's CES production function. Table 2 presents the average capital lifetimes and the historical rate of Hick's-neutral technological change assumption for each SGM sector. These rates were calculated based on historical data on the use of factor inputs in production, and are applied only to historical vintages in the SGM (i.e., vintages prior to period 0). Future productivity growth assumptions were determined separately and are documented in Fisher-Vanden, et. al. [1993].

Table 2

SGM Industry Category	Average Capital Lifetime (in years)	Rate of Hick's-neutral Technological Change (in %)*	Elasticity of Substitution in Production
Agriculture	20	0	0.4
Crude Oil Extraction	15	1.5	0.5
Natural Gas Extraction	15	1.5	0.5
Coal Mining	15	2.5	0.5
Uranium Mining and Processing	15	1.0	0.5

lifetime), adjustments to the capital stock data are needed to reflect the SGM assumption that discards occur at the time the capital's lifetime has been reached. This is done by summing annual investment values (the difference between the current year's gross capital stock and last year's gross capital stock plus the current year's annual discards value given by the BEA) over the 5-year vintage period and adding a "vintage" discards value which is calculated based on the SGM capital retirement assumption. By calculating vintage capital stock this way, the only discards taken into account are those based on the SGM assumption; BEA discards are not included. Since capital stock values include equipment and structures, "vintage" discards in these benchmark data will only exist in cases where either an industry's equipment or structure lifetime is less that the average lifetime for both equipment and structures. This is done only for benchmarking purposes only, and once in the SGM, equipment and structures are combined and retired at the average lifetime of both.

Electricity Generation, Transmission, and Distribution	35**	1.0	0.2
Oil Refining	30	0.5	0.1
Gas Transmission and Distribution	30	0.5	0.15
Everything Else	20	0.5	0.5

* Applied to vintages prior to period 0.
** Except for hydroelectric power plants (65 years).

II.d. Subsectors

In order to fully understand the effects of certain economic activities on potential greenhouse gas emissions and to adequately address the consequences of certain policy actions to reduce greenhouse gas emissions on these activities, some further disaggregation of SGM industries is necessary. In this version of the SGM, the following disaggregation of particular SGM industries was done: (1) the Crude Oil Extraction sector was disaggregated into three subsectors each representing a different "grade" of crude oil; (2) the Natural Gas Extraction sector was also disaggregated into three subsectors each representing a different "grade" of natural gas; and (3) the Electricity Generation sector was disaggregated into six subsectors each representing a different method of electricity generation (e.g., oil-fired electricity generation).

"Grades" of crude oil and natural gas pertain to different levels of extraction costs[8]. For example, grade 1 of crude oil has the lowest cost of extraction which could represent the process of extracting oil close to the earth's surface. Grade 3, on the other hand, would have the highest cost of extraction and could represent extraction which requires much more extensive drilling procedures. Due to the different method of extraction associated with each "grade", a different production function specification is required for each grade. Using assumptions based on the cost of extraction for each grade, the I-O accounts and capital stock data for both the Crude Oil Extraction sector and Natural Gas Extraction sector are partitioned into different grades. It is important to note that although each grade has an associated method of extraction, the output produced is assumed to be homogeneous; thus, unlike sectors within the SGM, each grade faces a common output price of either crude oil or natural gas. Therefore, the likely outcome of the model would be that more of the "cheapest" grade (i.e., the grade with the lowest cost of extraction) would be produced relative to other grades.

The Electricity Generation sector was disaggregated into the following six subsectors based on the method of generation: (1) oil-fired electricity generation; (2) natural gas-fired electricity generation; (3) coal-fired electricity generation; (4) biomass-fired electricity generation; (5) nuclear electricity generation; and (6) hydro or solar electricity generation[9]. Data on annual net electricity generation by energy source and associated costs in addition to assumptions on capital intensity were used to separate the I-O accounts and capital stock data of the Electricity

[8] In the SGM, "grades" do not refer to the quality of crude oil extracted, but rather to the cost of extraction.
[9] Capital purchased in this subsector prior to 1991 is assumed to be used in hydroelectric generation. Subsequent purchases of capital are assumed to be used in solar electricity generation. Different "vintage" production functions are used to reflect this separation.

Generation sector into these six subsectors. As with Crude Oil and Natural Gas Extraction, these data are used to create production functions for each subsector and each subsector faces a common price of output (i.e., the price of electricity).

II.e. Elasticities of Substitution in Production

The final items necessary to estimate production function parameters for each sector (or subsector) are assumptions on the elasticities of substitution among factors of production. Although in most cases elasticities of substitution for each production function were obtained from existing literature (e.g., Ballard et al [1985]), some were estimated based on the underlying assumptions of the SGM. For instance, since activities at a lower level of aggregation are being described within the electricity sector, a lower level of substitutability among factors is implied. Therefore, a quasi-Leontif production function (i.e., a CES production function with an elasticity of substitution value close to 0) was assumed for the electricity subsectors. Table 2 provides the elasticity of substitution values chosen for each sector in the SGM.

III. ESTIMATION OF MODEL PARAMETERS

III.a. Calibration of the CES Production Functions

As previously discussed, each SGM sector and subsector has associated with it a unique production function in order to reflect differences in production processes. As shown in equation (2) above, total production in each sector and subsector is the sum of vintage production (i.e., output associated with each vintage capital stock). Each vintage production is described by the following CES production function:

$$q_{v,s} = \alpha_{0,s,v} \left(\sum_{i=1}^{N-1} \alpha_{i,s} X_{i,s,v}^{\rho} + \alpha_{N,s} X_{N,s,v}^{\rho}\right)^{\frac{1}{\rho}} \quad (v = -V_s \ldots 0) \qquad (3)$$

where

$q_{v,s}$ = output of commodity s produced with vintage v capital stock;
$\alpha_{0,s,v}$ = scale coefficient in vintage v's production of commodity s;
$\alpha_{i,s}$ = factor intensity of the ith input in the production of commodity s;
N-1 = number of variable inputs (N = total number of inputs; 1 refers to the number of fixed factors (i.e., capital) in Version 0.0);
$X_{i,s,v}$ = demand for input i in vintage v's production of commodity s;
$\alpha_{N,s}$ = factor intensity of the capital input (input N) in the production of commodity s;
$X_{N,s,v}$ = demand for the capital input (input N) in vintage v's production of commodity s;
ρ = elasticity of substitution parameter; and
$-V_s$ = oldest vintage capital stock for industry s (equal to the negative of the average lifetime of capital for industry s divided by the length of a period (i.e., 5 years) plus 1)

As evident from equations (2) and (3), Version 0.0 of the SGM assumes that relative production function factor intensities do not differ between vintages. The difference in production between vintages is due to the overall efficiency of all inputs; not to the efficiencies (or inefficiencies) of individual inputs to production. Therefore, Version 0.0 of the SGM assumes that the factor intensity parameters of each vintage production function (within a sector or subsector) differ only by a scalar (reflected in the scale parameter ($\alpha_{0,s,v}$)). This scalar comprises the Hick's-neutral technological change parameter; a parameter which reflects the overall production efficiency of the vintage. The relative factor intensity parameters, therefore, do not differ between vintages within a sector or subsector and the scale parameters of each vintage production differ only by the rate of Hick's-neutral technological change.

As previously discussed, the following seven data items are required to estimate each sector's production function coefficients: (1) intermediate production data (based on the I-O accounts) by sector and subsector; (2) industry value-added data (also based on the I-O accounts) by sector and subsector; (3) final demand sector and subsector data; (4) capital stock data by sector and subsector and vintage; (5) assumptions on the lifetimes of each sector's capital stock; (6) assumptions on the rate of Hick's-neutral technological change; and (7) assumptions on the elasticities of substitution in production. Once these data are compiled, a method to compute CES production function coefficients is applied. This method was specially developed for the SGM in order to handle vintaged capital stock in production. The steps involved in the computation of these coefficients are as follows:

1. Except for land and labor, set all 1985 input prices[10] equal to 1. Compute the price of land and labor as follows[11]:

$$P_{land} = \frac{TE_{land}}{Total\ Land} \tag{4}$$

$$P_{labor} = \frac{TE_{labor}}{Total\ Labor} \tag{5}$$

where

TE_{land}	=	Total land expenditures in 1985 (discussed in Section 3.2.2).
TE_{labor}	=	Total labor expenditures in 1985 (based on I-O accounts).
Total Land	=	Total U.S. managed land in 1985 (in 1000 km^2).
Total Labor	=	Total U.S. employed population in 1985 (in 1000 persons).

2. Compute the output price of a commodity as,

[10] Setting an input price to 1 is interpreting the unit good as the quantity of the input which can be purchased in 1985 with 1 million 1982 dollars (since the data of the SGM are in millions of 1982 dollars).
[11] Since the price of land is obtained by dividing 1985 total land expenditures (in millions of 1982 dollars) by total managed land (in 1000 km2), the price of land can be interpreted as the millions of 1982 dollars required to purchase 1000 km2 of land in 1985. Similar to the interpretation of the price of land, the price of labor can be interpreted as the millions of 1982 dollars required to hire 1000 workers annually.

$$P_0 = \frac{TO - IBT}{TO} \qquad (6)$$

where

P_0	=	Output price of the commodity[12] (in millions of 1982 dollars).
TO	=	Total output of the commodity (in millions of 1982 dollars).
IBT	=	Total indirect business taxes paid in 1985 associated with the production of the commodity (in millions of 1982 dollars).

3. As discussed above, relative factor intensities within a sector or subsector do not differ. Therefore, factor intensity parameters for the variable inputs can be calculated based on the assumption that total output is produced from one vintage (i.e., total production can be described by one CES production function rather than a summation of multiple CES production function (as in equation (2)). The production function factor intensity parameters for the variable inputs are computed using the following equation which is a direct result of the SGM's profit-maximizing assumption:

$$\alpha_{i,j} = \left(\frac{X_{i,j}}{X_{i,other}}\right)^{\frac{\rho}{\mu}} \frac{P_{0,j}}{P_{0,other}} \qquad i = 1 \ldots N-1 \qquad (7)$$

where,

$\alpha_{i,j}$	=	factor intensity of the ith input in the production of commodity j,
$X_{i,j}$	=	total demand for the ith input in the production of commodity j,
$X_{i,other}$	=	total demand for the ith input in the production of the "other products" commodity,
$P_{0,j}$	=	output price ("price received") of commodity j,
$P_{0,other}$	=	output price ("price received") of the "other products" commodity,
ρ	=	elasticity of substitution parameter,
μ	=	$\rho / (\rho-1)$,
N-1	=	number of variable inputs.

Derivation of Equation (7)

Hotelling's Lemma states that the partial derivative of the profit function with respect to the price of the ith input results in the negative profit-maximizing total factor demand for that input; i.e.,

$$\frac{\partial \pi_s}{\partial P_{i,s}} = - X_{i,s} \qquad (8)$$

where

π_s = total profit in the production of commodity s; i.e.,

[12] This price refers to the price *received* by this sector. The price *paid* is set to 1 (as mentioned in the input price discussion previously) and is the same as the input price for the commodity produced in this sector. As implied, the price received by producers of a commodity is less than the price paid by purchasers of the commodity as long as IBT is positive (i.e., taxes paid in a sector is less than subsidies received).

$$\pi_s = P_{0,s} q_s - \sum_{i=1}^{N-1} P_{i,s} X_{i,s} \tag{9}$$

where

$P_{0,s}$	=	output price (price received) of commodity s,
$P_{i,s}$	=	input price (price paid) of the ith commodity in the production of commodity s,
$X_{i,s}$	=	total demand of the ith input in the production of commodity s,
q_s	=	total output of commodity s,
N	=	number of inputs to production,
N-1	=	number of variable inputs to production (since there is only one fixed factor (capital)).

Evaluating equation (8) using equation (9) and the "single vintage" CES production function defined as,

$$q_s = \alpha_{0,s}\left(\sum_{j=1}^{N-1} \alpha_{i,s} X_{i,s}^{\rho} + \alpha_{N,s} X_{N,s}^{\rho}\right)^{1/\rho} \tag{10}$$

the demand for the ith factor input to the production process can be directly calculated as,

$$X_{i,s} = \left(\alpha_{0,s} P_{0,s} \frac{\alpha_{i,s}}{P_{i,s}}\right)^{\frac{\mu}{\rho}} \left(\frac{Y}{Z}\right)^{\frac{1}{\rho}} \qquad i = 1 \ldots N-1 \tag{11}$$

where, assuming capital is the only fixed factor,

$$Y = \alpha_{N,s} X_{N,s}^{\rho} \tag{12}$$

and

$$Z = 1 - (\alpha_{0,s} P_{0,s})^{\mu} \left(\sum_{i=1}^{N-1} \alpha_{i,s}^{(\mu/\rho)} P_{i,s}^{-\mu}\right) \tag{13}$$

Equation (7) is the result of normalizing Xi,s in equation (11) by dividing by the factor input demand equation for the "Other Products" sector. Note: the aother,s parameter is assumed to be equal to 1 in order to obtain the $\alpha_{i,s}$ parameters in relative terms.

4. As discussed in Step 3, the vintage capital structure of the SGM does not affect the calculation of factor intensity parameters for variable inputs. This vintage capital structure, as designed in Version 0.0 of the SGM, allows for overall efficiency gains in the production process. These overall efficiency gains are incorporated into the scale factor for each vintage, defined as,

$$\alpha_{o,s,v} = \beta_{o,s} * (1+g_s)^{5*v} \tag{14}$$

where

$\alpha_{o,s,v}$ = scale factor in vintage v's production of commodity s;
$\beta_{o,s}$ = overall scale factor in the production of commodity s (constant between vintages);
g_s = Hick's-neutral techological change rate in the production of commodity s;
v = vintage (e.g., v = -3...0 for a sector or subsector whose capital lifetime equals 20 years).

In addition to the calculation of the scale parameter ($\alpha o,s,v$), "vintaging" also affects the calculation of the capital intensity parameter ($\alpha_{N,s}$). As previously discussed, total output in a sector or subsector is described as the summation of vintage production (equations (2) and (3) above). Capital is entered into the production process as separate vintage capital stock; not as a total annualized cost as with the variable inputs to production. Although the capital intensity parameter does not differ between vintages (similar to the variable inputs), due to the vintage capital structure of the SGM, the capital intensity parameter cannot be calculated similar to the variable inputs.

From equation (14), the vintage scale parameter ($\alpha_{0,s,v}$) can be determined given the Hick's-neutral technological change rate and the overall scale factor ($\beta_{o,s}$). Therefore, upon completion of Steps 1 through 3, two parameters still need to be estimated--the overall scale factor ($\beta_{o,s}$) and the capital intensity parameter ($\alpha_{N,s}$). Due to the vintage structure of the production process, these parameters cannot be directly determined; therefore, an iterative process must be applied to solve for $\beta_{o,s}$ and $\alpha_{N,s}$.

The steps involved in this iterative process are as follows:

(1) Choose an initial value for $\beta_{o,s}$.
(2) For each variable factor input, compute $X_{i,s}$ as the total expenditure for the ith input factor in the production of commodity s (value from the IO table) divided by the factor input price ("price paid")[13].
(3) For each variable factor input, calculate $\alpha_{i,s}$ using equation (7).
(4) Solve for $\alpha_{N,s}$ using equation (2) with equation (3); the variables determined in Steps (1) through (3); and assumptions on the elasticity of substitution parameter.
(5) Compute the difference between the actual and estimated input demand for the "other products" commodity in the production of commodity s. The estimated input demand for the "other products" commodity in the production of commodity s is defined as,

$$X_{other,s} = \sum_{v=-V_t}^{0} X_{other,s,v} \tag{15}$$

where

$X_{other,s}$ = estimated input demand for the "other products" commodity in the production of commodity s;

[13] Except for land and labor, input price (price paid) should be equal to 1 in the benchmark year (as previously explained).

$-V_s$ = oldest vintage capital stock for industry s (equal to the negative of the average lifetime of capital for industry s divided by the length of a period (i.e., 5 years) plus 1); and

$X_{other,s,v}$ = estimated input demand for the "other products" commodity in vintage v's production of commodity s defined as,

$$X_{other,s,v} = (\alpha_{0,s,v} P_{0,s} \frac{\alpha_{other,s}}{P_{other,s}})^{\frac{\mu}{\rho}} (\frac{Y}{Z})^{\frac{1}{\rho}} \tag{16}$$

where

$$Y = \alpha_{N,s} X^{\rho}_{N,s,v} \tag{17}$$

and

$$Z = 1 - (\alpha_{0,s} P_{0,s})^{\mu} (\sum_{J=1}^{N-1} \alpha^{\mu/\rho}_{other,s} P^{-\mu}_{other,s}) \tag{18}$$

(6) If the difference computed in Step (5) is sufficiently close to zero (less than a specified convergence criterion), a solution is obtained; otherwise, a search procedure is applied to adjust $\beta_{0,s}$ and Steps (1) through (5) are repeated until a solution is reached.
(7) Once a solution has been found, the factor intensity parameters for each sector are normalized to sum to 100 in order to compare relative intensities between sectors. In addition, estimated production levels and profit rates are verified with actual data from the IO table.
(8) Steps (1) - (7) are repeated for each SGM sector and subsector.

III.b. Computation of Reserves

Upon completion of the CES production function calibration, reserves of depletable resources by vintage for the base year (period 0) are calculated based on estimated levels of production in the depletable resource sectors. Actual total reserves produced in the base year (1985) is available from existing sources, but due to the vintage production structure of the SGM, reserves produced by each vintage need to be estimated. The ratio of actual energy extracted to actual levels of production was used to obtain estimated energy extracted (reserves) from estimated levels of production. The following equation was used to determine vintage reserves of depletable resources produced by each vintage in period 0:

$$Reserves_{j,v} = Q_{j,v}(L_j + 5 * v)\frac{PRDEN_j}{PRD_j} \qquad v = 0 \ldots -3 \tag{19}$$

where

$Reserves_{j,v}$[14] = reserves (in exajoules) of depletable resource j produced by vintage v;
$Q_{j,v}$ = output (in $) of depletable resource sector j produced from vintage v;

[14] Vintage 0 reserves pertain to the amount of resources which will be transferred to reserves in period 0.

L_j	=	lifetime of capital stock in sector j;
$PRDEN_j$	=	total depletable resource extracted of commodity j (exajoules) in period 0[15];
PRD_j	=	actual total production of commodity j (in $ - from IO tables).

III.c. Calibration of the Investment Function

Annual aggregate investment levels in each sector of the SGM is represented by the following functional relationship which is essentially an accelerator from the previous period's total investment levels:

$$I_{t,s} = \alpha_0 I_{t-1,s}(baserate_t)^{\alpha_1} f(\exp(\pi_{t,s}))^{\alpha_2} \tag{20}$$

where

$I_{t,s}$	=	annual level of investment in sector s at time t;
$I_{t+1,s}$	=	annual level of investment in sector s at time t+1;
$baserate_t$	=	underlying growth in the economy affecting investment;
$f(\exp(\pi_{t,s}))$	=	a function of the expected profit rate;
a_0	=	scale coefficient; and
a_1, a_2	=	sensitivity parameters.

In version 0.0 of the SGM, the baserate variable is represented by the growth in potential employment (labor supply) and growth in lagged productivity; specifically,

$$baserate_t = \left(\frac{PE_t}{PE_{t-1}}\right)\left(\frac{\left(\frac{GNP}{E}\right)_{t-1}}{\left(\frac{GNP}{E}\right)_{t-2}}\right) \tag{21}$$

where

PE	=	potential employment (population ages 15 to 64);
GNP	=	gross national product;
E	=	total employment; and
$(GNP/E)_{t-1}$	=	gnp per worker (productivity) at time t-1.

In version 0.0 of the SGM, the function of expected profit is defined as the growth in expected profit ; specifically,

$$f(\exp(\pi_{t,s})) = \frac{\exp(\pi_{t,s})}{\exp(\pi_{t-1,s})} \tag{22a}$$

where

$\exp(\pi_{t,s})$ = the expected profit rate in sector s at time t.

[15] These data were obtained from the Annual Energy Review 1985.

The expected rate of profit can be interpreted as the present value of an average profit rate occuring at the middle of each year for the lifetime of the capital investment; specifically,

$$f(\exp(\pi_{t,s})) = \frac{1}{(1+r+w_s)^{0.5}} \sum_{i=0}^{lifetime_s - 1} \frac{\pi_{t,s}}{(1+r+w_s)^i} \tag{22b}$$

where

r	= the real interest rate (assumed to be 3% in the baseyear);
w_s	= the sector-specific interest rate wedge (representing the additional interest rate risk associated with sector s);
$lifetime_s$	= sector-specific lifetime of capital investment; and
$\pi_{t,s}$	= sector-specific profit rate at time t.

Calibration to the base year

Calibrating sector level investment to the base year involves a two step process. First, in order to obtain the scale and sensitivity parameters (α_0, α_1, α_2) an aggregate investment function (described by equation (20)) was econometrically estimated on the macroeconomy level. Next, these scale and sensitivity parameters were used in each sector-specific investment equation (equation (20) for each sector) to determine sector level investment in the base year. Estimated sector-specific investment levels in period 0 were reconciled with actual investment levels by adjusting the investment wedge parameter for each sector and subsector.

Investment levels at the subsector level are determined separately from sector-level investment. For each sector without subsectors, the investment equation given in equation (20) was calibrated by using the scale and sensitivity parameters which were estimated on an economy-wide scale and adjusting each sector's interest rate wedge until its base year investment level is achieved. Sector-specific variables in the investment equation include lagged investment and the expected profit rate. The base rate variable and the scale and sensitivity parameters are identical across sectors.

In the SGM, investment is determined at the sector level; therefore, investment equations only exist for sectors and not subsectors. Within a sector, investment for each subsector is determined by allocating sector level investment using the following logit share equation:

$$Share_{t,iss} = \frac{(E\,\pi_{t,iss})^{\rho}}{\sum_{iss=1}^{niss} (E\,\pi_{t,iss})^{\rho}} \tag{23}$$

where

$Share_{t,iss}$	= Share of total sector investment allocated to subsector iss;
$E\pi_{t,iss}$	= expected profit rate for subsector iss at time t; and
ρ	= sensitivity parameter.

In order to calibrate the investment equation for a sector with subsectors, aggregate values for the sector-specific variables (i.e., lagged investment and the expected profit rate) within the investment equation are required. Lagged investment at the sector level is obtained by aggregating subsector lagged investment.

As previously stated, once all other variables and parameters in the sector-level investment equation are determined, the sector-specific interest rate wedge was adjusted to reconcile estimated investment with actual investment. To accomplish this task for a sector with subsectors, calibration of the logit share equation was required. From the investment equation, the sector-level expected profit rate was determined directly since all other variables and parameters are known. This sector-level expected profit rate is essentially the denominator of the logit share equation raised to the sensitivity parameter. Since the share of sector investment for each subsector and the sensitivity parameter were known for the baseyear, subsector-specific investment rate wedges are calculated directly from the logit share equation.

III.d. Calibration of Final Demands

The SGM comprises three final demand sectors - government, households, and trade. These final demand sectors consume commodities produced in the nine producing sectors of the SGM and are not producers of any market commodity[16]. Input-output accounting ensures that the amount of commodities produced by the producing sectors is equal to the amount of commodities consumed by the producing and final demand sectors. Calibration of the final demand sectors is performed to ensure equilibrium by choosing final demand parameters which result in an exact replication of the final demand values provided in the baseyear input-output accounts. Details of each final demand sector's calibration process is provided below.

Government Final Demand

Commodities and primary factors of production (e.g., labor, land) are consumed by the government final demand in order to provide government services. Within the SGM, three government services comprise the government final demand sector - education, national defense, and general government which encompasses all other government services. Government expenditures must satisy the following identity:

$$TXtot - S_{gov} = TR_{gov} + \sum_{i=1}^{N} P_i X_{i,gov} \quad (24)$$

where

TX_{tot} = total net tax revenues[17];
S_{gov} = net government savings or, for negative values, net government borrowing;
TR_{gov} = transfer payment by the government;

[16] The government final demand sector produces "government services" which are provided "free of charge" to all sectors of the economy. Therefore, although the government final demand sector produces services, it is not a producer of any market commodity as is the case with producing sectors.
[17] Subsidies are measured as negative taxes.

P_i	=	price paid for input i; and
$X_{i,gov}$	=	government demand for input i.

Equation (24) states that government expenditures (right side of the equation) should not exceed the government's budget constraint (left side of the equation).

Net tax revenue

Net tax revenue in the SGM comprises tax revenue from the following four sources: indirect business tax; corporate income tax; social security tax; and personal income tax. The SGM interprets indirect business tax as the difference between price paid (by consumers of a commodity) and price received (by the producer of a commodity)[18]. Indirect business tax expenditures for each producing sector is provided by the input-output accounts in industry value-added. The SGM calculates indirect business tax revenue by applying an indirect business tax rate to the value of production of each commodity. The following equation is used to calculate the indirect business tax rate for each commodity

$$IBTrate_i = \frac{IBTtot_i}{TO_i - IBTtot_i} \qquad (25)$$

where

$IBTrate_i$	=	indirect business tax rate for commodity i;
$IBTtot_i$	=	total indirect business tax expenditures in the production of commodity i;
TO	=	total output of commodity i.

Combining Equations (6) and (25),

$$IBTrate_i = \frac{1}{P_0} - 1 \qquad (26)$$

Corporate income tax is a tax on corporate profits. The SGM applies an average corporate income tax rate to all producing sectors. This average corporate income tax rate was determined by solving for CITR in the following equation:

$$Total\ Corporate\ Taxes = \sum_{i=1}^{N} IBT_i + \sum_{i=1}^{N} CITR * Profit_i \qquad (27)$$

where

IBT_i	=	total indirect business taxes paid by sector i;
CITR	=	average corporate income tax rate;
$Profit_i$	=	total profits of sector i ("other value added" in the I/O accounts); and
N	=	number of producing sectors.

[18] For all practical purposes, indirect business tax can be interpreted as a sales tax.

Total corporate tax expenditures in 1985 was obtained from the "Economic Report of the President - 1990" and, as previously mentioned, total indirect business tax expenditures and profits for each producing sector was estimated from the 1985 input-output accounts. With knowledge of these data, an average corporate income tax rate can be determined directly from equation (27).

Social security tax is a tax on labor of which half is paid by employers as a tax on labor expenditures while the other half is paid by employees as a tax on earnings. For employers, the social security tax rate was determined using the following equation:

$$SSTR_{employer} = \frac{TLE}{(TLE - TSS / 2)} - 1 \tag{28}$$

where

$SSTR_{employer}$ = social security tax rate for employers (applied to each employer's labor expenditure);
TLE = total labor expenditures across all sectors; and
TSS = total social security tax expenditures across all sectors.

The social security tax rate for both employers and employees was assumed to be equal; therefore, the social security tax rate computed in equation (28) was assumed to be the social security tax rate charged to employees also.

Lastly, the personal income tax is a tax on income earned by consumers. This income includes: (1) labor income after taxes, (2) income from land rents (all land is assumed to be owned by consumers), and (3) corporate profits net of taxes and retained earnings (corporations are assumed to be owned by consumers (i.e., shareholders)). Both total personal income tax paid by consumers and total personal income for 1985 were obtained from the "Economic Report of the President - 1990" allowing an average personal income tax rate to be determined.

Government transfer payments

It was determined that a significant linear relationship exists between total government transfer payments and population. Therefore, a linear regression was conducted on the following equation using total population and total government transfers time series:

$$Total\ government\ transfers = G0 * Population + G1 \tag{29}$$

where

GO, G1 = appropriate empirically determined coefficients.

Government demand for goods and services

The demand for goods and services by the government sector is modeled in the SGM as a constrained optimization problem. Instead of maximizing profit subject to a budget constraint (as is the case with the producing sectors), the objective of the government is to maximize utility subject to the government's budget constraint defined in equation (24). The following CES utility function defined over the three government services is used:

$$GU = \left(\sum_{ss=1}^{NGS} \delta_{ss} G_{ss}^{\mu}\right)^{(1/\mu)} \tag{30}$$

where

GU	=	government utility, an unobservable variable;
G_{ss}	=	the production of government service ss;
δ_{ss}	=	distribution parameter for service ss;
μ	=	elasticity parameter (equal to -0.5); and
NGS	=	number of government services (equal to 3 in SGM Version 0.0).

As discussed in Edmonds, et. al. [1991], the goal of the government sector is to maximize utility (Equation (30)) subject to its budget constraint (Equation (24)). The utility-maximizing production of government service ss is described as:

$$G_{ss} = (TXtot - S_{gov} - TR_{gov}) \beta_{ss} P_{g,ss}^{(\gamma-1)} \left(\sum_{iss=1}^{NGS} \beta_{iss} P_{g,iss}^{\gamma}\right)^{-1} \tag{31}$$

where

β_{ss}	=	δss(-1/(m-1));
γ	=	μ/(μ-1); and

$$P_{g,ss} = \sum_{i=1}^{N} a_{i,g,ss} P_i \tag{32}$$

where

$P_{g,ss}$	=	the cost of the next unit of government service ss;
P_i	=	the price of input i in the production process; and
$a_{i,g,ss}$	=	the amount of input i required to produce government service ss.

The government utility function was calibrated to the base year as follows. First, the $\alpha_{i,g,ss}$ parameters are defined as the ratio of the quantity of input i used in the production of service ss. Therefore, these parameters can be calculated using the input-output account values of each input in the production of government service ss, and the assumed base year prices of these inputs; i.e.,

$$a_{i,g,ss} = \frac{\left(\frac{IO_{i,g,ss}}{P_i}\right)}{\sum_{j=1}^{NIN} IO_{j,g,ss}} \tag{33}$$

where

$IO_{i,g,ss}$	=	value of input i used in the production of government service ss (from the input-output accounts);
P_i	=	price of input i ("price paid"); and
NIN	=	number of inputs.

These $\alpha_{i,g,ss}$ are then used in equation (32) to obtain the value of $P_{g,ss}$ for each government service ss. Once the values of $P_{g,ss}$ are determined, the δ_{ss} parameters in equation (31) can be estimated using an interative process. This process involves minimizing the sum of squared differences between the actual and estimated production of each government service (G_{xx}) by choosing values for the parameters δ_{ss} (substituting $\delta_{ss}^{(-1/(\mu-1))}$ for β_{ss} in equation (31)).

Note: As discussed in Section II.b. above, since the final demand sectors of the I/O table do not include "value added", labor expenditures of the government final demand sectors are found in the row component titled "Government Industry" of the I/O tables. This industry would be included in the SGM "Other Products" sector; therefore, the 1985 "Government Industry" values was separated from government's consumption of the "Other Products" commodity and considered labor expenditures for each of the government final demand sectors.

Similar to the process used to estimate land expenditures for each SGM industry (discussed in Section II.b.), government land expenditures were estimated by applying an average cost of agricultural land to the amount of land used for defense and education obtained from the "Statistical Abstract of the U.S., 1992" published by the Department of Commerce. These land expenditures were then subtracted from government's consumption of the "Other Products" commodity in order to guarantee data consistency.

Net government savings

If positive, net government savings is subtracted from total net tax revenues to obtain the government's budget constraint. In the year 1985, the government (federal, state and local together) ran a budget deficit (implying net government borrowing); therefore, this value would be added to total net tax revenues to obtain the government's budget constraint. Net government savings is calculated for the 1985 base year by subtracting 1985 total government expenditures from total net tax revenue (discussed above). To fund this government deficit, total savings (including personal savings and corporate retained earnings) less total investment was used. Since this amount is not adequate to cover the total government deficit in 1985, the excess was assumed to be funded through a foreign supply of capital. Since this version of the SGM is a closed economy (except for crude oil), the amount of foreign capital supplied was specified exogenously in the SGM's trade component as an import of capital in the base year and is constant through future periods. Since the SGM assumes market equilibrium, no government deficit will exist in future years; but in order to calibrate the SGM to the base year, this exogenous supply of foreign capital is necessary.

Household Final Demand

The SGM assumes that a portion of the households' budget (personal income) is allocated to personal savings while the remainder is used to purchase produced commodities and primary factors of production. Disposable personal income consists of income from wages less taxes on labor; land rents (consumers are assumed to own all usable land) less taxes on land; corporate profits less profits tax and retained earnings; and government transfer payments.

Labor Supply

Household labor supply is estimated in the SGM using the following equation:

$$X_{labor} = WAP * \alpha_{labor} * (1 - e^{\beta_{labor} * P_{labor}}) \qquad (34)$$

where

WAP	= total working age population (ages 15 to 64);
α_{labor}	= the maximum potential share of working age population employed in any given year;
β_{labor}	= a labor supply price responsiveness coefficient; and
P_{labor}	= an average annual wage rate ($M per 1000 persons).

The following steps were taken to calibrate equation (34) to the base year: (1) the total working age population in 1985 was obtained from the "Statistical Abstract of the U.S."; (2) an average annual wage rate was calculated by dividing total labor expenditures (less amount paid in social security tax) in 1985 by total employment in 1985 (in thousands of persons); (3) the maximum potential share of working age population employed in any year was estimated to be 0.90 (or 90% of working age population) which assumes that in any given year 10 percent of the working age population cannot be employed; and (4) the labor supply price responsiveness coefficient was directly calculated from equation (34) given the information in (1) through (3).

Land Supply

Land supply is estimated in the SGM using the following equation:

$$X_{land} = TLA * \alpha_{land} * (1 - e^{\beta_{land} * P_{land}}) \qquad (35)$$

where

TLA	= total surface area potentially available for allocation;
α_{land}	= the maximum potential share of land supplied to the market;
β_{land}	= a land supply price responsiveness coefficient; and
P_{land}	= an average annual rental rate on a unit of land ($M per 1000 km^2).

The following steps were taken to calibrate equation (35) to the base year: (1) total usable surface area (which excludes unusable land such as deserts, marshes, rock, etc) was obtained from the "Statistical Abstract of the U.S." (equal to 8313 km2); (2) an average annual land rental rate was calculated by dividing total land expenditures in 1985 by total usable land area (in thousands of km2); (3) the maximum potential share of land supplied to the market was estimated to be 1 (or 100% of TLA) since TLA represents total usable land area; and (4) the land supply price responsiveness coefficient was directly calculated from equation (35) given the information in (1) through (3).

Household Savings Supply

The following equation is used in the SGM to estimate the supply of household savings:

$$S_{hh} = Y * \alpha_{hhsave} * (1 - \delta_{hhsave} e^{\beta_{hhsave} * r}) \tag{36}$$

where

Y	=	disposable personal income;
α_{hhsave}	=	the maximum potential savings rate;
δ_{hhsave}	=	a scale parameter;
β_{hhsave}	=	the price sensitivity of households to the available interest rate; and
r	=	the real market interest rate.

Equation (36) was calibrated by first assuming that the maximum potential savings rate for the U.S. is equal to 0.20 (i.e., 20% of total disposable personal income) and the real market interest rate is equal to 0.03 (i.e., 3%). With these assumptions and knowledge of the 1985 values for disposable personal income and total personal savings, equation (36) can be written in terms of δ_{hhsave} and β_{hhsave}:

$$\delta_{hhsave} = (1 - \frac{S_{hh}}{Y * \alpha_{hhsave}}) e^{-\beta_{hhsave} * r} \tag{37}$$

In addition, the interest elasticity of savings was assumed to be equal to 0.40. The equation for the interest elastiticity of savings is defined as:

$$\frac{\delta S_{hh}}{\delta r} * \frac{r}{S_{hh}} = (\frac{-\delta_{hhsave} \beta_{hhsave} e^{\beta_{hhsave} * r}}{(1 - \delta_{hhsave} e^{\beta_{hhsave} * r})}) * r = 0.40 \tag{38}$$

Combining equations (37) and (38), values for dhhsave and bhhsave can be determined.

Household Demand for Final Products

Household demand for the primary factors land and labor are computed separately from demands for other goods and services. Household demand for land is defined as:

$$X_{land,hh} = NHH \; \alpha_{land,hh} \; P_{land} \tag{39}$$

where

$\alpha_{land,hh}$	=	the household land intensity factor;

P_{land} = the price of land; and
NHH = the number of households (in 1000s) which is defined as,

$$NHH = \frac{TOTPOP}{\beta_{hh}} \tag{40}$$

where

TOTPOP = total population (in 1000s); and
β_{hh} = the average number of people per household.

Equation (40) was calibrated to the base year (1985) by solving for β_{hh} using 1985 actual values for NHH and TOTPOP. Similarly, equation (39) was calibrated to the base year by solving for $\alpha_{land,hh}$ using estimated 1985 household demand for land (discussed in Section II.b.); 1985 price of land (discussed in Section III.a.); and the estimated 1985 value for NHH from equation (40).

Similar to the process used to estimate land expenditures for each SGM industry (discussed in Section II.b.), household land expenditures were estimated by applying an average cost of agricultural land to a portion (assumed to be 75%) of urban and transportation land obtained from the "Statistical Abstract of the U.S., 1992" published by the Department of Commerce. These land expenditures were then subtracted from household's consumption of the "Other Products" commodity in order to guarantee data consistency.

Household demand for labor is defined as:

$$X_{labor,hh} = X_{labor} \; \alpha_{labor,hh} \; P_{labor} \tag{41}$$

where

$\alpha_{labor,hh}$ = the household labor intensity factor;
P_{labor} = the price of labor; and
X_{labor} = total labor supply (in 1000s).

Equation (41) was calibrated to the base year by solving for $\alpha_{labor,hh}$ using estimated 1985 household demand for labor; 1985 price of labor (discussed in Section III.a.); and the estimated 1985 total labor supply from equation (34).

Since the final demand sectors of the I/O table do not include "value added", labor expenditures of the household final demand sector is found in the row component titled "Household Industry" of the I/O tables. This industry would be included in the SGM Everything Else sector; therefore, the 1985 "Household Industry" value was separated from household's consumption of the Everything Else commodity and considered labor expenditures for the household final demand sector.

Household demand for other goods and services are estimated as follows:

$$Xd_{i,hh} = \alpha_{i,hh} \; P_i^{\beta_{i,hh}} \; Y_c^{\gamma_{i,hh}} \left(\frac{1}{\lambda}\right) \tag{42}$$

$$Y_c = Y - S_{hh} - X_{land,hh} \; P_{land} - X_{labor,hh} \; P_{labor} \tag{43}$$

where

$Xd_{i,hh}$	= household demand for good i;
$\alpha_{i,hh}$	= the household demand intensity factor for good i;
$\beta_{i,hh}$	= the household price elasticity of demand for good i;
Y_c	= total value of consumption which is defined as,
$\gamma_{i,hh}$	= the household income elasticity of demand for good i; and

$$\lambda = \sum_{i=1}^{NS} \alpha_{i,hh} \; P^{\beta_{i,hh}+1} \; Y_c^{\gamma_{i,hh}-1} \tag{44}$$

Table 3 contains the household price and income elasticities used in the SGM which were obtained from existing literature.

Table 3

	Price Elasticity	Income Elasticity
Agriculture	-0.28	0.30
Everything Else	-1.00	1.10
Crude Oil	N/A	N/A
Natural Gas	N/A	N/A
Coal	-0.82	0.89
Biomass	N/A	N/A
Uranium	N/A	N/A
Electricity	-0.82	0.89
Refined Oil	-0.82	0.89
Gas T&D	-0.82	0.89

N/A: commodity not consumed by the household sector.

Except for values of $\alpha_{i,hh}$, 1985 values of all the variables in equation (41) were determined as follows: (1) 1985 household demand for each good was obtained from the input-output accounts; (2) as previously discussed, all prices (except land and labor) were assumed to be 1 in the base year; (3) Since the 1985 values all of the components of equation (43) are either known or have been previously calculated, the total value of consumption (Y_c) can be determined. With these values determined, the values of $\alpha_{i,hh}$ can be calculated from equation (42).

Trade

As previously discussed, Version 0.0 of the SGM assumes a closed economy (i.e. zero trade) for all goods except crude oil. For calibration purposes, it is necessary to exogenously add 1985 net exports to demand and supply in order to replicate the 1985 base year values. Net exports for all tradeable commodities[19] (except Crude Oil and Other Products) are held constant at 1985 values for each period in the model. Net exports in the Crude Oil sector are set at 1985 values from the I/O tables for the base year, but are allowed to change in future periods; making up for the difference in domestic excess demand for crude oil. The SGM assumes balanced trade and implements this constraint by making up for any trade imbalances in the Other Products sector; therefore, a trade deficit would be set to zero by an equal amount in export demand for the Other Products commodity.

[19] In the SGM, "tradeable" commodities refer to those commodities which could be traded and in Version 0.0 include all commodities except electricity, land, and labor.

BIBLIOGRAPHY

Bacharach, Michael (1971), *Bi-proportional matrices and input-output change*, Cambridge, Cambridge University Press.

Ballard, Charles L, Don Fullerton, John B. Shoven, John Whalley (1985), *A General Equilibrium Model for Tax Policy Analysis*, National Bureau of Economic Research, The University of Chicago Press.

Chipman, John S. (1991), Introductory Statement at the Round Table: " The Payoff of Investment in CGE-Modelling," Workshop on *Issues in International Economics: Questions to and Answers from Computable General Equilibrium Analysis*, 9 July 1991, University of Konstanz.

Edmonds, J.A.; Pitcher, H.M.;Barns, D.;Baron, R.;Wise, M.A.; (1991),"Modeling Future Greenhouse Gas Emissions: The Second Generation Model Description," *United Nations University Conference on Global Change and Modelling*, October, 1991, Tokyo, Japan.

Mansur, A.H. and J. Whalley (1984) "Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration and Data." In H.E. Scarf and J.B. Shoven (eds.) *Applied General Equilibrium Analysis*. Cambridge: Cambridge University Press.

Miller R.E. and P.D. Blair (1985) *Input-Output Analysis: Foundations and Extensions*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

St-Hilaire, France, and John Whalley (1983), "A Microconsistent Equilibrium Data Set for Canada for Use in Tax Policy Analysis," *Review of Income and Wealth*, 29 (June), 175-204.

U.S. Department of Commerce, Bureau of Economic Analysis (1987), *Fixed Reproducible Tangible Wealth in the United States*, 1925-85, Washington D.C., Government Printing Office.

U.S. Department of Commerce, Bureau of Economic Analysis (1990), "Annual Input-Output Accounts for the U.S. Economy, 1985", *Survey of Current Business*, Washington D.C.

U.S. Department of Commerce, Bureau of Economic Analysis (1991), *Benchmark Input-Output Accounts for the U.S. Economy*, 1982, Washington D.C., Government Printing Office.

U.S. Department of Commerce, Bureau of Census (1992), *Statistical Abstract of the United States*, Washington, D.C., Government Printing Office.

U.S. Executive Office of the President, Office of Management and Budget, *Standard Industrial Classification Manual*, 1987, Washington, D.C.

U.S. Government Printing Office (1992), *Economic Report of the President*, Washington, D.C.

Model Description: CETM

Background. The Carbon Emissions Trade Model (CETM), developed by Charles River Associates, is a composite model formed of a macroeconomic general equilibrium model of international trade (called MACRO) and an engineering (partial equilibrium) model of the energy sector (called ETA). Prices and quantitites and demand functions are passed between MACRO and ETA and iterating until input reference quantities from ETA are identical (within a specified error tolerance) to the solution quantities in MACRO. ETA is a modified version of the energy supply submodel from Manne and Richels' MERGE model.

Basics. The regions and time periods for the ETA and MACRO models are identical; the commodities, however, are different. CETM has 9 geopolitical regions: the United States, Japan, CANZ (Canada, Australia, and New Zealand), O-OECD (the other OECD nations), China, India, Eastern Europe and the Former Soviet, MOPEC (Mexico and OPEC), and the ROW. MACRO has an exogenous benchmark year of 1992 and ETA has a 1990 base year, but both solve in 10-year time periods from 2000 to 2100.

Dynamics. MACRO has 5 internationally traded commodities, 4 energy-intensive and 1 non-energy-intensive: non-ferrous metals, pulp and paper, transport industries, other energy intensive sectors, and other manufacturers and services (the aggregate non-energy-intensive sector). Electric energy is produced from the following technologies: hydro-electricity, natural gas, oil, coal, advanced high cost, and advanced low cost. Non-electric energy can be produced via a carbon free backstop, renewables, synthetic fuels (i.e., tar sands), oil, gas, and coal. ETA is a partial equilibrium of the energy sector, where demand for energy is a constant elasticity of demand function calibrated to MACRO. ETA has 4 internationally traded commodities: oil, gas, coal, and carbon rights; however, trade is subject to fixed marginal trade costs and upper bounds on permissable imports and exports.

Fine print. Business as usual GDP growth rates are taken from MERGE. ETA incorporates 3 constraints: 1) there are exhaustion constraints for natural gas and oil, 2) new technologies (advanced high cost and advanced low cost, synthetic fuels, renewables, and the non-electric backstop) are subject to expansion limits, and 3) there are decline limits on both new and existing technologies. The decline limits are expressed as exponential decay where a certain percentage of the existing stock can be retired each year. CETM assumes an AEEI of about 0.9% per year for the OECD and about 1% per year for the non-OECD countries. Trade is represented with an Armington elasticity of 2 for the aggregate good and 4 for all other goods: Imports are imperfect substitutes for domestically producted goods. As for fossil fuels, all regions are assumed to produce the same product. The cross elasticity of substitution between energy and non-energy inputs to production is 0.5. Materials inputs are complements; all other inputs are substitutes. All prices are in 1992 constant dollars.

Model Description: MRT

Background. The general equilibrium, multi-regional trade (MRT) model was developed by Charles River Associates to estimate the changes in international terms of trade which could result from carbon dioxide restrictions placed on a subset of countries. MRT is one of 2 compatible but separate models that compose the International Impact Assessment Model (IIAM). The companion model to MRT is a general purpose, partial equilibrium, open economy model that is used to study the implications of changes in international prices (provided by MRT) for any individual country. There is a one-way link between the MRT and the single country open economy (SOE) models.

Basics. MRT has 5 geopolitical regions: the OECD (OECD), Non-OECD Asia (ASIA), Eastern Europe and the Former Soviet Union or Centrally Planned Emerging Economies (CPEE), Middle East and North Africa (MIDE), and the ROW (ROW). The model solves for the benchmark year 1992, and then solves in 5 year intervals spanning the horizon from 2000 to 2030. The year 2000 is the first endogenous year. MRT is a Ramsey growth model with fully dynamic, forward looking investment behavior. It also allows for international trade in all goods and capital flows. Savings and investment behavior determines the level of capital flows.

Dynamics. There are 6 commodities: four fuels (oil, coal, natural gas, and a carbon-free backstop energy source), a savings good, and a non-energy macro-good (aggregate macro output). Regions trade crude oil, natural gas, and coal freely at a price determined by the interfuel supply and demand conditions. Therefore, all fuels are traded internationally under each fuel's world price. Depletion is assumed to lead to rising fossil fuel prices under constant demand. But the relation between depletion effects on the supply of oil, gas, and coal, and the actual supply of these fuels are ignored. That is, the model does not keep a record of the current stock of each fuel in the time period. World supply and demand determine the world price of fossil fuels. Current energy taxes and subsidies are included in each country's energy prices. The carbon-free backstop establishes an upper bound on the world fossil fuel prices. This backstop fuel is a perfect substitute for the 3 fossil fuels and is available in infinite supply at one price, which is calculated to be a multiple (factor of 6) of the countries' fossil fuel price in the benchmark year (1992).

Fine print. The base year is 1992, and all prices are in 1992 constant dollars. MRT assumes an AEEI of 0.7. The baseline level world emissions growth path is taken to be the IPCC's reference scenario IS92A, which projects worldwide CO2 emissions to growth from 6.0 billion metric tonnes in 1990 to 10.7 billion by 2025. Benchmark data for energy prices and quantitites are from the IEA. All non-energy data is from the 1995 GTAP database at Purdue University. Trade is represented with an Armington elasticity of 1.5 for all goods: Imports are imperfect substitutes for domestically producted goods. As for fossil fuels, all regions are assumed to produce the same product. The oil price supply elasticity is 8. The end-use demand elasticity (a.k.a. the elasticity of substitution between energy and other factors of production) is assumed to double over the model's 30 year time horizon; OECD countries start with a value of 0.25, non-OECD countries begin at 0.2. The interfuel elasticity is 1; however, the backstop fuel costs 6 times the 1992 fossil fuel energy aggregate. MRT currently only handles CO2, but Charles River Associates is considering adding the other gases at a later date. MRT does not address sinks or the clean development mechanism/JI. Concerning "hot air" or "paper tons" in Russia and Eastern Europe, MRT uses forecast emissions from DOE.

POLICY FORUM

Uncertainties in Projections of Human-Caused Climate Warming

J. D. Mahlman

Mankind's activities have increased carbon dioxide (CO_2) in the atmosphere. This increase has the potential to warm the earth's climate by the "greenhouse effect" (*1*) in which CO_2 absorbs infrared radiation and then re-radiates it back toward the surface of the planet. Other gases also act as greenhouse gases and may warm the climate even further (*2*), although human-produced airborne sulfate particles can cause cooling that offsets some of the warming (*3*). Computational models that include these factors predict that the climate will warm significantly over the next century.

These forecasts of likely climate changes have forced a realization that it is necessary to reduce human-caused emissions of greenhouse gases. But because of the potential social disruptions and high economic costs of such reductions, vigorous debate has arisen about the size and nature of the projected climate changes and whether they will actually lead to serious impacts.

A key element of these spirited—and often acrimonious—debates is the credibility (or lack thereof) of the mathematically and physically based climate models (*4*) that are used to project the climate changes resulting from a sustained buildup of atmospheric CO_2. Some skeptics ask, to put it bluntly, why should we believe such models' attempts to describe changes in such a dauntingly complex system as Earth's climate? The cheap answer is that there are no credible alternatives. But the real answer is that the climate models do a reasonably good job of capturing the essence of the large-scale aspects of the current climate and its considerable natural variability on time scales ranging from 1 day to decades (*4*). In spite of these considerable successes, the models contain weaknesses that add important uncertainty to the very best model projections of human-induced climate changes.

I express here a "policy-independent" evaluation of the levels of current scientific confidence in predictions emanating from climate models. This climate model uncertainty is distinct from the high social uncertainty associated with future scenarios of greenhouse gas and airborne particle concentrations. I assume that detailed future greenhouse and airborne particle scenarios are part of the policy question and thus do not discuss them further.

The author is at the Geophysical Fluid Dynamics Laboratory, National Oceanic and Atmospheric Administration, Princeton University, Princeton, NJ 08542, USA. E-mail: jm@gfdl.gov

A fair-minded and exhaustive attempt to find a broad consensus on what science can say about this problem is contained in the most recent 1996 IPCC Working Group I Assessment (*3*). Some of my evaluations differ in detail from those of IPCC 1996, mostly because of the addition of new research insights and information since 1994. A good guideline for evaluating contrary "expert" opinions is whether they use the IPCC science as a point of departure for their own analysis. In effect, if we disagree scientifically with IPCC, we should explain why. Without such discipline, contrary arguments are not likely to be scientifically sound.

Virtually Certain "Facts"

These key aspects of our knowledge of the climate system do not depend directly on the skill of climate model simulations and projections:

■ Atmospheric abundances of greenhouse gases are increasing because of human activities.

■ Greenhouse gases absorb and re-radiate infrared radiation efficiently. This property acts directly to heat the planet.

■ Altered amounts of greenhouse gases affect the climate for many centuries. The major greenhouse gases remain in the atmosphere for periods ranging from a decade to centuries. Also, the climate itself has considerable inertia, mainly because of the high heat capacity of the world ocean.

■ Changes in other radiatively active substances offset somewhat the warming effect of increased greenhouse gases. Observed decreases in lower stratospheric ozone and increases in sulfate particles both produce cooling effects. The cooling effect of sulfate particles remains insufficiently quantified.

■ Human-caused CO_2 increases and ozone decreases in the stratosphere have already produced more than a 1°C global average cooling there. This stratospheric cooling is generally consistent with model predictions.

■ Over the past century, Earth's surface has warmed by about 0.5°C (±0.2°C).

■ The natural variability of climate adds confusion to the effort to diagnose human-induced climate changes. Apparent long-term trends can be artificially amplified or damped by the contaminating effects of undiagnosed natural variations.

■ Significant reduction of key uncertainties will require a decade or more. The uncertainties concerning the responses of clouds, water vapor, ice, ocean currents, and specific regions to increased greenhouse gases remain formidable.

I further illustrate these climate uncertainties using two extrapolations of the IPCC idealized scenarios of increases of 1% equivalent atmospheric CO_2 concentration per year (*5*). The first case levels off at a CO_2 doubling after 70 years; the second levels off at a CO_2 quadrupling after 140 years. Both correspond to simple extrapolations of current trends in greenhouse gas emissions. Considering the long residence time of CO_2 at such large concentrations, these leveled-off scenarios are physically plausible but are presented as illustrations, not as social predictions.

Virtually Certain Projections

These projections have a greater than 99 out of 100 chance of being true within the predicted range (*6*):

■ The stratosphere will continue to cool significantly as CO_2 increases. If ozone continues to decrease, the cooling will be magnified. There is no known mechanism to prevent the global mean cooling of the stratosphere under these scenarios.

■ Global mean amounts of water vapor will increase in the lower troposphere (0 to 3 km) in approximately exponential proportion (roughly 6% per 1°C of warming) to the global mean temperature change. The typical relative humidities would probably change substantially less, in percentage terms, than would water vapor concentrations.

Very Probable Projections

These projections have a greater than 9 out of 10 chance of being true within the predicted range:

■ The global warming observed over the past century is generally consistent with *a posteriori* model projections of expected greenhouse warming, if a reasonable sulfate particle offset is included. It is difficult, but not impossible, to construct conceivable alternate hypotheses to explain this observed warming. Using variations in solar output or in natural climate to explain the observed warming can be appealing, but both have serious logical inconsistencies.

■ A doubling of atmospheric CO_2 over preindustrial levels is projected to lead to an equilibrium global warming in the range of 1.5° to 4.5°C. These generous uncertainty brackets reflect remaining limitations in modeling the radiative feedbacks of clouds, details of the changed amounts of water vapor in the upper troposphere (5 to 10 km), and responses of sea ice. In effect, this means that there is roughly a 10% chance that the actual equilibrium warming caused by doubled atmospheric CO_2 levels could be lower than 1.5°C or higher than 4.5°C. For the answer to lie outside these bounds, we would have to discover a substantial surprise beyond our current understanding.

- Essentially all climate models predict equilibrium global temperature increases that are nearly linear in the logarithm of CO_2 changes. This effect is mainly due to increasing saturation of many of the infrared absorption bands of CO_2. That is, a quadrupling of CO_2 levels generally produces projected warmings that are about twice as large as those for doubled CO_2.
- Models predict that by the year 2100, global mean surface temperature changes under these two idealized scenarios would be 1.5° to 5°C.
- Sea level rise could be substantial. The projections of 50 ± 25 cm by the year 2100, caused mainly by the thermal expansion of sea water, are below the equilibrium sea level rise that would ultimately be expected. After 500 years at quadrupled CO_2 levels, the sea level rise expected due to thermal expansion alone is roughly 2 ± 1 m. Long-term melting of landlocked ice carries the potential for considerably higher values but with less certainty.
- As the climate warms, the rate of evaporation must increase, leading to an increase in global mean precipitation of about 2 ± 0.5% per 1°C of global warming.
- By 2050 or so, the higher latitudes of the Northern Hemisphere are also expected to experience temperature increases well in excess of the global average increase. In addition, substantial reductions of northern sea ice are expected. Precipitation is expected to increase significantly in higher northern latitudes. This effect mainly occurs because of the higher moisture content of the warmer air as it moves poleward, cools, and releases its moisture.

Probable Projections

The following have a greater than two out of three chance of being true:

- Model studies project eventual marked decreases in soil moisture in response to increases in summer temperatures over northern mid-latitude continents. This result remains somewhat sensitive to the details of predicted spring and summer precipitation, as well as to model assumptions about land surface processes and the offsetting effects of airborne sulfate particles in those regions.
- Climate models imply that the circum-Antarctic ocean region is substantially resistant to warming, and thus little change in sea-ice cover is predicted to occur there, at least over the next century or two.
- The projected precipitation increases at higher latitudes act to reduce the ocean's salinity and thus its density. This effect inhibits the tendency of the water to sink, thus suppressing the overturning circulation.
- Very recent research (7) suggests that tropical storms, once formed, might tend to become more intense in the warmer ocean, at least in circumstances where weather and geographical (for example, no landfall) conditions permit.
- Model studies project that the standard deviations of the natural temperature fluctuations of the climate system would not change significantly. This indicates an increased probability of warm weather events and a decreased probability of cold events, simply because of the higher mean temperature.

Incorrect Projections and Policy Implications

There are a number of statements in informal writings that are not supported by climate science or projections with high-quality climate models. Some of these statements may appear to be physically plausible, but the evidence for their validity is weak, and some are just wrong.

There are assertions that the number of tropical storms, hurricanes, and typhoons per year will increase. That is possible, but there appears to be no credible evidence to substantiate such assertions.

Assertions that winds in midlatitude (versus tropical) cyclones will become more intense do not appear to have credible scientific support. It is theoretically plausible that smaller-scale storms such as thunderstorms or squall lines could become stronger under locally favorable conditions, but the direct evidence remains weak.

There is a large demand for specific climate change predictions at the regional and local scales where life and life support systems are actually affected. Unfortunately, our confidence in predictions on these smaller scales will likely remain relatively low. Much greater fidelity of calculated local climate impacts will require large improvements in computational power and in the physical and biological sophistication of the models. For example, the large uncertainty in modeling the all-important responses of clouds could become even harder at regional and local levels. Major sustained efforts will be required to reduce these uncertainties substantially.

Characterizations of the state of the science of greenhouse warming are often warped in differing ways by people or groups with widely varying sociopolitical agendas and biases. This is unfortunate because such distortions grossly exaggerate the public's sense of controversy about the value of the scientific knowledge base as guidance for the policy deliberation process.

It is clear that much is known about the climate system and about how that knowledge is expressed through the use of physically based coupled models of the atmosphere, ocean, ice, and land surface systems. This knowledge makes it obvious that human-caused greenhouse warming is not a problem that can rationally be dismissed or ignored. However, the remaining uncertainties in modeling important aspects of the problem make it evident that we cannot yet produce a sharp picture of how the warmed climate will proceed, either globally or locally.

None of these recognized uncertainties can make the problem go away. It is virtually certain that human-caused greenhouse warming is going to continue to unfold, slowly but inexorably, for a long time into the future. The severity of the impacts can be modest or large, depending on how some of the remaining key uncertainties are resolved through the eventual changes in the real climate system, and on our success in reducing emissions of long-lived greenhouse gases.

References and Notes

1. The greenhouse effect for CO_2 was first calculated over 100 years ago by S. Arrhenius, *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* **41**, 237 (1896).
2. Intergovernmental Panel on Climate Change, *Climate Change, the IPCC Scientific Assessment*, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1990).
3. Intergovernmental Panel on Climate Change, *Climate Change 1995, The Science of Climate Change*, J. T. Houghton *et al.*, Eds. (Cambridge Univ. Press, Cambridge, 1996).
4. Climate models are mathematically based models that attempt to calculate the climate, its variability, and its systematic changes on a first-principles basis. The fundamental equations solved are the conservation of mass, momentum, and energy. The interactions among the atmosphere, ocean, ice, and land surface systems are calculated on rather widely separated computational points on Earth (typical spacings are 200 to 400 km in the horizontal and 1 to 3 km in the vertical).
5. S. Manabe and R. J. Stouffer, *Nature* **364**, 215 (1993); *J. Clim.* **7**, 5 (1994).
6. The approach used here was tested and challenged in E. Barron, *Forum on Global Change Modeling, U.S. Global Change Research Program Report 95-02* (U.S. Global Change Research Program, Washington, DC, 1995). Earlier evaluations were published in J. D. Mahlman, *Climate Change and Energy Policy*, L. Rosen and R. Glasser, Eds. (American Institute of Physics, Los Alamos National Laboratory LA-UR-92-502, New York, 1992) and in J. D. Mahlman, U.S. Congressional Record, 16 November 1995, House Science Committee Hearing on Climate Models and Projections of Potential Impacts on Global Climate Change (1995).
7. T. R. Knutson, R. E. Tuleya, Y. Kurihara, in preparation.

tured set of donors. Once the DNA has been sampled, however, all personal and racial data will have to be removed to protect privacy—diminishing the scientific value of the project, but bolstering its ethical foundation.

Where those samples would come from—and how to ensure that donors have given appropriate consent and that their privacy is safeguarded—prompted the most intense debates. NHGRI staffers had set their hopes on getting a set of ready-made cell lines containing DNA from a broad sample of the U.S. population, created by the National Center for Health Statistics (NCHS). From 1989 to 1994, that agency's National Health and Nutrition Examination Survey (NHANES) collected blood from more than 17,000 representative individuals around the country to obtain a snapshot of the health of the U.S. population. Karen Steinberg of the Centers for Disease Control and Prevention later converted more than 8000 of these samples into immortalized cell lines. But Chakravarti warned that "it is not a done deal" that genome researchers would be allowed use this material. The reason: Because DNA studies had not been foreseen, NHANES staff did not ask the donors for permission to put their DNA in a database.

Managers of the NHANES data asked their human subject research panel for guidance on this issue more than a year ago. In September, the panel said it would be acceptable to run some health studies on the cell lines, but only if the samples were made completely anonymous by stripping them of all identifiers (*Science*, 21 November, p. 1389). Edward Sondik, director of the NCHS, has interpreted this ruling to mean that DNA data from these samples cannot be put in a database—even with anonymous identifiers—without consent, because a third party who knows the name and genes of an individual might still be able to ferret out unique genetic information.

But the prospect of asking for fresh consent from donors concerned NHANES officials. As Diane Wagener of NCHS explained, they worry that if people receive a letter informing them that their DNA has already been immortalized in cell lines and requesting approval for hard-to-understand genetic studies, they might say, "I don't want to have anything to do with [NHANES]."

As the cell lines seemed to become less accessible by the hour, an annoyed Collins declared that, after months of discussion, "I am very troubled to learn that there still doesn't seem to be a clear answer" about whether they can be used. After a coffee break, Sondik announced that 600 DNA samples that are not part of the primary NHANES set will be made available for the SNP project, and possibly a small fraction of the primary set, as well. Consent will have to be obtained from the donors, only 75% of whom are expected to be reachable through old addresses. But even with a strong response, the NHANES contribution will not be enough. For example, it is short on Asian and Native American DNA. NHGRI will therefore have to find other donors, perhaps among patients in ongoing NIH projects.

The NHANES samples will, at least, allow the SNP project to get started. Now NHGRI staffers must lay out the technical parameters, the sequencing goals, deadlines, and cost limitations. They hope to complete all of this by January. Then, if the whole scheme doesn't run into a wall, the genome community will witness a brand-new competition in gene discovery.

–**Eliot Marshall**

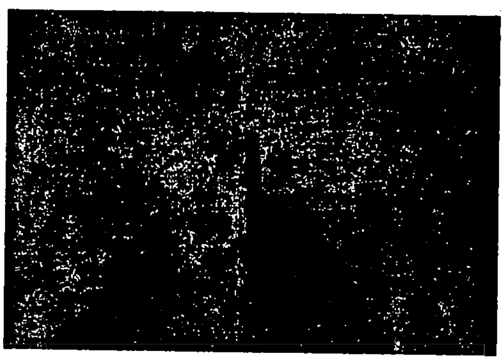
CLIMATE CHANGE

Thirty Kyotos Needed to Control Warming

When exhausted delegates emerged from round-the-clock negotiations in Kyoto, Japan, last week with a global agreement to curb emissions of heat-trapping gases, some observers hailed the deal as a diplomatic miracle. Climate scientists say, however, that it will be miraculous indeed if the Kyoto pact—which calls for 38 industrialized nations to cut their emissions by an average of 5.2% from 1990 levels by 2012—even temporarily slows the accumulation of warming gases in the atmosphere. The cuts are too small and are likely to be overwhelmed by developing nations, they say. "It is a laudable and reasonable first step," says Jorge Sarmiento of Princeton University, "but much deeper emissions cuts will be needed in the not too distant future if we are going to meaningfully reduce the rate of warming."

If approved by major industrialized nations such as the United States and Japan—and that is far from certain—the new Kyoto Protocol to the 1992 Climate Change Treaty could reduce emissions of six greenhouse gases, including carbon dioxide, methane, and nitrous oxide. The United States—the world's leader in greenhouse emissions, with 25% of the total—agreed to a 7% cut from 1990 levels by 2012, while the 15 nations of the European Union committed themselves to an 8% reduction and Japan to 6%. If the cuts are achieved, industrialized nations will reduce their collective greenhouse emissions to two-thirds of what they would be in 2012 without action, according to the United Nations.

Even this significant reduction, however, won't prevent total global greenhouse emissions from rising, analysts predict. The cuts will be swamped early in the next century by increases in emissions from developing nations, such as China and India, which successfully resisted being bound by the protocol. For example, China, currently in second place, is expected to overtake the United States as the world's leading emitter of carbon dioxide within decades, as it burns more of its massive coal reserves. From 1990 to 2015, the U.S. Energy Information Administration predicts, carbon dioxide emissions from developing countries—including Russia and Eastern European nations—will nearly double, and will account for 58% of the global total even if industrial countries do not cut back.


PHIL BORDEN/PNI

Haze over Beijing. Emissions from developing nations like China could overwhelm Kyoto cuts.

At that rate, the 1992 treaty will not achieve its major objective—stabilizing atmospheric concentrations of carbon dioxide—says Tom Wigley, a climate researcher at the National Center for Atmospheric Research in Boulder, Colorado. Currently, carbon dioxide levels stand at about 360 parts per million (ppm), up from preindustrial levels of 280 ppm. Computerized climate models created by Wigley and others suggest that concentrations will at least double by 2100 unless developing nations hold their emissions steady and industrial nations progressively reduce emissions by roughly half.

"A short-term target and timetable, like that adopted at Kyoto, avoids the issue of stabilizing concentrations entirely," Wigley says. As a result, it will at best delay the predicted warming trend by just a few decades. Jerry Mahlman, director of the Geophysical Fluid Dynamics Laboratory at Princeton, adds that "it might take another 30 Kyotos over the next century" to cut global warming down to size.

Still, says Sarmiento, "you have to start somewhere, and the protocol at least provides a framework for revisiting the issue as our understanding improves."

–David Malakoff

David Malakoff is a writer in Bar Harbor, Maine.

DEPARTMENT OF THE TREASURY
WASHINGTON, D.C. 20220

October 22, 1997

MEMORANDUM TO: DEPUTY SECRETARY SUMMERS

FROM: JONATHAN GRUBER

RE: **Responses to Your Questions on Climate Change**

You had asked nine questions related to the economic analysis of the administration's climate change proposal:

Variation in Gas and Energy Prices Over Time

Depending on the ultimate rise in carbon permit prices, the increase in gasoline prices expected from the President's plan may be no larger than the normal month-to-month and year-to-year variation in these prices.

Retail gasoline prices vary considerably from one month to the next. For example, in November 1995, new rules requiring oxygenated fuels in the winter months went into effect in Washington and several other metropolitan areas. This caused the price of gasoline at the pump in the Washington area jumped by 10 cents per gallon overnight – an increase equivalent to a $40 per ton carbon tax, yet few consumers noticed. In the same way, the seasonal increase in summertime demand raises gasoline prices by several cents per gallon for several months each year.

Year-to-year changes have often been greater than the price change expected to result from the President's plan. We attach to this memo (**TAB A**) a graph of gas and energy prices since 1970, as well as a printout of the underlying data points.

- The table shows: real gas prices; the year to year change; the energy price index; and the year to year percentage change in that index.

- The average of the absolute value of year to year changes since 1970 for gas prices is 11 cents; this is equivalent to the gas price increase from a $42/ton price of carbon. There are five years over this period in which price changes exceeded 26 cents, or the equivalent of $100/ton

- The average from 1983 to 1997 is 8 cents, equivalent to a $31/ton price of carbon; there is only one large change overthis period.

- The changes in overall energy prices is much less pronounced year to year, and does not seem to make the point as well.

Moreover, the effects of the President's plan would not all be felt in one year, further dampening the effect on prices.

We should note, however, that this argument *appears to contradict the comparison you have drawn with the OPEC oil shocks throughout the internal Administration debate.*

Historical Perspective on Energy and Resource Utilization

After both oil shocks, we heard predictions of the catastrophes that lay ahead -- oil prices would continue to climb, and the economy would crash. For example:

- On March 31, 1979, President Carter said, "There is a dwindling supply of energy sources. Prices are going to rise in the future no matter which party occupies the administration in Washington, no matter what we do." Actually, prices then fell for five straight years, from 1981 through 1986. In 1982, the economy launched its longest postwar expansion, which continues today, 15 years later. The Clinton Administration's climate policy is not expected to have nearly the effect on energy prices than the oil shocks.

- The 1972 bestseller, *The Limits to Growth,* contained dire predictions of impending resource depletion: the world would run out of gold by 1981, mercury by 1985, tin by 1987, zinc by 1990, **petroleum by 1992**, and copper, lead, and natural gas by 1993. None of these predictions came true; indeed the real prices of natural resources have been steadily dropping.

We attach (**TAB B**) a list of other recent resource forecasts that turned out to be very wide of the mark.

Detailed Evaluation of the Emissions Implications of Electricity Restructuring

We attach to this memo (**TAB C**) a draft memo from the Energy Department on carbon emissions implications of restructuring, including the administration add-ons of the RPS, the Public Benefits Fund, and green marketing. Under pressure from EPA, the Energy Department has presented a broad estimate, ranging from an emissions increase of 20 MMT to an emissions reduction of 84 MMT. This consists of a narrower range of effects of retail restructuring itself (-25 to +33 MMT), along with modest impacts of administration add-ons (-36 to -13 MMT). The consensus among economics experts such as Paul Joskow is that the *best guess for the long run is a small emissions reduction* (on the order of 20-40 MMT).

Relative to trend emissions in this sector, *this consensus is plausible.* Current emissions in the electric sector are 506 MMT, projected to rise to 626 MMT in 2010. So the consensus estimate of a 20-40 MMT reduction represents a reduction in emissions growth of one-sixth to one-third; even the upper bound estimate would have emissions growing by almost 10% above today's level.

The Potential for Worldwide Trading

We attach to this memo (**TAB D**) a qualitative analysis describing the great potential of international cooperation for reducing carbon abatement costs. In particular, the attachment discusses how the energy inefficiency and greater expected growth of non-OECD countries make joint implementation (JI) and permit trading important avenues for reducing costs. We note in particular that a World Bank study suggests that emissions reductions in China before 2020 could save roughly as much in carbon emission as the U.S. would have to reduce to achieve 1990 levels by 2010. Anecdotal evidence describes the untapped potential for efficiency gains in developing and transitional economies and also highlights the success of JI pilot projects.

How do we Distinguish Our "Phase I" Plan from the Climate Change Action Plan?

Phase I of the president's plan calls for new technology spending of roughly $1 billion per year, but no explicit price of carbon. The question is whether this represents a real step beyond the Climate Change Action Plan, which has been regarded by some as a failure. The White House has produced a good set of talking points on this issue, which we draw on and expand here:

- The President's plan includes substantially ***more funding***: $5 billion over 5 years--about 6 times as much funding as for the Climate Change Action Plan (Note on funding: the President's plan has about 3 times more funding than CCAP plus the Partnership for a New Generation of Vehicles).

- The President's proposal now includes ***binding*** targets. In expectation of these binding targets, firms and households will begin to adjust their behavior today – a factor not present in the Climate Change Action Plan.

- To provide further incentives for firms to take action now, the President has indicated his strong support for developing an ***early credit*** program of appropriate rewards for those who take prompt early action.

- The President has indicated his support for environmentally-friendly ***electricity restructuring***, which has the potential to reduce emissions significantly.

- The President has announced that the US will provide $1 billion over the next 5 years to ***help developing nations*** and countries in transition to reduce the threat of climate change.

What are the Assumptions of the Models that Generate Small Economic Effects?

The White House talking points cite model results that suggest that with worldwide permit trading, the United States could reach 1990 emissions levels by 2010 with a permit price of $25 in 2010, and a loss of only 0.1% of GDP.

These results come from Battelle's Second Generation Model (SGM), used in the IAT's work earlier this year. SGM is a 12-region model that includes 10 supply sectors (of which 8 are energy-related), with capital modeled as "putty-clay". SGM includes 2 end-use sectors, households and government, which consume final products, provide labor, land, and capital to the markets, and determine the savings rate. The model allows regions to trade goods. SGM models energy as a depletable, graded resource for both fossil and non-fossil fuels.

Can Other Examples be Used to Demonstrate that our Assumptions are Overly Pessimistic?

As you know, a recent article in the American Prospect highlighted a number of other environmental control programs where the initial cost estimates turned out to be overly pessimistic. Unfortunately, most of their examples have fundamental flaws in one way or another. There are three examples that do bear scrutiny:

- ***Cotton dust.*** Actual costs were below estimated costs in part because estimates were based on models that did not include the effects of technical change in the industry, which was accelerated by the new standards.

- ***Strip mining.*** Early costs estimates referred to reclamation at mines in operation at the time. In response to the law, however, producers expanded operations at sites where reclamation costs were lower, often on flatter terrain.

- ***Vinyl chloride.*** Early estimates were based on static cost models, and did turn out to be too high.

A number of examples are not relevant, as discussed in the attached memo. In particular, you asked about CFCs. EPA's estimates for the cost of reducing CFC production fell from $3.55 per kg (1988) to $2.45 per kg (1996), with the latter price for a more stringent standard. But the well-publicized problem of CFC smuggling indicates that control costs at the margin, which is what counts, are much higher than these estimates. CFC-12, the most common form, now has a street value of about $50/kg. By one estimate, 10 thousand tons of CFCs are now smuggled into the US every year; by comparison, legal production is 100 thousand tons this year.

We attach (TAB E) a memo that describes this conclusion in more detail, as well as the American Prospect article itself.

What Assumptions Underlie the Estimates of Massive Job Loss from the President's Plan?

The widely publized recent job loss estimates come from the EPI, a labor union think-tank, which projects job losses of 1.7 million by 2010. These estimates are implausible, for a number of reasons:

- Many IAT reviewers, including Nordhaus and Jorgenson, note that short-term macro models, such as the EPI-GRI model, are not appropriate for long-term predictions.

- The DRI model used in this study is very sensitive to changes in assumptions. In this study, DRI ran a short-term macro model with assumptions that would provide a worst-case result: a $200 permit price, increased emissions baseline, and decreased rate of efficiency improvements.

- The study also ignores Annex I trading, JI, or worldwide trading; worldwide trading has been estimated to lower costs by 50-75% in other models.

- A key contributor to the large unemployment effects appears to be large trade effects, which are inconsistent with other models and probably reflects weak trade modelling.

- It is worth noting that this is not the first time that EPI has staked out this position on job loss; their estimates of the effects of NAFTA have been proven to be wildly pessimistic.

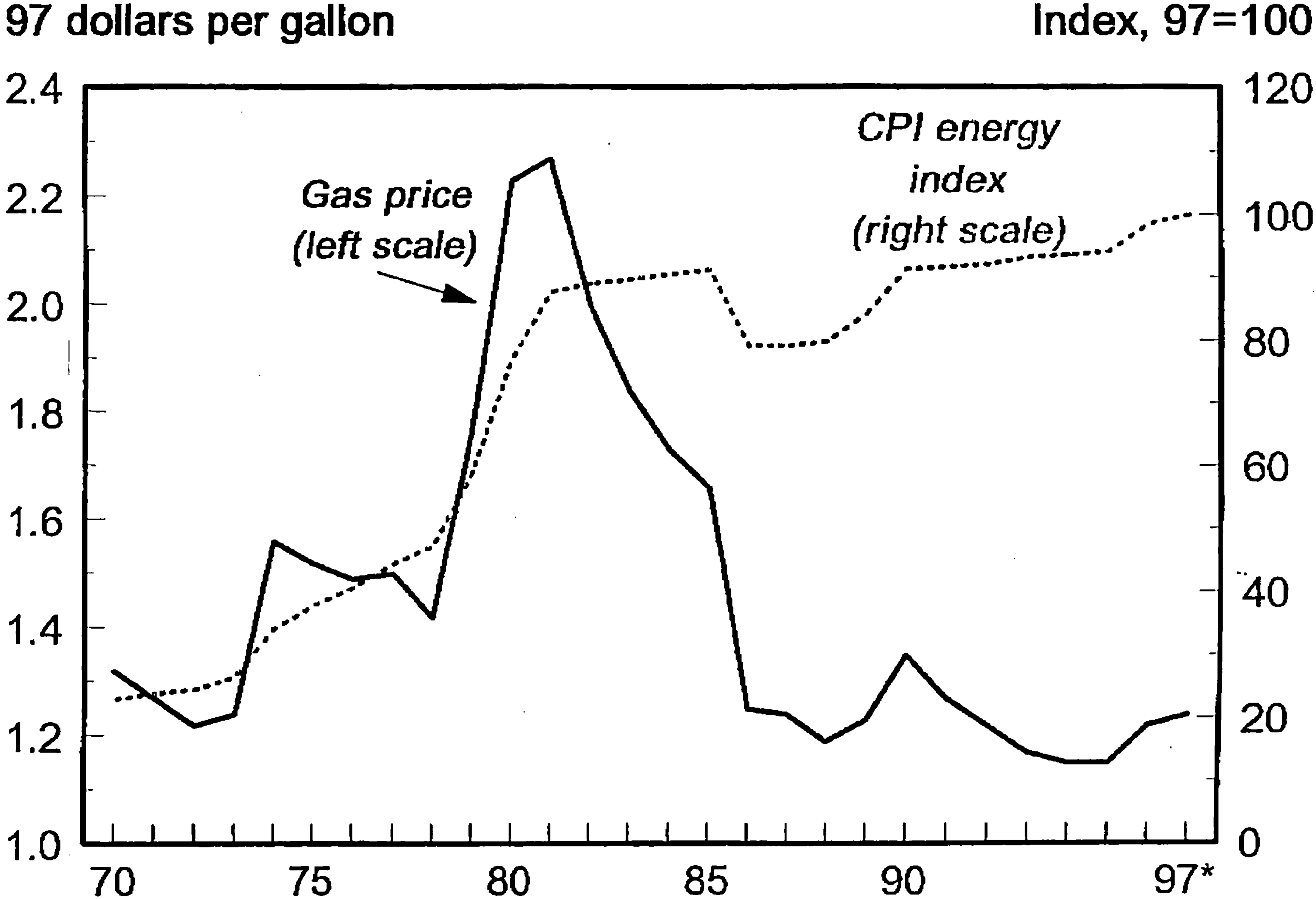
We attach a detailed critique of the EPI-DRI study as TAB F.

To What Extent can the Cost Savings from Electricity Deregulation Offset Price Increases Due to our Climate Change Plan?

- Electricity restructuring would reduce electricity prices by 0.5 to 1.1 cents per kw-hour; a carbon tax of $30 to $70 per ton would raise electricity prices by the same amount. This comparison is misleading, however, since the price reduction from electricity restructuring falls only on the electricity sector, while the price increase from a carbon tax would increase prices for other carbon-based fuels as well.

- Electricity restructuring is expected to save the average 4-person family about $232-$488 per year; a carbon tax of roughly $15 to $35 per ton would cost the average family about the same amount.

RETAIL ENERGY PRICES



* 1997 based on 7-month average

RETAIL PRICES OF GASOLINE AND TOTAL ENERGY

	Gasoline (1997 price per gallon)	Year-to-year change	Consumer energy price index (1997=100)	Percent Change
1970	1.32		22.911	
1971	1.27	-0.04	23.824	1.0
1972	1.22	-0.06	24.483	1.0
1973	1.24	0.02	26.453	1.1
1974	1.56	0.32	34.179	1.3
1975	1.52	-0.04	37.803	1.1
1976	1.49	-0.02	40.544	1.1
1977	1.50	0.01	44.385	1.1
1978	1.42	-0.08	47.207	1.1
1979	1.77	0.35	59.097	1.3
1980	2.23	0.46	77.321	1.3
1981	2.27	0.03	87.781	1.1
1982	2.00	-0.26	89.091	1.0
1983	1.84	-0.16	89.727	1.0
1984	1.73	-0.11	90.618	1.0
1985	1.66	-0.07	91.240	1.0
1986	1.25	-0.41	79.283	0.9
1987	1.24	-0.01	79.298	1.0
1988	1.19	-0.05	79.889	1.0
1989	1.23	0.04	84.419	1.1
1990	1.35	0.11	91.375	1.1
1991	1.27	-0.08	91.742	1.0
1992	1.22	-0.05	92.206	1.0
1993	1.17	-0.05	93.299	1.0
1994	1.15	-0.02	93.688	1.0
1995	1.15	0.01	94.227	1.0
1996	1.22	0.06	98.637	1.0
1997 (7-mo	1.24	0.02	100.000	1.0

	Standard Deviation	Average of Absol. Value of Yr/Yr Change	Standard Deviation	Average of Absol. Value of Yr/Yr Change
1970-97	0.32	0.11	26.80	1.06
1983-97	0.22	0.08	6.28	1.01
1985-97	0.13	0.08	6.74	1.01

DIRE PREDICTIONS THAT WERE PROVED WRONG

1. In 1972, The Club of Rome published in *The Limits of Growth* dire predictions that the world would run out of gold in 1981, mercury in 1985, tin by 1987, zinc by 1990, **petroleum by 1992,** and copper, lead, and natural gas by 1993. None of these predictions came true. Indeed the real prices of natural resources have been steadily dropping. For example, the price of crude petroleum in 1992 dollars, as measured by the composite of domestic and imported crude oil refiners acquisition costs, was $10.69 per barrel in 1972, rose with the oil price shock in 1974 to $23.56, and reached a high of $53.47 in 1981 before more or less steadily declining to $18.82 in 1996. (See reference A.)

2. On March 31, 1979, President Jimmy Carter predicted " There is a dwindling supply of energy sources. The prices are going to rise in the future no matter which party occupies the administration in Washington, no matter what we do." Subsequently, prices fell for 5 straight years from 1981 through 1986. (See reference B.)

3. Secretary of Energy Schlesinger was quoted by the *U.S. News and World Report* on July 10, 1978: "What we face I the middle 1980s is a notional worldwide shortage of about 5 million barrels of oil a day." Instead, there was a crude petroleum glut and price collapse. (See reference B.)

4. Kenneth Arrow, quoted in *Forbes* magazine on February 4, 1980, predicted that "We're heading into a world of considerably higher prices. There will be a major impact on housing by 1983, and I'd be surprised if gasoline is less than $2 per gallon plus whatever inflation adds." Housing prices actually dropped in the late 1980s and during the 1990s. The actual price of a gallon gasoline was about $1.16 in 1983 and has not reached $2 plus inflation since. (See reference B.)

5. In 1979, the Annual Report to Congress (ARC) forecast for oil prices per barrel for 1990 ranged from $39.47 to $64.32 (in 1987 dollars). All were substantially above the actual oil price in 1990. 1980 projections by the Energy Information Administration (AEI) were also badly off the mark: their 1985 projection was 70.9 percent too high; their 1990 projection was 194 percent too high; and their 1995 projection was an astounding 385 percent too high. Its 1985 projections for 1990 and 1995 were a little better, 71.7 percent and 239 percent too high, respectively.

A.) Joseph Blast, Peter Hill, and Richard Rue, *Eco-Sanity,* 19xx.

B.) Malcom Shealy of decision Focus Inc., *A Review of Energy Forecasts: What Have We Learned?* February 16, 1989.

Version That was "almost" agreed to last night

DRAFT**DRAFT**DRAFT**DRAFT

The Impact of Retail Restructuring and Federal Legislation on Carbon Emissions in 2010

An ad hoc agency staff group from DOE, EPA, and CEA considered the carbon reductions that are likely to occur in 2010 if DOE's proposed restructuring bill becomes law. Per discussion at the principals level, we attempt to separate the emissions effect of the explicit carbon friendly provisions of the DOE proposal from the effects of retail restructuring itself, which would be accelerated by, but is not entirely dependent on, Federal restructuring legislation. This memo reflects a quick-turnaround effort. Analyses are continuing at both agencies.

a. The Emissions Impact of Explicit "Carbon Friendly" Provisions of the DOE Proposal

There is agreement between DOE and EPA staff that the explicit "carbon friendly" provisions of the bill (Renewable Portfolio Standard, Public Benefits Fund, and Information Disclosure, the latter of which supports marketing of "green" power from renewable resources to interested customers. The estimated impact of these provisions is a carbon reduction of 13 to 36 million metric tons (MMT) of carbon in 2010 – see summary table for components.

b. The Emissions Impact of Retail Restructuring Itself

Both DOE and EPA staff agree that substantial retail restructuring is likely to occur with or without Federal legislation. Indeed, major states such as California and Pennsylvania have already implemented retail competition, and other states are in various stages of developing such plans. The effect of retail competition on carbon emissions outside of the explicit "carbon friendly" provisions noted above is subject to considerable dispute, in part because the evolution of service offerings under incentives in the future competitive market are not presently known.

On the emissions-increasing side, retail competition should lower electricity prices, which will increase demand, and increase incentives for economically efficient dispatch, which could result in more use of existing coal plants in cases where capacity is available. Restructuring could also increase pressures for early retirements of nuclear power plants.

On the emissions-reducing side, retail competition will provide a financial incentive for generating plant owners to improve their heat rate, reducing the amount of fuel burned to generate each kilowatt-hour of electricity. In addition, competing retailers will likely increase value of their product to buyers by creating packages of electricity and efficiency services that take advantage of cost-effective efficiency opportunities (such as those identified in the recent "five lab" study), or by selling "green power" derived from renewable sources to environmentally-conscious consumers. Finally, some of the increased demand for electricity will reduce end-use consumption of primary fuels, reducing emissions outside the electric sector.

Given the number of factors involved, the ad hoc agency staff group settled on a range of estimates from an emissions reduction of 48 MMT to an emissions increase of 33 MMT in 2010 for all of the components discussed in the previous two paragraphs and included under headings "b1" and "b2" of the summary table. If, as EPA staff believes, no increase in efficiency services can be expected from differentiated product competition among competitive suppliers under any plausible circumstances (i.e. both the high and low estimate of this component are zero) then the range of estimates for emissions impacts due to restructuring are an emissions reduction of 25 MMT to an emissions increase of 33 MMT, as presented under heading "b1" of the summary table. In both cases, these emissions changes are "over and above" the reductions presented

"almost" agreed
p #2

above in section a of the memo and the summary table.

c. Caveats

There is considerable two-sided uncertainty regarding many of these estimates. For example, green power may be more attractive, heat rate improvements may be lower or greater than projected, and efficiency oriented marketing of electricity services may be greater or less than the range presented above. Notwithstanding these uncertainties, the ranges presented above reflect the best estimates of reasonable ranges of emissions impacts based on available information.

In addition, the distinction of "carbon friendly" provisions of the DOE bill and restructuring itself is somewhat fuzzy, given that the DOE bill is expected to speed the transition to retail competition. An indeterminate portion of the emissions impacts identified in Section (b) of this note are probably attributable to the DOE bill.

Summary Impacts of Restructuring and the DOE Bill on Carbon Emissions in 2010

Factor	Change in Carbon Emissions in 2010 (MMT)
a. Explicit "Carbon Friendly" Provisions, *including:*	**-36 to -13**
Renewable Portfolio Standard	-12 to -6
Public Benefits Fund	-11 to -4
Information Disclosure (supports "green marketing" -- reflects ½ of total green power estimate)	-13 to -3
b1. Retail Restructuring, *including:*	**-25 to +33**
Electricity Demand Increase / Fuel Mix Change	+25 to +32
Nuclear Unit Retirement due to Retail Competition	+3 to 10
Green Pricing (½ of total "green power" estimate)	- 13 to -3
Generation Efficiency (heat rate) improvements	-15 to -5
Demand Reduction for Direct Use of Primary Fuels	-2 to -1
b2. Efficiency Marketing by Energy Service Companies	**-23 to 0**
SUM OF COMPONENTS (a +b1 +b2)	**-84 to +20**

The Potential Benefit from Worldwide Trading

Lesser-Developed Countries (LDCs) and Economies in Transition (EITs) offer low-cost opportunities for reducing carbon emissions. Joint implementation and international trading mechanisms can help the world mitigate global warming in the most efficient manner.

Great Potential Benefits

There are three fundamental reasons why non-OECD countries offer the world such great opportunities for reducing carbon emissions:

Energy Efficiency. LDCs and particularly EITs are much less energy efficient than OECD countries. In many cases, these relative inefficiencies provide *negative cost* opportunities to reduce carbon emissions. For example:

- Chinese coal-fired boilers are only 2/3 as efficient as US boilers. Retro-fitting Chinese plants with US boilers saves more money than it costs.
- Retrofitting Khrushchev-era Russian apartments saves 30% of heat use and saves more money than it costs. Many other negative cost efficiency improvements have been identified for Russian industry, including the use of quality insulation around steam piping, improved energy control systems, and more efficient motors.

Overall, the possibilities from energy efficiency improvements provide large opportunities for carbon reduction. For example, a $2 million study conducted by the World Bank and Chinese officials found that China could reduce its carbon emissions nearly 15% from its projected 2020 levels through zero and negative cost energy efficiency improvements.

- That is, we *could reduce total emissions by roughly 333 MMT through these low or no cost improvements; this amounts to roughly the reduction required by the U.S. to reach 1990 levels in 2010.* Approximately 2/3 to 3/4 of these improvements would come as a result of market oriented restructuring, while the remainder would come from specific, technical projects.

New Capacity. Due to their high growth rates, developing countries have an advantage over the OECD in their ability to meet their reduction targets by installing new, carbon-efficient plants rather than by retrofitting existing plants.

- Loosely speaking, OECD countries will have to balance the costs of building new, natural gas plants against simply continuing to operate existing coal plants -- large coal price adjustments will clearly be required to make building the new natural gas plant the preferable option. Developing countries, however, will balance the costs of installing new natural gas plants against the costs of installing new coal capacity. For these countries, little if any coal price adjustment would be required to make natural gas the economic choice.

Energy Subsidies. Recent World Bank estimates indicate that developing countries could reduce carbon emissions by 7 - 9% by eliminating energy subsidies.

For all of these reasons, the cost of carbon reductions is much lower in developing and transitional economies. For example, if the US, instead of reducing its own emissions to 1990 levels by 2010, transferred its reduction burden in entirety to China, China could accomplish these reductions at only 35% of the costs (this result comes from the mainstream SGM model).

Tapping the Potential: Current Success in JI Pilot Projects

Since its foundation in 1993, the US Initiative on Joint Implementation (USIJI) has accepted 25 project proposals which help US firms tap the potential outside the OECD for low-cost carbon reduction. Some of these projects have already begun to reduce carbon concentrations by implementing new, carbon-efficient power plants, improving energy efficiency, or through other methods such as planting new forests. For example:

- A project in the Czech Republic converted a district heating plant from coal to natural gas and built a cogeneration plant to provide both steam and electricity. This project is projected to reduce carbon emissions by 165,000 tons over 25 years.

- A project in Costa Rica has replaced fossil-fuel burning power sources with a 20 MW wind farm which is expected to reduce carbon emissions by 72,000 tons over 15 years.

- A project in Russia planted 506 hectares of trees and is expected to reduce carbon concentrations by 35,000 tons over 60 years.

Other projects, in various stages of implementation, include:

- A large forest management project in progress in Bolivia combines forest regeneration and protection with the promotion of sustainable forest-product enterprises to reduce atmospheric carbon by an estimated 14.5 million tons over 30 years.

- A project in Russia will improve heating efficiency in Zelenograd simply by installing new heat exchangers, pumps, and control equipment. This project can reduce carbon emissions by 440,000 tons over 30 years.

Joint Implementation, while very valuable in helping to efficiently reduce carbon emissions, can serve other useful purposes including: the opening of overseas markets, the wider dissemination of advanced technologies, and the creation of local health and environmental benefits.

Tapping the Potential: The Future

The success of JI pilot projects shows that they can work. Once countries face binding —

emissions limits -- and are allowed to acquire offsets from other countries -- JI and more general mechanisms for international cooperation will become essential in meeting common goals at the least cost. Many analysts believe that international permit trading and JI can reduce costs by 50% or more.

If LDCs and EITs sign on to binding agreements, international permit trading will allow the world to focus its carbon reduction efforts in the most efficient places. A portion of the easy reductions possible in developing and transitional economies stem from possible market oriented reforms and the elimination of energy subsidies. Reductions through these means will be of great benefit to other countries in an international permit trading regime, but will be difficult to tap in a project-oriented joint implementation setting. Insofar as developing countries and others choose to remain outside an international agreement -- so that they could not take part in a permit trading program -- JI will be relied on to play an important role.

The World Bank is exploring the possibility of a carbon investment fund to act as a market intermediary for JI projects. The fund, on behalf of its investors, would undertake JI type projects and sell the resulting carbon offsets to make a profit. Such a fund would improve on the efficiency of today's bilateral JI pilot projects by reducing transaction and search costs, providing efficient administration, and pooling risk. The Bank is continuing to investigate this and other mechanisms to help in international carbon offset trading.

October 21, 1997

MEMORANDUM FOR DEPUTY SECRETARY SUMMERS

FROM: Jonathan Gruber
Deputy Assistant Secretary (Economic Policy)

SUBJECT: **Do we always overestimate environmental control costs?**

In "Polluted Data: Overestimating Environmental Costs," *(The American Prospect,* Nov/Dec 97), Eban Goodstein and Hart Hodges argue that most pollution control programs turn out to be far less costly than had been estimated beforehand. They claim that "reducing pollution emissions at the source ... is almost certain to be (substantially) cheaper than we think it will be." But why, one might ask, are the experts always wrong -- and always in the same direction? "The reason, of course, is technology forcing," answer the authors. "When industry is required to lower pollution output, it usually doesn't just slap a new filter on an existing process; it often invents new technology."

The authors give a list of environmental programs in which, they claim, technical innovation came to the rescue and dramatically reduced costs, compared to initial estimates. Some of these examples lend credence to the authors' thesis, but many do not.

Convincing Examples:

Cotton dust. Actual costs were below estimated costs in part because estimates were based on models that did not include the effects of technical change in the industry. As the standards were introduced, the textile industry was about to replace its older capital stock with new machines that, among other things, markedly reduced the amount of cotton dust in the air. The standard accelerated this change.

Strip mining. The authors quote compliance cost estimates in the range of $6 to $12 per ton of coal, as against actual costs of 50 cents to $1 per ton. Early costs estimates referred to reclamation at mines in operation at the time. In response to the law, however, producers expanded operations at sites where reclamation costs were lower, often on flatter terrain. Thus, these early "static" estimates overstated costs.

Vinyl chloride. The authors say that control cost estimates fell from about $100 million per year to $20 million per year. John Morrall of OIRA reports that the earlier estimates, which were based on static cost models, did turn out to be too high. We should note, however, that the authors also claim that the 1 ppm standard was met with a price increase of only about 6 percent. The US vinyl chloride market today is about $1 billion, so 6 percent implies $60 million annually

Prepared by Ray Squitieri

in direct control costs, undercutting their $20 million estimate.

Problematic Examples

Asbestos. The paper says that one study by a consulting firm in the early 1970s estimated control costs that turned out to be too high by a factor of two. This refers only to the earliest estimates, done in support of OSHA's proposal in the early 1970s. Two later OSHA cost estimates, in the late 1980s and early 1990s, did not substantially overestimate control costs, according to John Morrall, now a branch chief at OIRA, who was responsible for reviewing all three sets of estimates.

Benzene. The paper cites a process that substituted other chemicals for benzene, "and virtually eliminated control costs." Benzene is one of the most widely used organic chemicals, with over $2 billion in sales last year. The new process alluded to (using maleic anhydride) replaced benzene in only a small portion of its uses.

CFCs. The paper correctly quotes EPA's price estimates for reducing CFC production, which fell from $3.55 per kg (1988) to $2.45 per kg (1996); the latter price was for a more stringent standard. On the other hand, the well-publicized problem of CFC smuggling indicates that control costs at the margin, which is what counts, are much higher than these estimates. When the US ceased CFC production in January 1996, a CFC smuggling industry was already in place. CFC-12, the most common form, now has a street value of about $50/kg. By one estimate, 10 thousand tons of CFCs are now smuggled into the US every year.

Coke ovens. The paper quotes a 1974 study that gave a range of $200 million to more than $1 billion, and says that a later study by the Council on Wage and Price Stability (COWPS) estimated the actual cost of the standard at $160 million. The author of the COWPS estimate, John Morrall of OIRA, says that he did not make an independent estimate, but simply took the low end of the industry estimate that OSHA was using, on the grounds that industry had an incentive to overstate control costs. He also says that the authors' range ($200 million to more than $1 billion) appears to be the range in the industry study he used, with $160 million rounded upward to $200 million. Moreover, the OSHA standard was never met.

More General Critique

The authors are correct in their general claim that many cost estimates come from models that do not factor in technical innovation. But their argument is incomplete, and sometimes wrong.

First, analysts are often mistaken about the costs of environmental controls, but not just on the high side; this article has clearly selected its examples to illustrate its point, downplaying examples which cut the other way. For example:

- The National Ambient Air Quality Standards (NAAQS), set by the original Clean Air Act (CAA) of 1970, were estimated to be achievable in 7 years. Twenty-seven years later, we still do not know how, when, or even if the original goals will ever be met. At the time EPA tightened the ozone NAAQs earlier this year, 75 areas did not even meet the standard then in place, which is looser than the original standard set a quarter century ago. These non-attainment areas contain 75 million people, and include most of the country's major cities: Los Angeles, Houston, Dallas, St. Louis, Chicago, Pittsburgh, Cleveland, Boston, New York, Philadelphia, Baltimore, Washington, and Atlanta.

- The Clean Air Act Amendments of 1990 established a program for "clean-fuel vehicles" in California, with a target of 150,000 vehicles to be purchased annually in model years 1996, 1997, and 1998, and 300,000 vehicles (about 25% of sales) in model years 1999 and after. The writers of this technology-forcing law seriously underestimated the cost of producing this vehicle. As of now, there appears to be no way to produce this car at a price consumers will accept, and EPA has, in effect, allowed the program to lapse.

- The authors make a false distinction between controlling pollution and the source, and treating soil and water after it has been contaminated. They concede that some programs, such as Superfund and the Clean Water Act, have been far more costly than anticipated. But they assert that this occurred because cleaning up existing contamination is not subject to the same forces of innovation as preventing pollution at the source. The authors offer no support for this claim.

Second, most ex-post cost estimates, including all those cited by the authors, include only direct compliance costs. Indirect costs, which are borne elsewhere in the economy, are harder to measure, but no less real. An often-cited 1990 study by Kopp and Hazilla of Resources for the Future estimates that indirect costs of environmental rules are roughly equal to direct compliance costs. In a 1993 study of the paper, oil refining, and steel industries, Gray and Shadbegian estimate that for every $1 in compliance costs, total factor productivity is reduced by $3 to $4. In a series of papers this decade, Jorgenson and Wilcoxen calculated that environmental regulations have reduced the US capital stock by 4.3 percent, increased the cost of capital by 5.5 percent, and reduced real GDP by more than 3 percent annually, with indirect costs accounting for most of this burden.

Third, the authors do not support their claims about technology forcing. They quote Michael Porter, who has written that environmental regulations often yield "innovation offsets." But they try to prove their case with anecdotes. Anecdotes alone do not prove an assertion, because we have no guarantee that the speaker has not selected only those that support his position. Moreover, we have survey evidence that runs the other way. When the BEA conducted its surveys of environmental compliance costs, it asked about "product offsets," resulting from compliance with the regulation in question. In contrast to Porter's claims, only two percent of respondents identified any "product offsets."

Fifth, the same market forces that drive down compliance costs also drive down benefits. For example, several years ago OSHA estimated very large benefits for its new rules intended to control the spread of tuberculosis. But at the same time that OSHA's program was being put in

---

Prepared by Ray Squitieri

place, tuberculosis rates were falling, as the Centers for Disease Control (CDC) increased its focus on tuberculosis. This slowed the spread of the disease and reduced the benefits of OSHA's program. Similarly, OSHA's recent rules on blood-borne pathogens aimed to limit transmission of AIDS and, especially, hepatitis-B. The recent vaccine for hepatitis-B has considerably lowered the value of OSHA's rule.

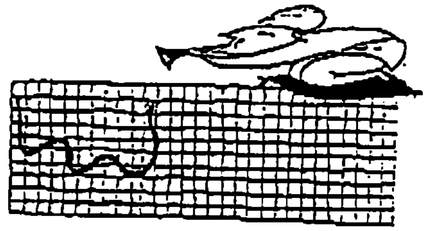
More fundamentally, program costs can get wildly out of control when EPA takes a program with modest goals, and sweeps into it activities that were not intended to fall into its purview. Superfund is an example of this driftnet approach. Superfund began life as a program to clean up a few big sites on the order of Love Canal, but metamorphosed into "a behemoth, towering over American environmental policy, gobbling vast quantities of public and private cash and management time." [Francis Cairncross, environment editor of *The Economist*, in her book *Costing the Earth*]. On a smaller scale, EPA's rule on toxicity characteristics provided a way that a waste stream could be designated as hazardous. The agency estimated its cost in the low hundreds of millions of dollars per year. These estimates failed to anticipate that EPA would then insist on regulating many items posing low or negligible risk, including fluorescent light bulbs and telephone poles; as a result, the rule has been far more expensive than anticipated in these initial estimates.

EBAN GOODSTEIN AND HART HODGES

Polluted Data: Overestimating Environmental Costs

In July, Carol Browner, chief of the Environmental Protection Agency, issued new regulations reducing permissible levels of smog and particulate (fine soot) pollution. The political battle leading up to the decision was fierce, even within the administration. One staff member on the Council of Economic Advisers maintained that the regulations would cost a whopping $60 billion—a figure quickly seized upon by industry opposition. The EPA's own cost estimate was much more modest, between $6 billion and $8 billion. In making her case for the new regulations, however, Browner publicly disavowed even her own agency's cost estimates. She argued that industry would find a way to do it cheaper.

Whom to believe? Confronted with conflicting estimates, most lay people either throw up their hands or choose sides ideologically. But history provides a basis for evaluating these estimates. Not only do industry lobbyists wildly overestimate the costs of proposed environmental regulations. More surprisingly, academic and government economists consistently do too—and for an equally surprising reason. When forecasting the costs of new environmental regulations, economic analysts routinely ignore a primary economic lesson: Markets cut costs through innovation. And innovation can be promoted through regulation. This history is worth bearing in mind as we approach the most important environmental controversy to date—how to deal with the crisis of global warming.



THE ABCs OF OVERESTIMATION

In every case we have found where researchers have calculated actual regulatory costs and then compared them to *ex ante* estimates, the estimate exceeded the actual cost. We have uncovered a dozen such efforts, ranging from A (asbestos) to V (vinyl chloride). In all cases but one, the initial estimates were at least double the actual costs.

Asbestos. When the Occupational Safety and Health Administration (OSHA) instituted regulations covering exposure to asbestos in the early 1970s, they hired a consulting firm to estimate the cost of compliance. Two later studies found that the original prediction for the cost of compliance was more than double the actual cost, because of overly static assumptions.

Benzene. In the late 1970s, the chemical industry predicted that controlling benzene emissions would cost $350,000 per plant. Shortly after these predictions were made, however, the plants developed a process that substituted other chemicals for benzene and virtually eliminated control costs.

Chlorofluorocarbons (CFCs). In 1988, reducing CFC production by 50 percent within 10 years was estimated by the EPA to cost $3.55 per kilogram. By 1993, the goal had become much more ambitious: complete elimination of CFC production, with the deadline moved up two years, to 1996. Nevertheless, the estimated cost of compliance fell more than 30 percent, to $2.45 per kilogram. And where substitutes for certain CFCs had not been expected to be available for eight or nine years, industry was able to identify and adopt substitutes in as little as two years.

CFCs in automobile air conditioners. In 1993 car manufacturers estimated that the price of a new car would increase by $650 to $1,200 due to new regulations limiting the use of CFCs. In 1997 the actual cost was estimated to be $40 to $400 per car.

Coke ovens. The original OSHA estimate for the cost of complying with the 1976 coke oven standard was more than five times higher than estimates of actual costs. OSHA's contractor suggested that complying with the standard would cost from $200 million to more than $1 billion. However, a Council on Wage-Price Stability study later estimated the actual cost of the standard to be $160 million.

The OSHA consultant estimated that three steel firms in their sample would spend $93 million on capital equipment and $34 million in annual operating costs to comply with the regulations. A later study by Arthur Andersen determined that the three firms actually spent between $5 million and $7 million in 1977 to comply with the standard, and only $1 million to $2 million on capital expenditures. Ultimately, firms were able to meet the standard without incurring all of the capital costs in the first year, and actual compliance costs were dramatically lower than originally predicted.

In the late 1980s, coke production again came under regulatory scrutiny, this time by the EPA. In 1987, the agency estimated that the cost of controlling hazardous air pollution from coke ovens would be roughly $4 billion. By 1991 that estimate fell to between $250 million and $400 million.

Cotton dust. In 1976, OSHA proposed a maximum permissible exposure limit of 0.2 milligrams per cubic meter for cotton dust, and its consultant estimated that compliance costs would be approximately $700 million per year. The standard promulgated in 1978 actually allowed for higher exposure levels in some sectors of the textile industry, but the small changes in the standard do not fully explain the decrease in estimated compliance costs; in 1978 the estimate fell to $205 million per year. Moreover, a new study conducted in 1982, after the Reagan administration called for a review of the standard, concluded that compliance costs were $83 million per year.

Halons. In 1989 members of the United Nations Environment Program's Halons Technical Options Committee disagreed on whether direct halon replacements could be found and whether a phase-out was possible. However, in 1993 the committee concluded that a phase-out of halons, a substance found in fire extinguishers that destroys the ozone layer faster than chlorofluorocarbons, would be both technologically and economically feasible by 1994.

Strip mining. Prior to the passage of the 1978 Surface Mining Control and Reclamation Act, estimates for compliance costs ranged from $6 to $12 per ton of coal. Actual costs for eastern coal operations have been in the range of 50 cents to $1 per ton. After the regulations were adopted, the market switched away from coal deposits with high reclamation costs. Ready substitutes included surface-minable coal in flatter areas (with lower reclamation costs), and underground deposits.

Vinyl chloride. OSHA's vinyl chloride standard, set in 1974, provides a final example of wildly excessive cost projections. The agency's consultant estimated that it would cost $22 million per year to meet the permissible exposure limit of 2 to 5 parts per million (ppm) in the vinyl chloride monomer sector, and $57 million per year to meet the 10 to 15 ppm exposure limit in the polyvinyl chloride sector. In addition, the consultant argued that the 1 ppm permissible exposure limit simply could not be attained. The president of Firestone's plastics division said that a standard of 1 ppm "puts the vinyl plastics industry on a collision course with economic disaster."

In spite of these protests, OSHA did adopt the strict permissible exposure limit of 1 ppm. A study conducted several years later by researchers from the Wharton School of Business estimated that the total cost of compliance for *both* sectors had been about $20 million per year. A 1976 congressional research paper also indicated that the actual cost of compliance was dramatically less than the original prediction. The early claims that the 1 ppm standard could not be met evaporated; instead, the regulatory action led to about a 6 percent rise in polyvinyl chloride prices.

While costs have been consistently overestimated for emission reduction, they have been underestimated for environmental cleanup. For example, when the Clean Water Act was enacted in 1972, the EPA estimated that $12.6 billion was needed to provide secondary sewage treatment systems. According to the American Enterprise Institute, actual spending for sewage treatment between 1972 and 1981 exceeded $160 billion.

Costs for the Superfund program have also mushroomed. When first launched, people expected the mandated cleanups to apply to a small handful of Love Canals. However, the program has expanded dramatically, now covering far more than a thousand sites. In addition, cleanup has proved far more costly than predicted: The average cost overrun on cleanup expenditures at Superfund sites has been 44 percent.

The message from these cases is clear. On the one hand, treating already polluted water, cleaning dirty soil, and scrubbing oily rocks costs a lot of money, (much) more than expected. On the other, when it comes to reducing pollution emissions at the source, it is almost certain to be (substantially) cheaper than we think it will be. Updating *Poor Richard's Almanack*, an ounce of prevention is clearly worth a pound of cleanup.

Why were the estimated costs of reducing emissions at the source so inflated? The reason, of course, is "technology-forcing." When industry is required to lower pollution output, it usually doesn't just slap a new filter on an existing process; it often invents new technology. Frequently the new technology turns out to have higher productivity benefits, which help to offset the cost of the regulation. To see this, it is worth looking in detail at two high-profile cases where markets have responded to regulation by cutting costs.

Coke Break

Robert Hahn, a well-known environmental economist, is currently a resident scholar at the American Enterprise Institute and an adjunct research fellow at Harvard's Kennedy School of Government, and is a former senior staff member of Bush's Council of Economic Advisers. In 1990 he and a co-author wrote a report for the U.S. Business Roundtable predicting the impact of the proposed Clean Air Act amendments on employment. These amendments had the dual purpose of cleaning up both acid rain and so-called "air toxics" from industrial plants.

The executive summary of Hahn's report leaves "no doubt that, across the Clean Air Act Amendments studied, there are a minimum of several hundred thousand jobs at various levels of severity of risk—even with the more moderate [Bush] Administration proposals." Hahn's absolute minimum prediction was 20,000 jobs directly lost, mostly from the closing of coke ovens in the steel industry. Hahn and his co-author viewed this as "truly a limiting, rock-bottom estimate" for several reasons. Important among them was that it considered only job losses arising from one portion of the bill—control of air toxics.

The amendments did pass later in 1990. The bill was in most respects more restrictive on air toxics than the one on which Hahn's study based its minimum job loss estimates. The legislation also authorized retraining funds of $50 million per year for displaced workers, which gives a nice way to track job impacts.

In the almost seven years since passage of the legislation, fewer than 7,000 workers have received aid because their jobs were affected by the Clean Air Act amendments. And the vast majority of these have been eastern, high-sulfur-coal miners, who have been laid off due not to the air toxics provision, but to the acid rain amendment. (The same legislation has in fact led to a boom in the western, low-sulfur-coal industry.) No workers from shutdown coke oven plants have received adjustment assistance. And between 1992 and 1995, production in the coke and (closely related) blast furnace industries actually increased, from $1.74 billion to $1.95 billion.

Hahn was consulting for industry here, so it is not surprising that his numbers were a bit on the high side. Corporate America, when faced with new regulations, has never been shy about claiming that the sky is falling. But Hahn is not a hired gun; he has very solid academic credentials. How could he have gotten it so wrong?

It turns out that Hahn's overestimation of regulatory impacts, while extreme, is not unusual. In fact, as we have seen in every case for which we have been able to track down data, academic and government economists have routinely overestimated the costs of reducing pollution emissions—by at least 30 percent, and generally by more than 100 percent.

The Acid Test

The EPA's acid rain program is another dramatic case in point. Since 1995, electrical utilities have been required to hold permits for each ton of sulfur dioxide they emit. These permits, in limited supply, are distributed to firms each year by the government. The innovative feature of the program is that the permits can then be bought and sold. Given this, permit prices roughly reflect per ton pollution control costs. This is true because a firm generally wouldn't buy an extra permit if the cost of doing so exceeded the cost of reducing sulfur emissions by a ton.

When the tradable permits market was being designed in the early 1990s, credible industry estimates of permit prices (and thus control costs) were $1,500 per ton; the EPA was predicting $750. In 1997, permits were in fact selling for around $100 a piece.

Part of the current low permit price is due to a higher than expected initial supply of permits, but real compliance costs have in fact been two to four times lower than the EPA expected, and four to eight times below industry estimates.

The Virtue of Markets

When environmental economists figure their cost estimates, one particular lapse is quite startling. Economists have tended to grossly underestimate a virtue of markets they readily preach elsewhere: flexibility. When pollution regulation makes a certain type of production more expensive, markets adjust—in fairly rapid order, uncovering substitute methods of production, and developing cheaper cleanup technologies. This fact, while not completely ignored by economists, is seldom factored into their cost estimates. Instead analysts tend to predict future costs statically, as if firms would continue to use existing practices and technologies.

So, for example, the much lower than expected costs for the acid rain program can be explained in retrospect by the increased flexibility that firms were given to achieve their mandated reductions in sulfur dioxide emissions. Rather than install expensive scrubbers (or buy extra permits), many more firms than expected have met their sulfur dioxide targets by switching to low-sulfur coal, or developing new fuel-blending techniques. Railroad deregulation, along with economies of scale, led to an unexpected decline in low-sulfur-coal prices. And with the increased competition from coal, scrubber prices fell by half from 1990 to 1995.

All this is easy to see after the fact, but would have been very hard to predict. Hahn got his 20,000 lost jobs from air toxics regulation following this same practice—ignoring innovative market responses. While parenthetically noting that "technological improvements could reduce the direct economic impacts," the study explicitly ignores the possibility "because of the difficulties in predicting how technology will evolve." Because in the mid- to late 1980s, available control technologies for coke ovens seemed to be quite expensive, Hahn assumed that regulating air toxics would simply shut down much of the industry.

However, as we saw above, the EPA's own estimates of control costs for coke ovens were plummeting even as Hahn was writing his report. By 1991, they were down by a factor of ten or more from the 1987 forecasts. Hahn may not have been aware of the EPA's work; instead he cites an industry source to justify his claim that "there is widespread agreement that coke ovens will be required to close down, with an estimated loss of 15,000 jobs."

A secondary reason for the overestimates is that in implementation, legislation is never as draconian as it appears on paper. In practice, timetables get stretched out, compliance dates get extended, and waivers are granted. Eventually the regulations begin to bite, but industry is usually given a fair amount of time to adjust. Most cost estimates assume high degrees of near-term compliance.

Peering into the future is hard work. It is, in fact, close to impossible for economists to predict the specifics of how technology will evolve. This is especially true since much of the information about potential innovations consists of closely held trade secrets, which industry has little incentive to reveal. But basing cost predictions on scenarios that assume no technical evolution is guaranteed to produce gross overestimates. Innovation is indeed something at which markets are very good. When given a narrowly defined task—to produce commodity *x* emitting less of pollutant *y*—short-term substitutions and long-term shifts in technology guarantee large cost reductions over current practice.

Inflating Costs, Ignoring Benefits

In the late 1980s, when the international phase-out of ozone-destroying CFCs got underway, a company called Nortel began looking for substitutes. The company, which had used the chemicals as a cleaning agent, invested $1 million to purchase and employ new hardware. Once the redesigned system was in place, however, Nortel found that it actually saved $4 million in chemical waste-disposal costs and CFC purchases.

The CF
ance costs
$1 million.
in the $4 n
mists have
dollar spe
pollution c
cost to soc
that the co
er, because
ing "diver
from more
In rece
Michael P
Business Sc
to exampl
that enviro
forcing fir
duction pr
to lower c
lend a com
More g
reported c
regulatio
invest in n
thorough
both clea
tive. Many
would hav
later anyw
of regulati
investmen
to firms.
old machi
sarily wor
pens, hov
sured com
just early
This in t
complian
higher tha
Resear
the Futur
study aski
on enviror
ly costs a
industries
answer w
due to th
others, no

The CFC regulatory compliance costs for Nortel clearly were $1 million. But how do we figure in the $4 million savings? Economists have long recognized that a dollar spent on environmental pollution control is not the "true" cost to society. Some have argued that the cost is in fact much higher, because environmental spending "diverts" capital investment from more productive uses.

In recent years, by contrast, Michael Porter of the Harvard Business School has been pointing to examples like Nortel to argue that environmental regulations, by forcing firms to rethink their production processes, can often lead to lower production costs and lend a competitive advantage.

More generally, much of the reported costs of environmental regulation occurs when firms invest in new capital equipment, thoroughly redesigned to be both cleaner and more productive. Many of these investments would have happened sooner or later anyway. So a primary effect of regulation is to speed up the investment process. This is costly to firms, since they must scrap old machinery that is not necessarily worn out. When this happens, however, much of measured compliance cost is in fact just early capital investments. This in turn implies that the compliance figures are much higher than the real costs.

Researchers at Resources for the Future recently conducted a study asking how much $1 spent on environmental protection really costs an industry. For some industries, specifically steel, the answer was little more than $1, due to the diversion effect. For others, notably plastics, the industry actually saved money as productivity was boosted. On average, the study concluded, $1 spent on environmental pollution control reflected a real expense of 13 cents. In general then, even when cost estimates are "correct," this new research suggests that the reported values often overstate the true costs to the firm, on average by a factor of seven.

The Road to Kyoto

The debate over compliance costs is now heating up for the mother of all pollution issues—global warming. International negotiators are at work on what are supposed to be binding carbon emission reduction requirements, to be announced in Kyoto in December. The European Union is pushing for a 15 percent cut below 1990 levels to be achieved by 2010; the members of the Alliance of Small Island States—whose very existence is at stake due to anticipated flooding—want a 20 percent cutback by 2005.

The United States, by far the world's biggest greenhouse polluter, is dragging its heels. President Clinton, when pressed to commit the U.S. to specifics, has promised only to convene a conference in the fall to try to achieve a consensus among American industry, labor, and other groups on the need for action. And Clinton will clearly face a tough sales job for ratification in the Republican-controlled Senate.

Academic economists have lined up behind a strong U.S. leadership role in Kyoto. Greenhouse "moderates" like Yale's William Nordhaus and Harvard's Dale Jorgenson headed up a list of more than 2,000 economists who signed a letter arguing that a first round of carbon emission reductions could be achieved at relatively low cost. And in late July, to the dismay of U.S. industry, the Clinton economic team published its official cost estimates, confirming this general view.

There is a minority opinion among economists that reducing greenhouse gas emissions will be very, very cheap, and in the long run, even profitable. The reasons? Already existing energy efficiency technologies can help the United States break its addiction to cheap oil without too much pain. And within a decade or two, renewable fuel sources—coupled with efficiently redesigned technologies—will be cheaper than oil or coal are today. In this view, the sooner we redirect the market into a serious search for alternatives to fossil fuels, the richer we will be in the future.

There are, however, likely to be transitional costs, both for workers, particularly in fossil fuel industries, and for Third World countries. In the past, government has not done a very good job in equitably sharing the burdens of such transitions. This is no reason to reject a global warming accord, but it is a strong reason to be alert to the allocation of costs and benefits.

In the global warming debate, as when past environmental regulations have been proposed, there are the three compliance cost scenarios: apocalyptic (industry), doable but costly (academic and government), and profitable (a few visionaries). Our guess, based on the record of previous academic and government cost forecasts, is somewhere between doable and profitable.□

EPI Review of DRI study of the Economic and Employment Impact of Climate Change Policies

On September 17, EPI released the results of its review of a study conducted by DRI on the economic and employment effects of climate change policy on the US economy. The results present a doom and gloom scenario largely because the model used by DRI is not appropriate for long term forecasting and because many of the assumptions tend to exacerbate the negative impacts.

WEFA has announced a study estimating the impacts of climate change polices. The only copy of their report that we have for review is methodologically bankrupt. However, the estimated permit price is similar to the EPI-DRI price and many of the results are of a similar magnitude. This attachment will focus on the EPI-DRI report because there is a detailed explanation of their methodology.

The model used in the DRI/McGraw-Hill study is a short-run forecasting model with an fixed coefficient, input-output-based structure. The shortcomings of this model for forecasting the impact of potential climate change policies are:

- Long-term climate polices are likely to alter significantly the structure of the economy and encourage fuel switching and capital-energy substitution. The model used by EPI-DRI fails to capture any of these changes because it relies on fixed, historical estimates and cannot adequately predict future production, investment, and labor supply/consumption decisions.
- This type of model tends to distort the adjustment behavior of the economy. As a result, errors due to the rigidity of the model are magnified as the time horizon of the forecast is lengthened. In other words, the forecasts for 2020 are less reliable than those for 2010, and the model is really only built to be able to produce reliable forecasts for two or three years in the future, in the present case the year 2000.
    - "[The DRI model] is highly inappropriate [for long-term predictions] and has some important limitations that are well-known to the community of economic forecasters. For example, the DRI long-term predictions are extremely sensitive to assumptions about energy prices." Jorgenson and Nordhaus from a memo to the IAT, April 24,1997.
    - The DRI model used fixed proportions of inputs to outputs which fails to capture any energy conservation of carbon emissions reductions. Therefore, "it is clearly unrealistic for periods of a decade or more." Jorgenson and Nordhaus.

As noted above, this type of model is very sensitive to changes in the assumptions such as energy prices. In many cases, the EPI-DRI modelers choose assumptions that would exacerbate any negative economic and employment effects resulting from climate change policies. For example, the EPI-DRI review:

- Assumes that the permit prices will be between $180 - $190 per mmtC (1995 dollars) in 2010. This permit price is approximately twice as high as found by the Interagency Analytic Team on the Economic Effects of Global Climate Change Policies (IAT) which estimated permit prices between $80 - $100 for the same scenario. As a result, energy price increases are much greater in the EPI-DRI review. These higher prices are a result of two modeling decisions:

    - The EPI-DRI model assumes slightly lower baseline improvements in energy efficiency (1% versus 1.25%). This also has an effect on baseline carbon emissions growth.

    - The EPI-DRI model assumes smaller price and substitution elasticities than used by the IAT; again, this is a result of the limitations of the model which does not handle substitution and fuel switching well.

- Overstates the amount of carbon emission in 2010 and 2020. Baseline carbon emissions estimates are greater for 2010 and 2020 in the EPI-DRI scenario than in either the Energy Department's AEO97 baseline or the IAT report.

    - For example, in 2010 the EPI-DRI report baseline case predicts 1,746 million metric tons (mmt). The Energy Department predicts 1,722 mmt, and DRI in the IAT report predicts 1,693 mmt in the reference case.

    - In 2020, EPI-DRI predicts 1,894 mmt while DRI predicts only 1,805 in the IAT.

- Ignores international emissions trading and the role of JI or worldwide trading, which other models predict can lower permit prices by 50% of more.

- Exaggerates impact of climate change policies on international trade and the trade deficit, multiplying the unemployment figures.

    - The EPI-DRI model predicts substantial increases in the trade deficit from our climate change policy. This largely reflects poor modelling of the trade sector in the DRI model, which is not built to handle international trade. In fact, other models (such as the SGM model) which more appropriately reflect international trading suggest only minimal impacts on the trade deficit.

        - Two-thirds of all carbon emissions are from "non-tradable"sectors: residential and transportation.

        - On average, energy costs account for only about 2% of input costs for the industrial sector. In other words, 98% of production costs are non-energy related.

        - A recent CEA analysis states that the bottom line is that the evidence is against the view that the exclusion of LDCs would have a substantial adverse effect on the overall US trade position.

- These increases in the trade deficit contribute substantially to the high unemployment numbers, since the DRI model simply multiplies the deficit to get trade-related unemployment.

- In 1992, EPI conducted a similar review of potential economic and employment estimates of the proposed NAFTA treaty. EPI stated that the available models were flawed and job losses would result from a NAFTA.

  - EPI highlighted the results of a1991 Economic Strategies Institute study found that, as a result of increased Mexican imports to the US, there would be a net job loss of 900,000 by 1999.

  - EPI continues to assert that NAFTA has cost the US jobs. In two recent issue briefs, EPI states that NAFTA has resulted in a net loss of 394,835 jobs in the US in its first three years.

  - In fact, after taking in account storing US economic performance, Mexico's balance-of-payments crisis and 1995 recession, and US implementation of MFN tariff cuts mandated by the Uruguay Round, several studies, including ones from DRI and the Federal Resereve Bank of Dallas, generally conclude that NAFTA in isolation has had a modest positive effect on the US economy. The Adminitration has recently announced an **increase** of 311,000 jobs supported by exports to Canada (189,000) and Mexico (122,000) since 1993.