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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.

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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[1] gases, it is the sum of all releases and absorptions of all gases by all human activities that governs the short-term[1] 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

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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 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.

Final Demand

-ectors

Productive

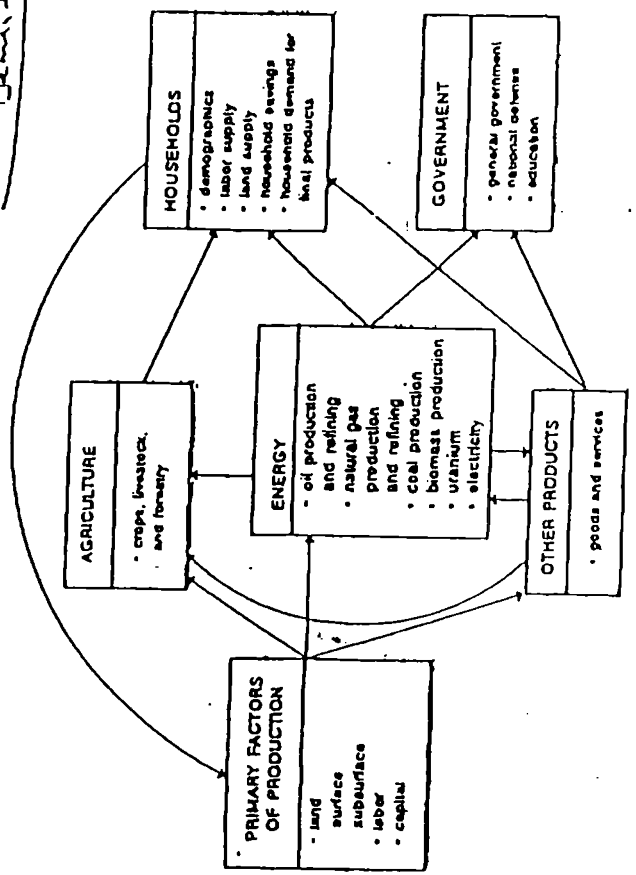


Fig. 1 The flow of goods and services in SGM version 0.0

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.

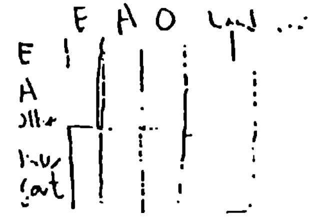
Overview of the SGM structure

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,

$$\mathrm{GNP} = \sum_{i=1}^{N}\left(P_iX_i - \sum_{j=1}^{N} P_jA_{j,i}\right) = \sum_{i=1}^{N}\left(\mathrm{TXibt}_i + \pi_i + \sum_{j=N+1}^{N+M} P_jA_{j,i}\right), \tag{2}$$

where TXibt_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 sig-

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

nificant 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.

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.

The generic production/cost relationship

sector
↓
subsector
↓
technology

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. *1

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,

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

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,

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

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

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

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

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

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:

$$P_{i,l} = \alpha_{i,l}[P_i(1 + \delta_{i,l}Tr_i)txa_{i,l} + txb_{i,l}], \tag{13}$$

where $\alpha_{i,l}$ is an adjustment factor to reflect markups and intraregional transport costs; Tr_i is the import transportation costs for the ith good; $\delta_{i,l}$ is a logic driven parameter whose value is 0 if the region is a net exporter, and 1 otherwise; $txa_{i,l}$ is the proportional tax on the ith product in region 1; and $txb_{i,l}$ is the additive tax on the ith product in region 1.

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

$$P_{i,l} = P_i(1 + \delta_{i,l}Tr_i). \tag{14}$$

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,

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

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,

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

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

$$\frac{NR_e}{K} = u_0 Pe_0 \left[1 - (Pe_0\alpha_0)^{\rho/(1-\rho)} \left(\sum_{i=1}^{N-M} \alpha_i^{1/(1-\rho)} Pe_i^{-(\rho/(1-\rho))}\right)\right]^{(1-\rho)/\rho}$$

$$\times \left(\sum_{i=N-M+1}^{N} \alpha_i x_i^{\rho}\right)^{1/\rho} (1 - tx). \tag{18}$$

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 $T_{construct}$ 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 $T_{construct}$, then in each period an investment of

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

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,

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

where, t is the investment period in which the investment decision is being made, $t = 1, \ldots T_{construct}$; and tc is an index of periods of investment remaining, $t = 1, \ldots, T_{construct}$. 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,

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

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

$$\alpha_0 = \alpha(C_t, C_{t-1}, \text{Atmos}_t, \text{Atmos}_{t-1}, t - t_0), \tag{21}$$

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,

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

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:

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

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,

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

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 detemination 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,

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

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,

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

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 in 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 π_{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

$Xs_{l,ss,tech,j,1,v}$ is the output of good j by sector l, 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,

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

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,

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

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,

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

where POP_{tot} is the total population; POP_{15-} is the population under age 15; POP_{65+} is the population over age 65; $\mathrm{POP}_{25\%Y}$ 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,

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

where $P_{g,ss}$ is the cost of the next unit of government service ss, that is P_l is the price of input l in the production process; and $a_{l,g,ss}$ is the amount of input l 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_l,[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 $\beta_{ss} = \delta_l^{-1/(\mu-1)}$ 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,

$$POP_{tot} = \sum_{age=1}^{NAGE} POP_{age,males} + POP_{age,females}, \tag{42}$$

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

For the youngest age group, age = 1,

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

where $POP_{age=1,gender,t}$ 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,

$$POP_{age,gender,t} = SV_{age,gender,t} POP_{age-1,gender,t-1} + POPmig_{age,gender,t}, \quad age = 2, \ldots, NAGE. \qquad (44)$$

where $sv_{age,gender,t}$ is the survival rate by gender from age group age to age + 1; $POPmig_{age=1,gender,t}$ 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.

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

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

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

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,

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

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,

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

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,

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

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

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

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

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

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

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

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.[13]

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, Yuanzheng Luo, Rett 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_0, 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

$$G_{ir} = \lambda^{1/(\rho-1)} G \beta_{ir} P^{\rho}_{i,ir}$$

where λ is a Lagrangian multiplier. For convenience define,

$$Y = TX_{ext} - S_{gt} - TR_{gt}$$

and note that

$$Y = \sum_{i=1}^{NGI} G_{ir} P_{i,ir}.$$

Substitute (1) into (2) to yield,

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

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.

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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 char-

acteristics 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

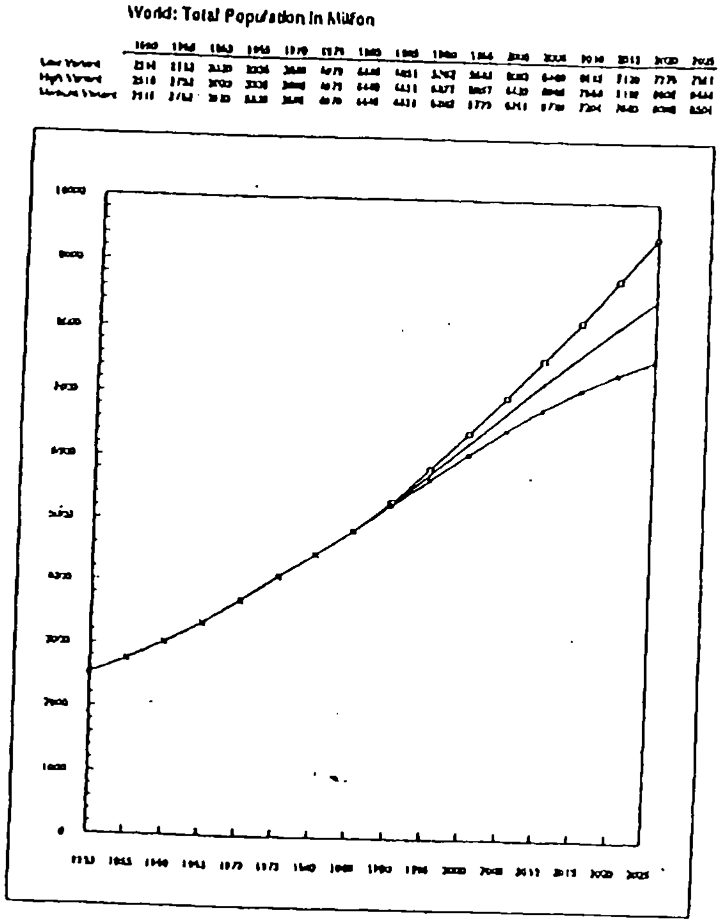

Fig. 1 World population growth, 1950 to the present and three alternative projections to the year 2025 (*UN World Population Prospects* 1990). In the case of the high variant the population is expected almost to double during the next 35 years. Despite the declining growth rates from now on, the high variant still leads to an increasing absolute population increase. By the year 2010 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 economies-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 gigaton 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-

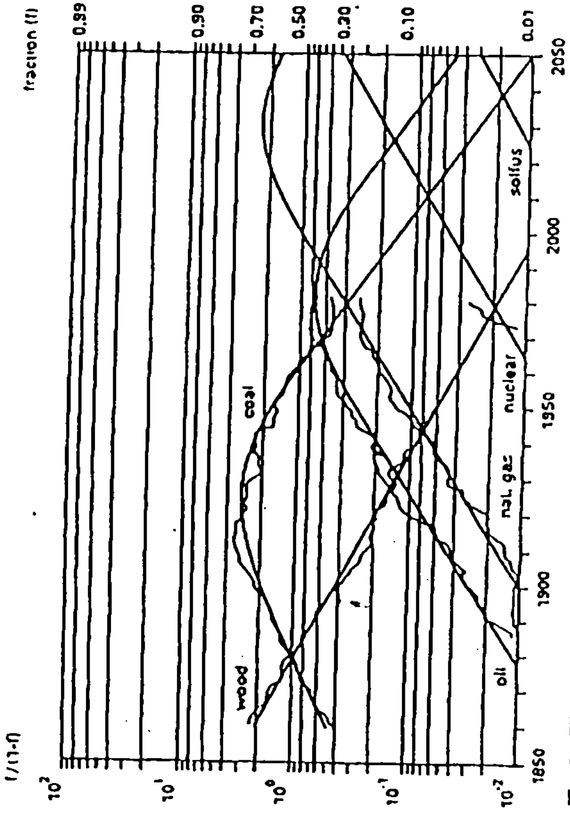

Fig. 2 World primary energy substitution. Shares of primary energy sources in global consumption. Smooth lines represent model calculations, and jagged lines are historical data. "Nat. gas" is natural gas; "solfus" is a term employed to describe a major new energy technology, for example solar or fusion (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).

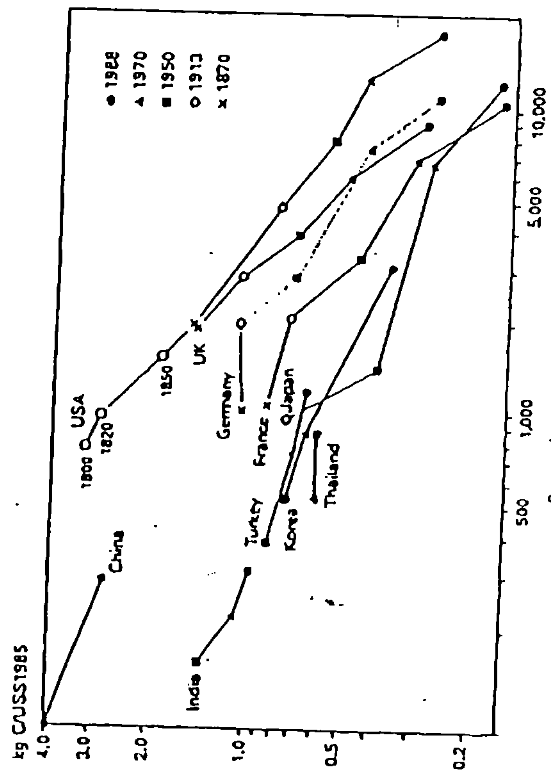

Fig. 3 Energy CO_2 emissions intensity per constant GDP in kg per constant 1985 US$ versus per capita GDP in constant 1985 US$. Energy data include also non-commercial sources such as fuelwood. In general, carbon intensity of economic activities improves as a function of differences between countries 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

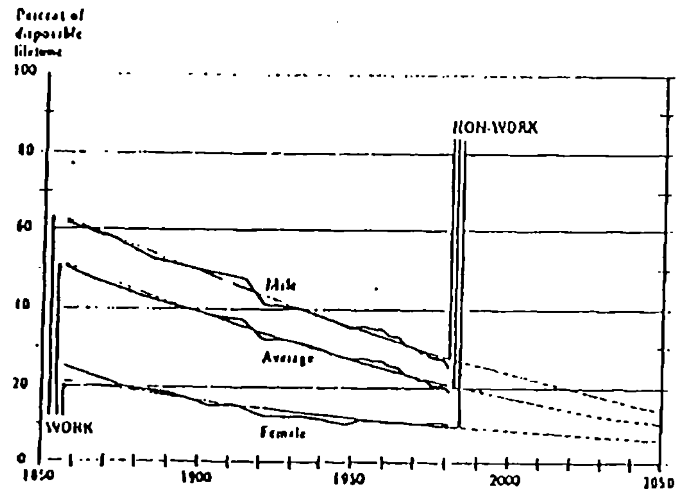

Fig. 4 Fraction of disposable lifetime spent at work and non-work of female, male, and average working population, UK 1856–1981. Figures are derived by comparing life hours of work to total disposable, active non-work hours for adults. Disposable hours are calculated by subtracting 10 years for childhood 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

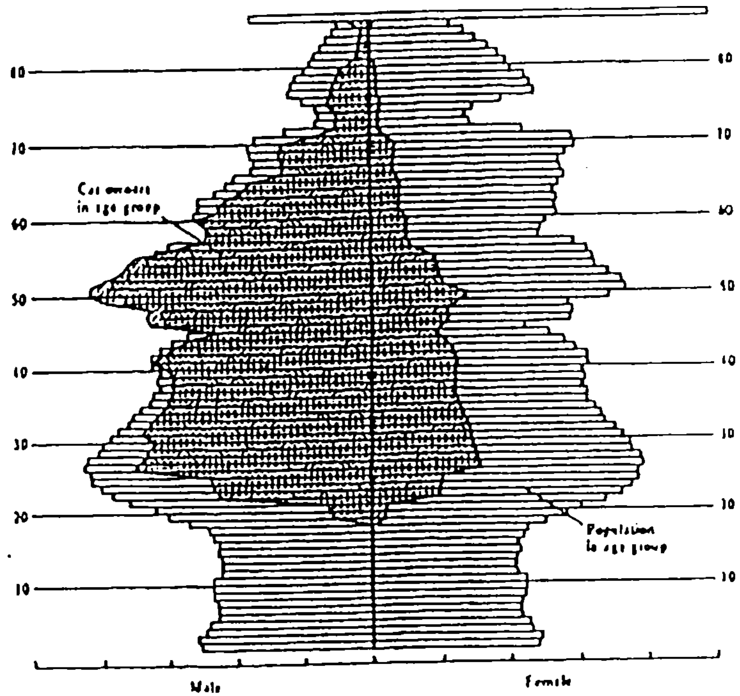

Fig. 5 Demographics of car ownership in Germany (only former FRG territory) in 1989 revealing significant intergenerational and gender differences in car ownership. Combined with demographic projections scenarios of future car ownership are developed at IIASA based on different scenarios of lifestyle 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: Bültner 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.

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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 caloric 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 Kantorovich 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.

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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

JA

Review Draft – Comments Welcome

11/14/97
PNNL-xxxxxx
Working Paper

Return to 1990: The Cost of Mitigating United States Carbon Emissions in the Post-2000 Period

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October 1997

Prepared for
U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest National Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

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ABSTRACT

The Second Generation Model (SGM) is employed to examine four hypothetical agreements to reduce emissions in Annex I nations (OECD nations plus most of the nations of Eastern Europe and the former Soviet Union) to levels in the neighborhood of those which existed in 1990, with obligations taking effect in the year 2010. We estimate the cost to the United States of complying with such agreements under three distinct conditions: no trading of emissions rights, trading of emissions rights only among Annex I nations, and a fully global trading regime.

We find that the cost of returning to 1990 emissions levels in the United States in the absence of trading opportunities is approximately $108 per metric ton carbon in 2010. The total cost in that year is approximately 0.2 percent of GDP. Emissions reductions are accomplished via energy conservation across a broad range of residential, commercial, industrial and transportation activities and by replacing coal fired power stations with natural gas facilities.

International trade in emissions permits lowers the cost of achieving any mitigation objective by equalizing the marginal cost of carbon mitigation among countries. This is sometimes referred to as "where" flexibility. "Where" flexibility allows least expensive emissions reductions to be undertaken first, regardless of where they occur among trade participants.

For the four mitigation scenarios in this study, economic costs to the United States remain below 1% of GDP through at least the year 2020. This was the case even in the scenarios where the United States met its mitigation targets without international trading of carbon permits.

Return to 1990
The Cost of Mitigating United States Carbon Emissions in the Post-2000 Period

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More than 160 nations have signed the Framework Convention on Climate Change (FCCC). That agreement required Annex I nations,[1] the developed nations of the world plus economies of the Former Soviet Union and Eastern Europe, to undertake measures to return emissions to 1990 levels or below in the year 2000. The parties to the FCCC met in Berlin in the Spring of 1995 and determined that additional measures were required to implement the ultimate objective of the FCCC, "*to stabilize the concentration of greenhouse gases in the atmosphere at a level which would prevent dangerous anthropogenic interference with the climate system.*"

Subsequent to the Berlin discussions, nations of the world have begun to consider measures that would set quantifiable emissions limitation requirements in the post-2000 period for Annex I nations. Various measures have been considered. The purpose of this paper is to explore the economic consequences of efficient policy instruments—carbon taxes or tradable emissions permits—which might be employed to achieve a variety of targets in the post-2000 time frame.[2] Using the Second Generation Model (SGM), we estimate the costs to the United States of complying with of four Annex I mitigation scenarios under three permit trading regimes. Specifically, we examine the carbon taxes required for emissions mitigation and provide measures of the costs of mitigation.

We begin by describing the variety of policy options to be considered and our general approach to modeling those policies. We then review some of the necessary assumptions for this exercise, as well as the structure and calibration of the SGM. Finally, we discuss the results of our analysis, including time paths of emissions and measures of cost.

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[1] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and the United States.

[2] In the United States, efforts were undertaken by the Interagency Analytical Team (IAT), and results were summarized in United States Government (1997). The Second Generation Modeling team was one of three modeling teams that participated in the evaluation of potential emission mitigation measures under discussion. Note that the results presented in this paper differ from SGM results presented under the auspices of the IAT. The IAT effort assumed higher rates of technical change induced by a response to policy implementation. This study does not make the same assumptions.

APPROACH

The SGM was used to simulate the impact of mitigation policies on the United States economy. The SGM is a computable general equilibrium economic model that projects economic activity, energy consumption, and carbon emissions for the United States and 11 other world regions. A more complete description of the SGM follows in the next section.

Four scenarios were constructed that reduce carbon dioxide emissions in Annex I countries by 2010. The four policies, designated 'M_', are listed below. Figure 1 shows United States emissions paths for the four scenarios and the reference case in million metric tons of carbon (MMTC). The reference case is a business-as-usual scenario, or what we project will happen in the absence of a mitigation policy. In each mitigation scenario, allowable emissions are reduced linearly from the reference level in 2000 to the emissions target in 2010.

M1990 — Emissions from Annex I regions must be no greater than 1990 emissions levels beginning in the year 2010.

M1990+10% — Emissions from Annex I regions must be no greater than 10% above 1990 emissions levels, beginning in the year 2010.

M1990-10% — Emissions from Annex I regions must be no greater than 10% below 1990 emissions levels, beginning in the year 2010.

M1995 — Emissions from Annex I regions must be no greater than 1995 emissions levels beginning in the year 2010.

[Figure 1. Carbon Dioxide Emissions Scenarios for the United States]

The four emissions mitigation scenarios each define a set of emissions rights for the Annex I regions. In a mitigation scenario, regions must possess permits, or rights to emit, for every million metric ton of domestic carbon dioxide emissions. Three emissions permit trading regimes were modeled under each mitigation policy: independent emissions mitigation, Annex I joint mitigation, and Annex I mitigation with global permit trading. The 12 SGM regions listed in Table 1 provide the necessary global coverage to simulate these trading systems. Carbon taxes were used to constrain emissions for each of the policy-trade combinations.

Table 1. Regions in the SGM

Annex I	Non-Annex I
United States	China
Canada	India
Western Europe	Mexico
Japan	South Korea
Australia	Rest of World[3]

[3] The Rest of World includes Latin America, Africa, and other Asian countries.

Former Soviet Union	
Eastern Europe	

In the independent mitigation case, each Annex I region must individually meet its required emissions targets without any trading of permits across regions. A time series of carbon taxes is determined for each region to reduce emissions to be equal to its allocated emissions rights.

With Annex I joint mitigation, a common carbon tax is applied to all Annex I regions to meet the overall Annex I emissions target. However, regions are allowed to trade permits amongst themselves so long as the total constraint is met in each time period. Regions may only emit more carbon than their allocated emissions rights allow if another Annex I region is willing to sell a corresponding number of its permits, thereby forcing the seller region to reduce its domestic emissions beyond the required target.

In the global trading case, emissions rights are allocated to Annex I regions at the same levels as in the Annex I trading case. Under global trading, however, the Annex I regions are allowed to purchase permits from each other and from non-Annex I regions so long as the global emissions constraint is met. The global constraint in each period is composed of the Annex I constraint and the sum of the non-Annex I regions' reference level emissions in that period. The SGM is used to determine a global carbon tax just large enough to meet the global emissions target.

In none of the above scenarios and trading combinations are non-Annex I regions forced to constrain their emissions below reference levels. No mitigation targets or emissions trajectories are imposed on those regions. Under the global permit trading regime, non-Annex I regions participate in the market for carbon permits only when it is to their economic benefit to do so. These regions are allocated permits equal to their projected reference emissions, so they are only required to reduce their emissions by an amount equal to the number of permits they wish to sell.

Eastern Europe and Former Soviet Union Permit Allocations

While carbon dioxide emissions in most regions are anticipated to continually increase over time beyond 1990 levels, this is not true for the Eastern Europe and Former Soviet Union regions. Emissions in these regions have declined since 1990. Their reference case emissions trajectories reflect this decline from 1990 to 1995 and then increase slowly from 1995 onward. The downturn in emissions poses a special problem when allocating emissions rights. Two approaches to permit allocations for the regions have been discussed in recent months. The first allocates permits based on the stated policy scenario (e.g., M1990 allocates permits based on 1990 emissions level) so that permits are allocated to them in the same way as they are to other Annex I regions. Because of the decline in emissions in those regions from 1990 to 1995, however, this approach results in emissions permits being granted to Eastern Europe and the Former Soviet Union in the policy years that are greater than their reference level emissions. These 'paper credits' are equal to the difference between the lower post-1990 emissions and the policy-level (i.e., 1990) emissions. For example, the Former Soviet Union's reference emissions level in 2010 is 836 TgC, significantly lower than its 1990 emissions of 1050 TgC. If granted permits equal to its 1990 emissions, it would receive 214 TgC worth of permits more in 2010 than its projected emissions, giving it 214 TgC worth of permits to sell without incurring any emissions reductions of its own.

The second approach to allocating permits to Eastern Europe and the Former Soviet Union is to grant permits equal to reference level emissions in each period until the projected path is constrained by the policy. For example, in the M1990 case, the Former Soviet Union would be granted permits equal to its projected reference emissions through 2020 because emissions in the policy years never recover to 1990 levels.

For the purpose of this exercise, we chose to emphasize the latter approach in allocating emissions to Eastern Europe and the Former Soviet Union. This reference allocation scheme ensures that the stated Annex I emissions targets are achieved in both the independent mitigation and permit trading scenarios. Because a final decision on the permit allocation method has yet to be made, however, we have also included a discussion of the impacts of the mitigation policies utilizing the first approach.

MODEL OVERVIEW

The SGM is designed specifically to address issues associated with global change. The model is designed to perform the following types of analysis:

1. Provide estimates of future time paths of environmentally important emissions associated with economic activity.

2. Provide estimates of the economic cost of actions to reduce greenhouse gas emissions.

Sectors

The SGM has nine producing sectors and twelve inputs to production. The inputs are land, labor, capital, and the nine produced goods. Economic detail is maintained in the energy supply and transformation sectors that are important for greenhouse gas emissions projections, but aggregated elsewhere into one large "everything else" sector.

Five different fuels are used for producing electricity, resulting in five subsectors for the electric generating sector. A separate economic production function, of the constant elasticity of substitution (CES) functional form, is used for each sector or subsector. Capital investment decisions depend on an assumed lifetime of capital for each sector or subsector. Capital lifetimes range from 15 years in the oil, gas, and coal production sectors to 70 years for hydroelectric power. The relative size of each production sector and subsector is shown in Table 2.

Table 2. Producing Sectors in the SGM

	Producing Sector	Gross Output in 1985 (millions of 1985 $)	
1	Agriculture	468,618	
2	Everything Else	5,086,486	
3	Oil Production	64,171	
4	Gas Production	45,804	
5	Coal Production	20,006	
6	Uranium Processing	2,195	
7	Electricity Generation	165,800	
	a. oil		10,959
	b. gas		34,152
	c. coal		85,930
	d. nuclear		21,370
	e. hydro		13,389
8	Petroleum Refining	145,015	
9	Gas Transmission and Distribution	105,330	

Market Clearing

In the SGM, markets are said to *clear*. In other words, the SGM solves for the set of prices for all markets (or sectors) in the modeled economy so that demands and supplies of each market are in equilibrium. The set of prices in which the equilibrium holds is called the *market-clearing* price set. In an equilibrium model like the SGM, markets are linked to other markets through the market-clearing process. For example, a change in the demand for coal will have an effect on not just the price of coal, but also the prices of oil, gas, and, at least indirectly, the prices of all markets in the economy.

Carbon permit prices and taxes are also solved by the SGM as part of the market equilibrium. Specifically, the SGM finds the carbon price such that the amount of carbon emitted is just equal to the carbon constraint of the region or group of regions under a carbon emissions limitation constraint.

Carbon Taxes and Revenue Recycling

The SGM uses a carbon tax within each region to provide an economic incentive for the economy to substitute away from carbon. Revenues obtained from the carbon tax can be very large, and how the revenues are recycled, or redistributed to the economy, makes a difference in the final economic cost. For this exercise, we assume that all carbon tax revenues are recycled back to consumers through a lump-sum government transfer.

For the cases where emissions rights are traded between countries, each SGM region is allocated an initial number of carbon emissions permits based on the stated mitigation policy (e.g., 1990 emissions levels for the M1990 scenario). Carbon permits can then be traded between countries at a price that clears the global market in these permits.

Modes of Operation

All of the SGM regions were initially developed as single-region models with a base year of 1985. Each regional model operates in five-year time steps generally through 2030, 2050, or 2100. Most of the single-region models were developed in collaboration with experts from that country. It is possible to run all of the regions individually or simultaneously in a global model with international trade. The three modes of operation for the SGM are:

1. Single Region
2. Global with Partial Market Clearing
3. Global with Full Market Clearing

Single-region operation. For each SGM region, all produced goods are classified as being tradable, nontradable, or traded at a fixed quantity. When SGM regions are operated independently, a fixed world price is assumed for certain tradable goods; regions may import or export as much of that good as desired at that fixed world price, subject to an overall balance of payments constraint. For all nontradable goods, the quantity of trade is fixed in advance. The following assignments are used when the United States model is operated independently:

Numeraire Sector:	everything else (price always equals 1)
Fixed World Price:	crude oil
Fixed Trade Quantities:	agriculture, coal, nuclear fuel, refined petroleum, electricity
Nontradables:	distributed gas, land, labor

For each region, the large 'everything else' sector is the numeraire, with its price fixed at 1 for all time periods. The prices of the other sectors in the economy are reported relative to this fixed value. The 'everything else' good is a tradable good for all regions. An exogenous balance-of-payments constraint is specified in advance for each region. Most regions are assumed to move linearly from a historical trade balance in 1985 to balanced trade by 2005.

Given a trial set of prices, the SGM computes supply and demand for all producing sectors and primary factors of production. Markets for the nontradables and goods traded at fixed quantities are brought into equilibrium by searching for a set of prices that equate supply and demand. Prices are adjusted until supply and demand are within 0.01% of each other.

Global model with partial market clearing. The global version of the SGM is used when there is at least one market that must clear globally. For the scenarios described in this paper, that market is tradable carbon emission permits. The model searches for a global carbon tax, which can be interpreted as a world carbon permit price, that clears the market for permits.

Each region is initially allocated a number of carbon permits and may trade those permits at the world permit price. Some regions will be sellers of permits and some will be buyers. After trading permits, all regions must hold permits equal to the domestic level of carbon emissions.

All regions are still subject to a period-by-period balance of payments constraint. The model does not allow borrowing to pay for carbon emissions permits. Imports of permits must be paid for with exports of some other good.

Global model with full market clearing. There are no longer any markets with a fixed world price. A set of world prices is found that clears all world markets. Also, world markets can be created for goods that were traded in fixed quantities in the single-region model.

All of the scenarios described in this paper were run in the second mode, global with partial market clearing. This mode was chosen for two reasons. The first is that we chose to adopt a fixed time path of world oil prices for SGM model runs that were completed for the United States Government during the spring of 1997. This meant that the world oil market would not be allowed to clear in the model. The second reason is that model results are often easier to interpret when some variables in the model remain predetermined over time.

Data Requirements

Three types of data are used to construct and calibrate each region of the SGM:

1. Economic and Demographic Data
2. Energy Balances
3. Technology Descriptions

Economic data include input-output tables and supplemental information from the national income accounts. Population projections were obtained from the World Bank. Energy balance tables were obtained either from the International Energy Agency or from government agencies within a region.

Input-output tables describe, in value terms, the flow of goods between industries and consumers in an economy. However, a model concerned with quantities of carbon emissions must also be concerned with quantities of energy. An input-output table alone is not sufficient to determine the quantities of oil, gas, coal, electricity, and refined petroleum that are produced and consumed. Supplemental information on energy quantities is required to map currency units from an input-output table to energy units needed to calculate levels of carbon emissions. We combine economic input-output tables with energy balance tables to create a hybrid input-output table with units of joules for energy products and real dollars for all other products. Miller and Blair (1985) provide a general description of, and the motivation for using, hybrid input-output tables.

Individual energy technologies are characterized by the annualized cost of providing an energy service. Data needed to determine the annualized cost include capital cost, equipment lifetime, annual fuel requirements, the interest rate, and other annual maintenance and operating costs.

REFERENCE CASE AND CALIBRATION

The cost of reducing greenhouse gas emissions is dependent on the reference case. The higher the growth rate of emissions in the reference case, the greater the cost of returning to 1990 emissions. Therefore, much effort is expended to create an acceptable reference case before running any of the mitigation scenarios.

Results for this study are reported for the years 1990 through 2020. The United States reference case was closely calibrated to the Annual Energy Outlook 1997 (AEO97). Since AEO97 projects only up to the year 2015, projections beyond 2015 are SGM model results and are not calibrated to any other established projections. Projections of carbon emissions, population, gross domestic product (GDP), energy consumption, and electricity generation for the United States are described below.

For the other global regions, economic and energy consumption growth rates were roughly calibrated to regional projections from the World Energy Outlook 1996 (WEO96). For the Eastern Europe and Former Soviet Union regions, projected energy consumption levels were adjusted downward from the WEO96 projection to reflect recent events. Population projections for all regions with the exception of the United States were set exogenously based on the World Population Projections 1994-1995, published by the World Bank. The United States population projection was set according to AEO97 projections. As mentioned earlier, the international crude oil price trajectory was also taken from the AEO97. Prices for all other fuels and goods in the model were determined endogenously.

The general calibration procedure was to first match GDP growth by adjusting parameters that control total factor productivity in the 'everything else' sector. Then energy consumption by fuel was calibrated by adjusting input-specific technical change parameters. Carbon emissions are an output of the model derived directly from primary energy consumption by applying fuel-specific emission factors.

Carbon Emissions

In 1990, total carbon dioxide emissions from the combustion of fossil fuels in the United States were 1,350 million metric tons of carbon. Model results show that total carbon dioxide emissions continue to rise as fossil fuel consumption increases and emissions reach 1,871 million metric tons by 2020. This amounts to a 39 percent increase in total emissions and an emissions growth rate of 1.1 percent per year. Reference case carbon emissions were shown earlier in Figure 1.

Gross Domestic Product

The two most important determinants of GDP are population growth and rates of change in productivity. Total population levels for the United States were taken directly from AEO97. United States population grows from 250 million in 1990 to 323 million in 2020. This represents an annual population growth rate of 0.85 percent per year.

GDP for the United States was matched to AEO97 projections by changing the total factor productivity parameter for the 'everything else' sector. Beginning with the 1990 GDP of 6.1 trillion dollars, the economy grows at nearly 2 percent annually to reach 10.6 trillion dollars by 2020.

Energy Consumption

Total energy consumption from 1990 to 2015 was calibrated to within 2 percent of projections from AEO97. Energy consumption by fuel is shown for the United States in Figure 2. Total consumption increases from 86 EJ in 1990 to 118 EJ in 2020. This increase represents an average annual growth rate of 1.1 percent over that period. The annual growth rate in energy consumption declines over time and by 2020 decreases to 0.5 percent per year.

Petroleum remains the major source of energy through 2020, but its share of total consumption declines over time, giving way to natural gas and, to a lesser extent, renewable energy sources. Coal is the third largest source of energy and its consumption grows steadily at slightly less than 1 percent per year. Nuclear energy's contribution to energy consumption declines over time.

[Figure 2. Energy Consumption – United States Reference Case]

Energy consumption does not grow as fast as GDP, which results in the energy-GDP ratio falling over time at an average annual rate of 1.0 percent per year. Figure 3 shows the energy-GDP ratio generated by the SGM for the United States reference case.

[Figure 3. Energy-GDP Ratio – United States Reference Case]

Electricity Generation

Projections of electricity generation are similar to those of the AEO97. SGM total electricity generation results are higher than the AEO97 projections by approximately 10 percent. Electricity generation from natural gas is the reason for the higher result. Total electricity generated in 1990 is nearly 11 EJ, which grows at 1.5 percent per year and expands to 17 EJ by 2020. The major source of electricity is the combustion of coal; however, electricity generation from natural gas plays a significantly larger role with time. In 1990, electricity generation from coal contributed 53 percent of the total generation, while that from natural gas combustion contributed 17 percent of the total. By 2020, the shares of electricity generation from coal and natural gas are closer. Electricity generation from coal and natural gas comprise 44 and 34 percent shares of the total, respectively. Highly efficient and low-cost natural gas combined cycle power plants incorporated into the SGM contribute to the growth of natural gas as the choice fuel for electricity generation. Nuclear power's contribution to the overall demand for electricity declines with time as existing power plants are retired and no new additional plants are constructed.[4] Renewable energy sources for electricity generation include hydroelectricity, solar photovoltaics and others. Generation of electricity from renewable sources increases slightly from 1990 to 2020; however, renewable energy's share of total electricity remains below 10 percent of the total.

COST OF EMISSIONS MITIGATION

[4] The assumption of no new starts reflects a de facto nuclear moratorium. Were nuclear power to be allowed to compete against other energy forms on the basis of price alone, the model would continue to build new facilities.

Although this exercise employed the 12-region version of the SGM, discussion of results in this paper will focus on the United States. The SGM provides output on regional GDP and its components and a detailed description of the composition of energy supply. In this analysis, we focus on the broad economic impacts to the economy. Specifically, we discuss the permit prices required to meet the various mitigation requirements and the costs to the United States economy of undertaking such policies. We also discuss the impacts of the domestic carbon taxes on energy consumption.

Permit Prices

Table 3 shows the permit prices by trading regime required for the United States to meet its emissions targets under the four mitigation scenarios. Permit prices in the United States must reach $108 per metric ton of carbon to reduce United States emissions to 1990 levels in 2010 in the independent mitigation case. This price increases significantly with the tighter constraint imposed under the M1990-10% case. Permit prices in the M1995 and M1990+10% scenarios are very similar as only 5 TgC separate the constraints in the two cases in 2010.

Table 3. United States Carbon Taxes Required to Meet Policy Goal
Eastern Europe & FSU Allocated Reference Case Permits
(1992 US$ per Metric Ton of Carbon)

- EE+FSU have higher permits in FY so
- Also umbrella & 6 gases lower.

	Independent Mitigation		Annex I Joint Mitigation		Annex I Mitigation with Global Trade	
	2010	2020	2010	2020	2010	2020
M1990	108	170	72	87	26	27
M1990+10%	60	110	42	58	16	18
M1990–10%	173	260	109	122	38	36
M1995	61	112	70	106	26	32

Permit prices fall as more regions are included in the market for carbon permits. In the independent emissions mitigation case, carbon emitters in the United States may undertake emissions mitigation options available only within the United States. In the Annex I joint and global permit cases, however, regions are included that have mitigation options with significantly lower costs, thereby lowering the marginal cost to the carbon permit market of meeting the desired emissions targets. As we will discuss, this 'where' flexibility in meeting emissions targets has a significant impact on costs as well as permit prices.

A fixed emissions level and an increasing reference case emissions level imply both a rising percentage emissions reduction and a rising price of meeting the fixed emissions target. Increasing population in the United States, and the economic growth that accompanies it, put upward pressure on emissions that, in turn, forces larger shifts away from coal toward natural gas and renewable energy sources. The availability of relatively inexpensive abatement options in the developing world allows the permit price to remain relatively constant over time in those cases.

As the permit prices decrease across trading regimes, the United States purchases increasing quantities of permits from abroad, thereby enabling it to emit more than its allocated permits alone would allow. Figure 4 shows United States emissions for the M1990 case across the three trading regimes. Under the independent emissions mitigation regime, the United States is limited to emitting only what it is allocated under the scenario, its 1990 emissions level. With Annex I trading, however, the United States purchases 209 TgC worth of permits in 2010 and 244 TgC in 2020 from the Former Soviet Union and Eastern Europe. The purchases increase to 316 TgC and 436 TgC in 2010 and 2020, respectively, under the global trading regime. Again, 'where' flexibility reduces the amount by which a permit-buying region must reduce its emissions and, therefore, reduces the cost to the region.

[Figure 4. United States Carbon Emissions – M1990 Cases]

The M1995 Annex I trading case is the only case in which the United States sells permits to other regions. The permit price under independent mitigation in 2010, as shown in Table 3, is less than that shown under Annex I trading. Because the United States can mitigate emissions less expensively in 2010 than other Annex I regions, it reduces its emissions beyond the required 1995 target and sells permits to other Annex I regions. By 2020, however, the United States begins to purchase permits from Eastern Europe and the Former Soviet Union.

Energy Consumption

Emissions mitigation is achieved primarily through two mechanisms: energy conservation - reduction in total energy consumption - and replacement of coal-fired capacity with less carbon-intensive fuels such as natural gas and renewables in the electricity sector. In the no-trading cases, fuel switching from coal to natural gas and renewable fuels in the electricity generation sector accounts for roughly 60 percent of the reduction in total emissions. Energy conservation makes up the remaining 40 percent of the reduction. The domestic carbon tax of $108 in 2010 in the M1990 case results in a reduction of total energy consumption by 14 percent relative to the reference case. Consumption of coal drops by 57 percent while consumption of petroleum drops by 7 percent. Consumption of natural gas, however, increases by 4 percent due to fuel switching. Figure 5 shows energy consumption by fuel in the year 2010 for the four mitigation scenarios. Note that even when emissions are returned to 1990 levels, the scale of the total energy system is not. The fuel switching mentioned above allows the emissions targets to be met without reducing total consumption by the same percentage as the required reduction in emissions.

[Figure 5. United States Energy Consumption in 2010]

Fuel substitution in the electricity sector results in the share of electricity generated from coal dropping from 45 percent in the reference case to 20 percent in the M1990 case. The reduction in electricity generation from coal is compensated for by increased generation from natural gas. The share of electricity generation from natural gas increases from 29 percent in the reference case to 51 percent M1990 case.

As discussed above, the domestic cost of stabilizing emissions at 1990 levels in 2010 without trade is $108 per metric ton carbon. This cost roughly reflects the cost of abandoning existing coal-fired power generation capacity and replacing it with a new combined-cycle natural gas-fired unit. A $108 per metric ton tax adds approximately $0.02 per kilowatt-hour to the operations and maintenance (O&M) cost of power generation in a coal-fired plant. This additional cost makes the O&M cost of the coal plant higher than the levelized cost of installing a new gas-fired combined-cycle unit, roughly $0.05 per kilowatt-hour. The $108 tax, therefore, provides an emissions mitigation plateau for permit prices that is not exceeded until most of the existing coal capacity is replaced.

Certain caveats apply to the discussion above concerning the marginal cost of substituting natural gas-fired electricity generation capacity for existing coal-fired capacity. The cost analysis requires that the tax be levied indefinitely. If the tax policy is believed to be only temporary, the amount of substitution is likely to be much less substantial and the tax level required for stabilizing emissions could be higher. The tax level required for mitigation also depends on the cost of developing the infrastructure necessary to supply natural gas to potential new users. Extending pipelines to particular areas, for example, might increase the cost of gas enough so as to discourage switching from coal-fired plants in those areas.

Cost Calculations

A very convenient way to characterize the response of any SGM region to a carbon tax is by constructing a marginal cost of carbon curve. Figure 6 is a scatter plot of various carbon taxes applied to the United States economy and the corresponding reduction in carbon emissions. Data points plotted in Figure 6 are from the four independent mitigation scenarios for the United States. Note that a positive tax is required to achieve any reductions in carbon emissions.

[Figure 6. Marginal Cost of Carbon]

The marginal cost curve is used to calculate one measure of cost that we will call the *direct cost*. For any level of carbon emissions mitigation, the direct cost is defined as the area under the marginal cost curve up to that amount of mitigation.[5] While the first units of emissions reductions are very inexpensive; successive units become more and more expensive. So, as the constraints on emissions become tighter across cases and over time, the cost of mitigation increases. Figure 7 shows the direct costs for the United States for the four independent mitigation scenarios. Direct costs are shown at 5-year intervals through 2020 as a percentage of GDP. These costs are plotted as negative numbers.

[Figure 7. Cost of Emissions Mitigation – No Trading]

[5] Note that these costs do not include the costs of establishing a domestic or international permit trading system nor do they include the transaction costs associated with permit trading among firms and/or regions.

Figure 8 focuses on the M1990 case and shows how costs to the United Sates are reduced with trade in emissions permits between countries. The 'independent' cost line shown in Figure 8 is the same as the M1990 cost line in Figure 7. In 2010, costs are reduced somewhat with Annex I trading and reduced by about one-half with global trading. In later years, the flexibility in where emissions reductions are undertaken impacts mitigation costs even more significantly.

[Figure 8. Illustration of 'Where' Flexibility – Costs for M1990 Cases]

Cost calculations for the emissions trading cases are different than in the independent case. Costs for the trading case take into account the value of permits traded. For a buyer of permits, such as the United States, net cost includes the direct cost plus expenditures on carbon permits. A breakdown of these two cost components is shown for the M1990 Annex I trading case in Figure 9. Direct cost is roughly half of the net cost. The remaining cost, the difference between the 'direct cost' and 'net cost' lines in Figure 9, is the value of emissions permits that would be purchased from other Annex I countries.

[Figure 9. Cost Breakdown – M1990 Annex I Trading Case]

Impact of Alternative Permit Allocation Approach

The results discussed thus far have been based on the assumption that Eastern Europe and the Former Soviet Union are allocated permits equal to the minimum of their reference-level emissions and the policy-level emissions. This section will discuss the impacts of an alternative permit allocation method in which Eastern Europe and the Former Soviet Union are granted permits equal to their policy-level emissions in every period. Recall that 'policy-level' refers to the emissions target set by the chosen mitigation policy. For example, the policy-level emissions in the M1990 case would be 1990 level emissions starting in 2010, and for the M1995 case they would be 1995 level emissions beginning in 2010. This assumption results in the 'paper credits' discussed earlier that significantly impact the permit prices required to meet Annex I emissions targets in the Annex I and global trading cases.

Table 4 shows the permit prices required to meet the policy goal under the policy-level permit allocation approach. The prices required for independent mitigation in the United States do not change from Table 3 above because the paper credits in those cases are not available for purchase outside Eastern Europe and the Former Soviet Union. Permit prices also remain unchanged under the M1995 case because by that time the two regions have already suffered the worst of their economic downturns so that emissions levels are at their lowest point in the 1990 to 2020 time frame. The permit prices under the other trading scenarios are significantly less under this allocation approach, however, because the regions are able to sell the paper credits without incurring any cost domestically. In the M1990 case in 2010, the paper credits allocated to Eastern Europe and the Former Soviet Union account for 37 percent of the emissions reductions necessary for the remaining Annex I regions to meet their target emissions. This addition of permits available for purchase reduces the permit price by $33, or by 46 percent, relative to the permit price under the reference-level allocation approach. Figure 10 shows the difference in permit prices for the M1990 case with Annex I trading between the two permit allocation approaches in 2010 and 2020.

Note that the difference decreases over time as emissions in Eastern Europe and the Former Soviet Union approach the policy goal.

Table 4. United States Carbon Taxes Required to Meet Policy Goal Eastern Europe & FSU Allocated Policy-level Permits (1992 US$ per Metric Ton of Carbon)

	Independent Mitigation		Annex I Joint Mitigation		Annex I Mitigation with Global Trade	
	2010	2020	2010	2020	2010	2020
M1990	108	170	39	73	15	22
M1990+10%	60	110	6	35	2	11
M1990–10%	173	260	88	124	31	36
M1995	61	112	70	106	26	32

[Figure 10. Permit Prices under Alternative Permit Allocation Methods for EE & FSU – M1990 Annex I Trading Case]

The lower permit prices under the policy-level approach result in lower total costs of emissions mitigation to the United States. In the M1990 Annex I trading case, costs as a percentage of GDP are reduced from 0.18 percent under the reference-level allocation approach to 0.12 percent under the policy-level approach in 2010. Figure 11 shows costs as a percentage of GDP for the M1990 Annex I trading case for both allocation methods.

[Figure 11. Cost of Emissions Mitigation under Alternative Permit Allocation Methods for EE & FSU – M1990 Annex I Trading Case]

DISCUSSION

In this section, we summarize some of the insights gained from our modeling activities using the SGM. First, economic costs depend a great deal on our assumptions about future carbon emissions. Second, several measures of cost are available from the SGM. Third, the distribution of costs among countries in a system of global permit trading is sensitive to assumptions on exchange rates as well as the initial allocation of permits. Fourth, any system of global trade in carbon permits implies potentially large transfers of wealth from one region to another. Finally, we discuss how some of our assumptions affect the results on costs.

Role of Reference Emissions in Shaping Marginal Mitigation Costs

All of the results in this study depend on assumptions used to create a reference emissions scenario from the present to 2020. The amount of mitigation required to return to 1990 levels depends directly on reference case emissions for each region. In the Annex I trading cases, carbon permit prices are particularly sensitive to reference scenarios for potential sellers of permits, especially Eastern Europe and the Former Soviet Union.

Among the Annex I countries, projecting future carbon emissions is especially uncertain for Eastern Europe and the Former Soviet Union. Of particular importance is when emissions in these regions will once again reach 1990 levels. If this point is reached before 2010, then we model EE and FSU just as any other Annex I country. If this point is reached after 2010, then emissions restrictions are not binding in EE and FSU until that point in time.

Measuring and Reporting Costs

At least two measures of cost are available from the SGM and from other models as well. The first measure, which we call the *direct cost*, can be thought of as either a deadweight loss or the integral under the marginal cost curve for carbon. Using either approach, direct cost is approximately equal to one-half of the carbon tax (or permit price) times the reduction in carbon emissions. For the permit trading cases, direct costs are then adjusted by the value of transfer payments required to purchase or sell permits. This measure of net cost is simple to construct and is comparable across models.

Of ultimate interest, however, is the net impact on some broader measure of economic activity (such as GDP) or on economic welfare (such as real consumption). There are many reasons why the change in GDP (or real consumption) is different than direct cost net of transfer payments. These other components of cost include the effects of pre-existing distortionary taxes, changes in terms of trade, and how tax revenues are recycled. In addition, measurement of GDP (or real consumption) depends on the choice of index and base year used to construct that index. This reflects real-world problems in constructing a quantity index for GDP when relative prices are changing.

Foreign Exchange Rates

Permit prices for the global permit trading cases are very sensitive to assumptions about exchange rates. And while the United States follows a largely free market approach to exchange rates, most developing nations do not. Therefore it may be perfectly reasonable to assume that over the long-term the United States exchange rate with other free market trading partners would tend toward the purchasing power parity rate, this assumption is questionable with other partners. This is particularly true for developing countries where market exchange rates, in local currency per U.S. dollar, can be three to five times the corresponding exchange rate based on purchasing power parity. A global permit price of $100 per metric ton translates, at market exchange rates, into a much higher relative price in the developing countries than in the United States.

Exchange rates based on purchasing power parity are usually used to compare income levels between countries, but market exchange rates must be used for goods actually traded between countries. This creates a potential problem for developing countries considering participation in a global permit trading program; carbon permits would be traded at market exchange rates, while GDP losses are better measured using purchasing power parity. For developing countries, losses in GDP could be greater than the value of carbon permits sold.

International Transfer Payments

We have modeled an international system of carbon permit trading that implies potentially large wealth transfers from buyers to sellers of permits. These transfers also change the pattern of other goods traded internationally. For a buyer of permits, this annual transfer of wealth is equal to the annual quantity of permits purchased times the world market price of the permits. The size of these transfers depends directly on the initial allocation of permits between countries. The initial allocation determines not only the amount of permits traded by each country, but also whether a country is a buyer or seller of permits.

For this study, the initial allocation of permits among Annex I countries is simply the emissions targets defined by the four mitigation scenarios. Non-Annex I regions were allocated permits equal to reference case emissions. These four mitigation scenarios represent only a few of the many possible ways of setting global emissions limits and allocating emissions rights among countries to meet those limits. Each allocation implies a different pattern of wealth transfers among countries.

Each region in the SGM is assigned a period-by-period balance of payments constraint. Buyers of carbon permits must, therefore, export more of other traded goods than otherwise to pay for the purchased permits. Conversely, sellers of permits use the permit revenues to increase imports of other goods.

Sensitivity of Costs to Model Assumptions

Economic costs reported by the SGM for the United States are sensitive to many of the model inputs. These include the choice of exchange rate, the inclusion of paper permits, and the method of revenue recycling.

If purchasing power parity exchange rates were used instead of market exchange rates for the developing countries, then any given world permit price would translate into a lower carbon tax in that country's local currency. For global trading cases, this would increase the global permit price needed to meet a global emissions limit, and the SGM would report higher costs for the United States.

For Eastern Europe and the Former Soviet Union, carbon permits were allocated based on their reference case, and not on 1990 emissions. If we had allocated permits based on 1990 levels, these extra 'paper credits' would create a less-stringent Annex I target. The model would then report a lower permit price for the trading cases, and a lower cost to the United States.

In this study, we assumed that all revenues from a carbon tax would be recycled as a lump sum to consumers. Another option is to use the carbon tax revenues to offset other taxes. This has the potential to reduce overall costs, since carbon tax revenues would displace other distortionary taxes.

KEY OBSERVATIONS

Economic costs are reduced with a permit-trading program that equalizes the marginal cost of carbon between countries. The least expensive emissions reductions are taken first, regardless of where they occur. Costs shown in Figure 8 provide a good example of the importance of this 'where' flexibility.

For the four mitigation scenarios in this study, economic costs to the United States remain below 1% of GDP through at least the year 2020. This was the case even in the scenarios where the United States met its mitigation targets without international trading of carbon permits.

Each region in the SGM can be characterized by a marginal cost of carbon curve, as was shown in Figure 6. This shows the approximate carbon tax required for any given level of carbon emissions reduction. For the amount of emissions reductions needed in 2010 to return to 1990 levels, a carbon tax of $108 per metric ton of carbon is required.

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Figure 1. Carbon Dioxide Emissions Scenarios for the United States

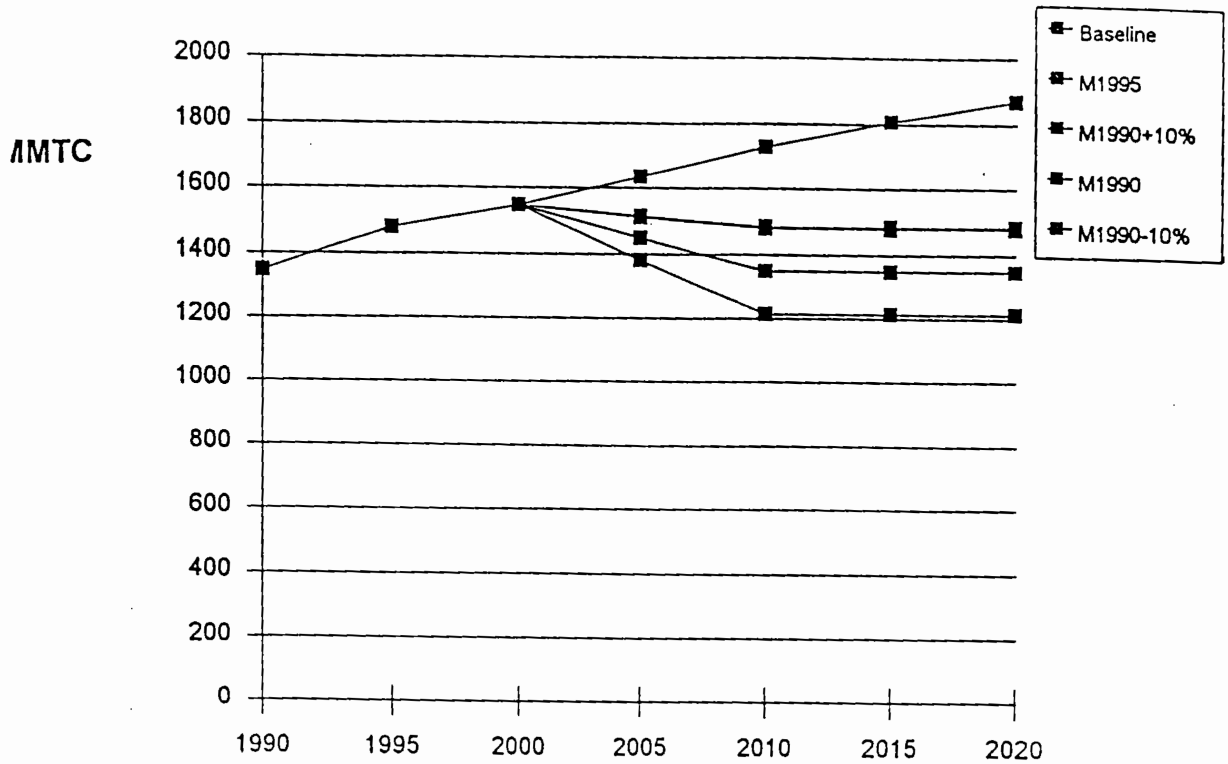


Figure 2. Energy Consumption United States Reference Case

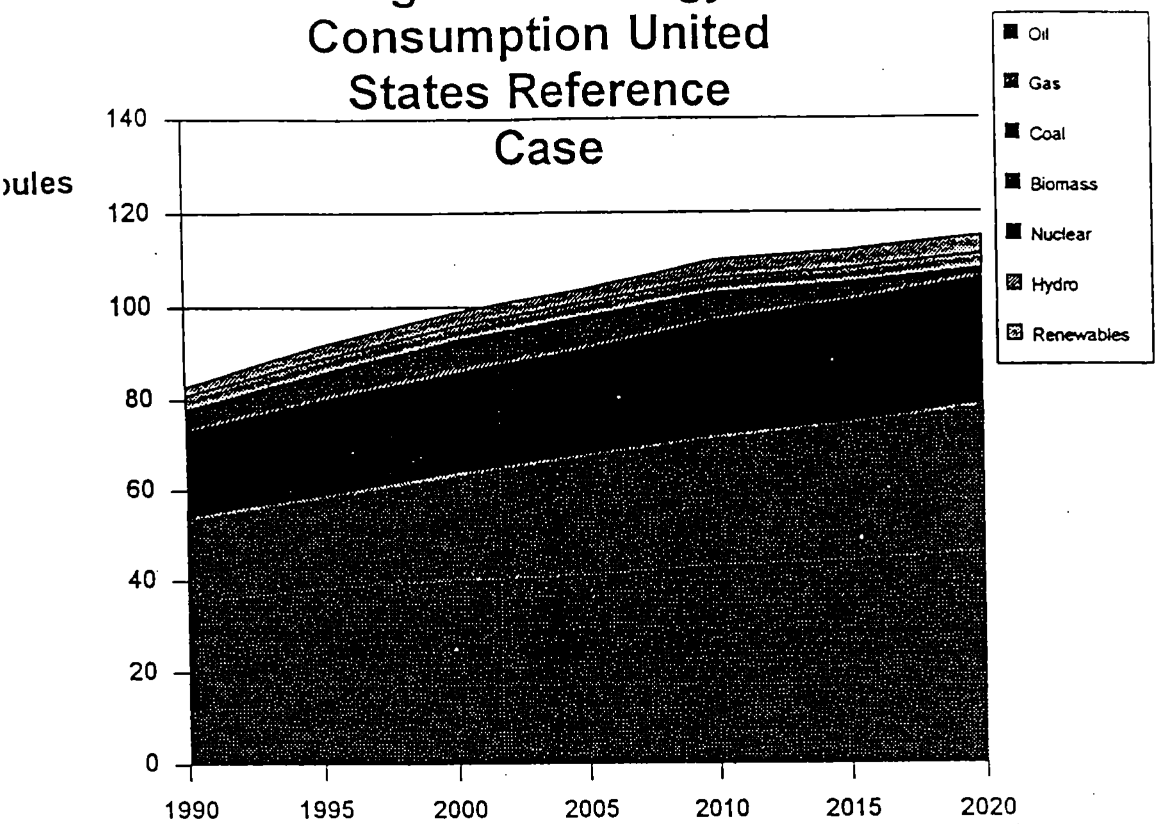


Figure 3.
Energy-GDP Ratio
United States
Reference Case

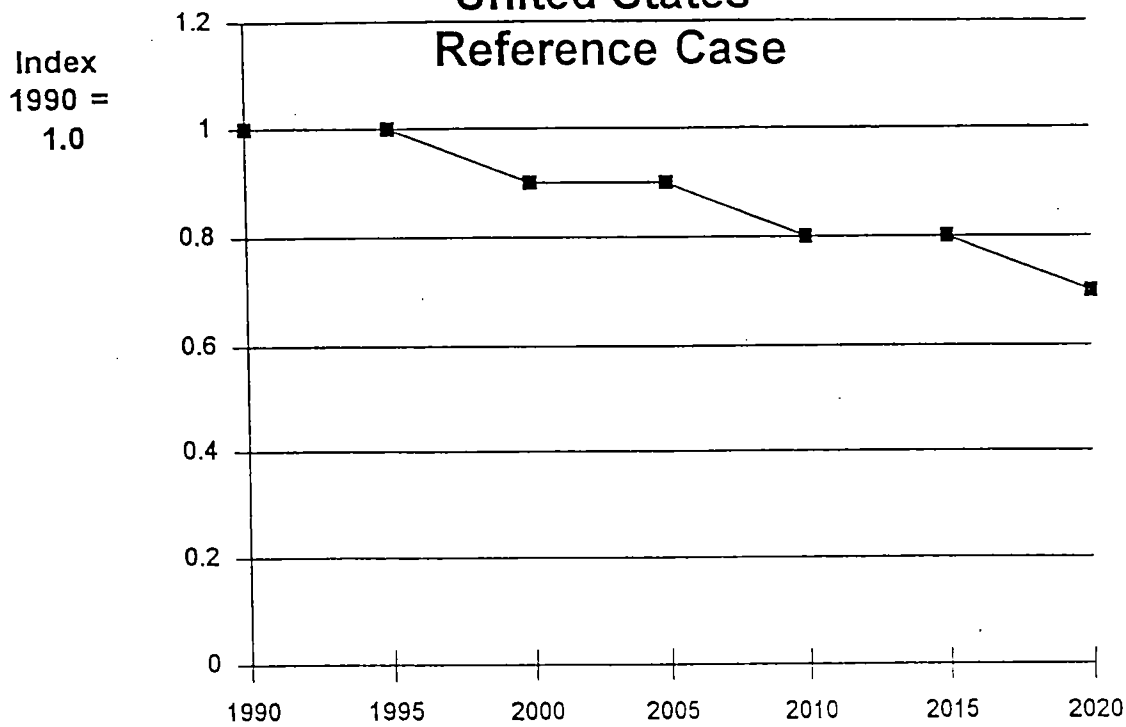
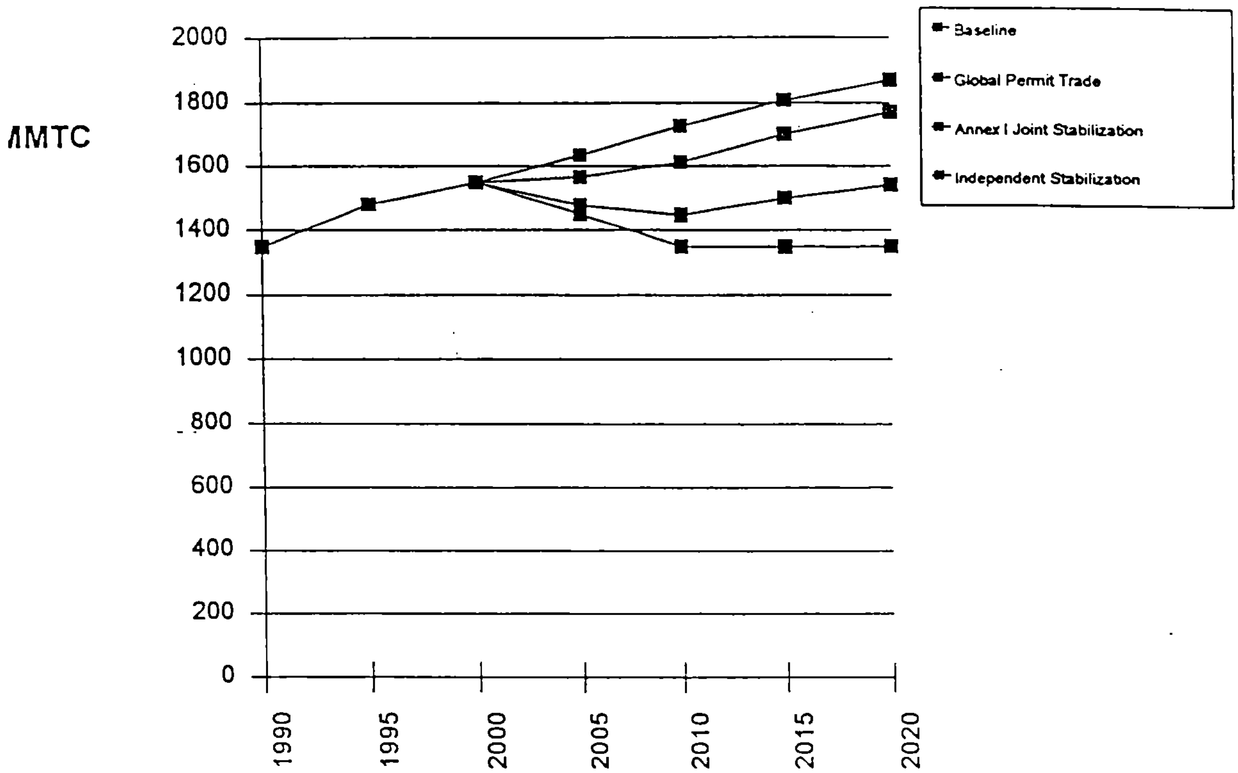


Figure 4. United States Carbon Dioxide Emissions M1990 Cases



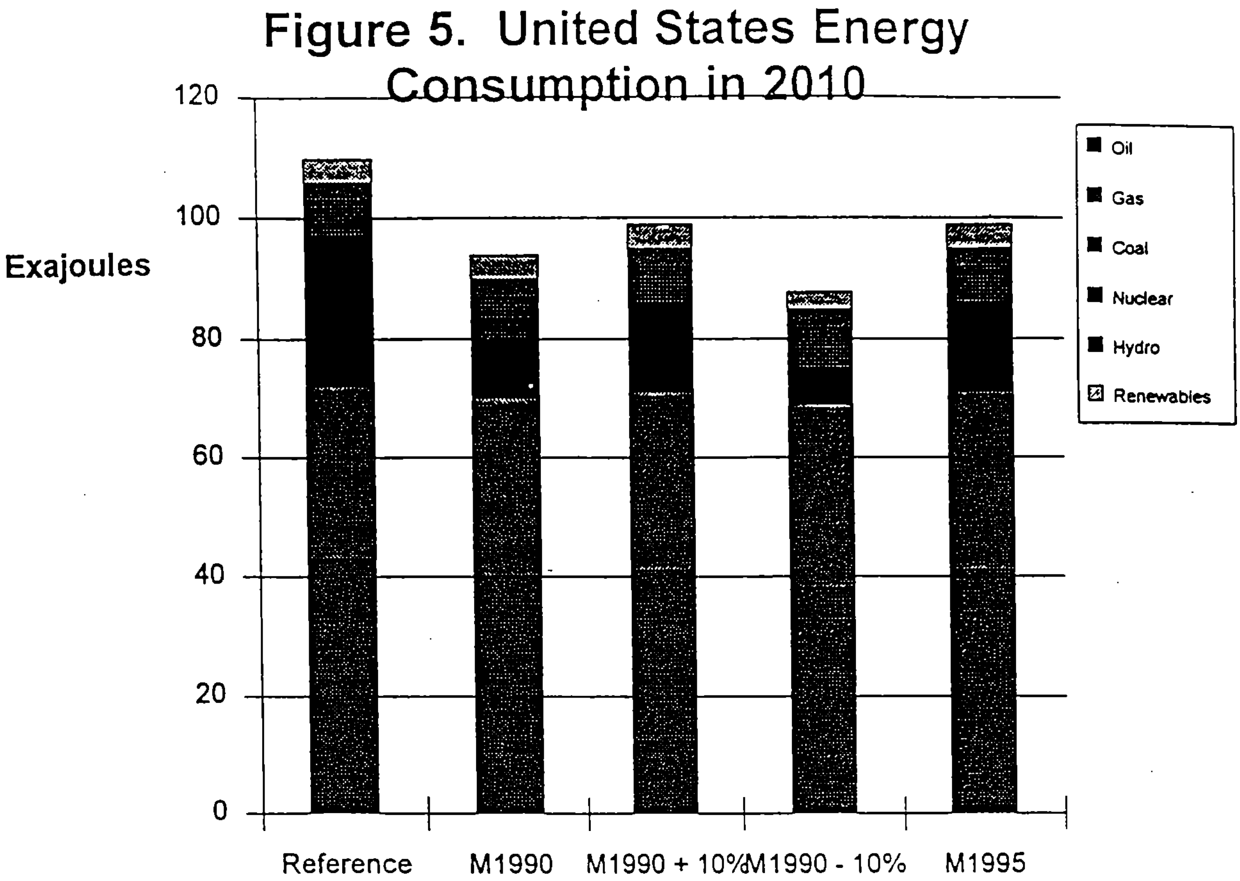


Figure 5. United States Energy Consumption in 2010
Exajoules
120
100
80
60
40
20
0
Reference
M1990
M1990 + 10%
M1990 - 10%
M1995
Oil
Gas
Coal
Nuclear
Hydro
Renewables

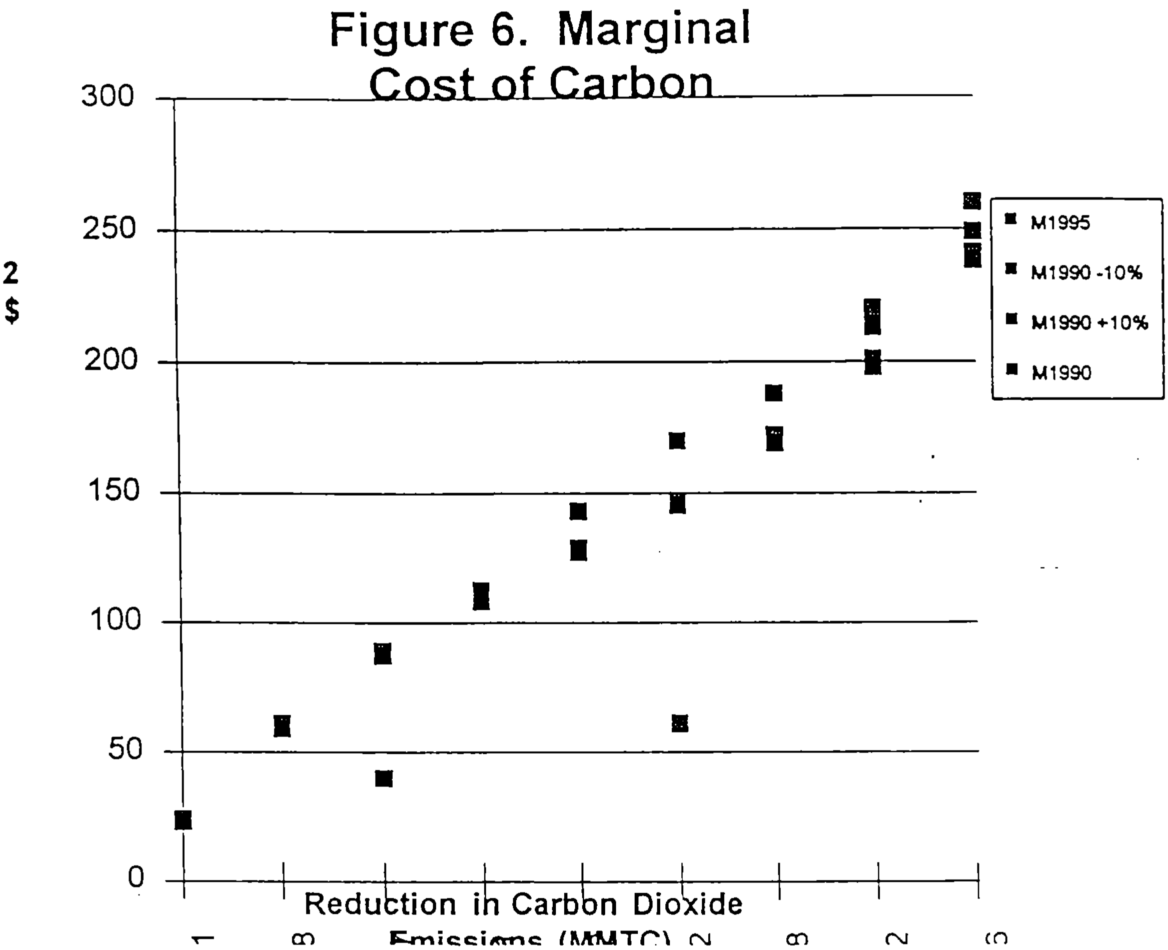


Figure 6. Marginal Cost of Carbon
300
250
200
150
100
50
0
2
$
M1995
M1990 -10%
M1990 +10%
M1990
Reduction in Carbon Dioxide Emissions (MMTC)

Figure 7. Cost of Emissions Mitigation No Trading

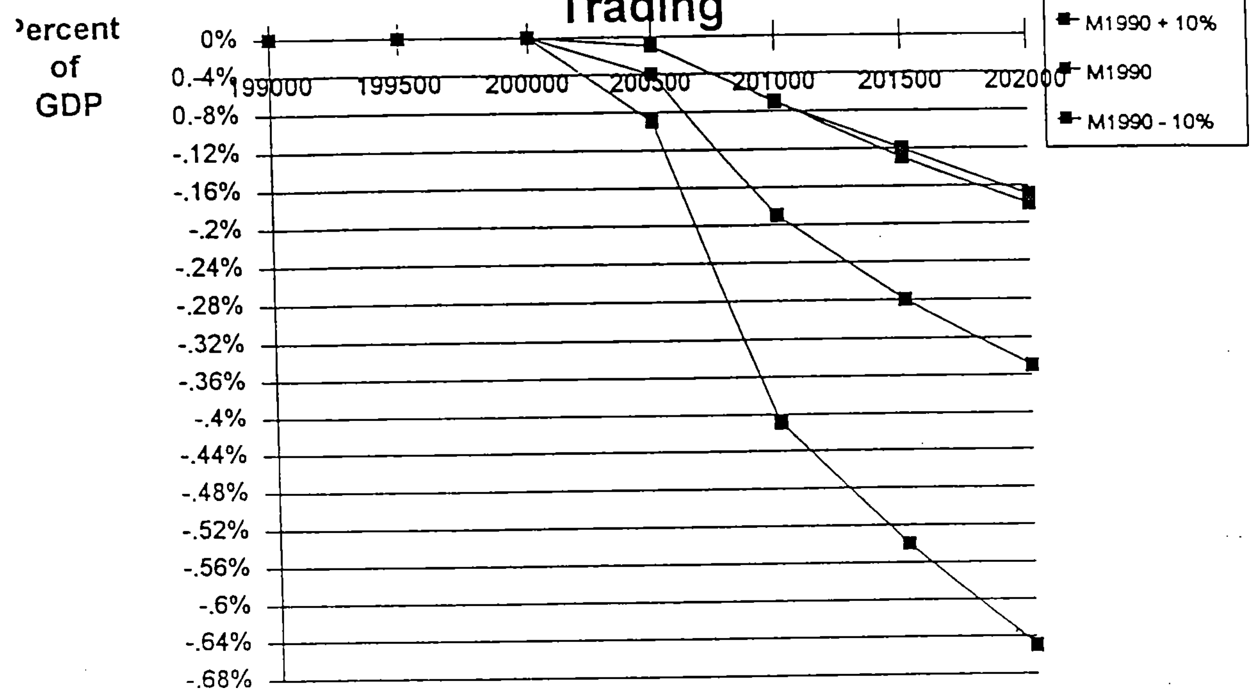
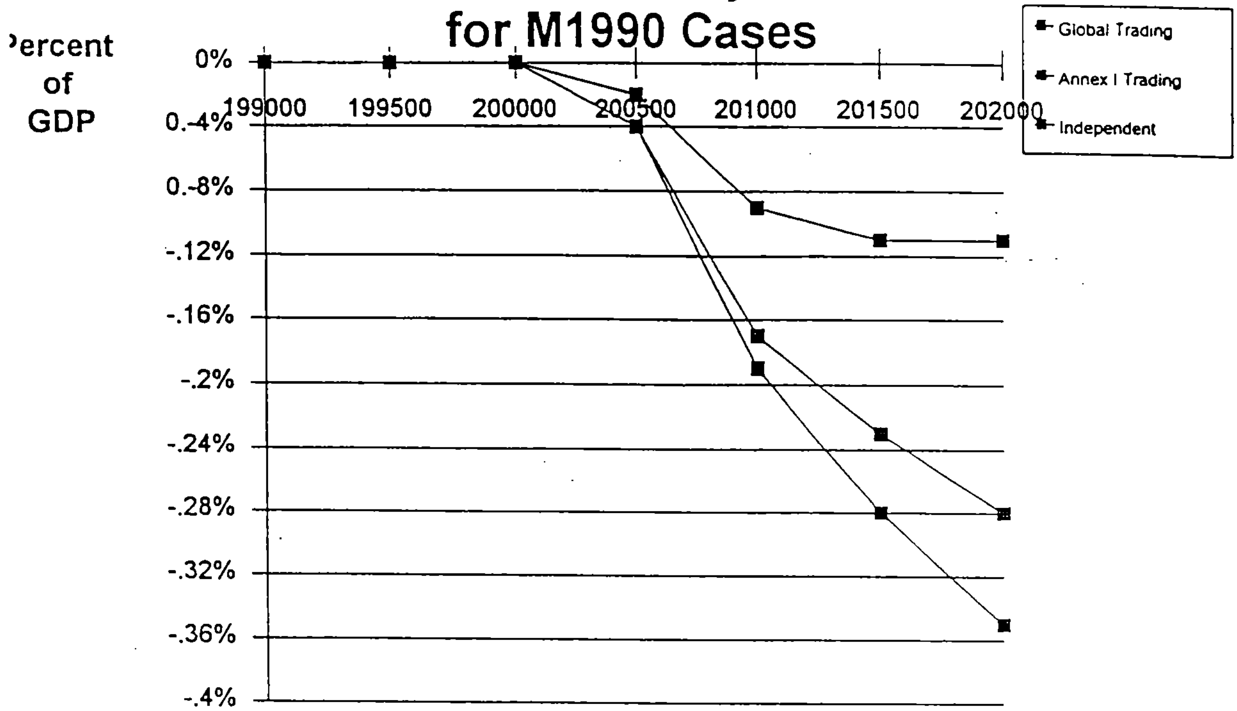


Figure 8. Illustration of 'Where' Flexibility Costs for M1990 Cases



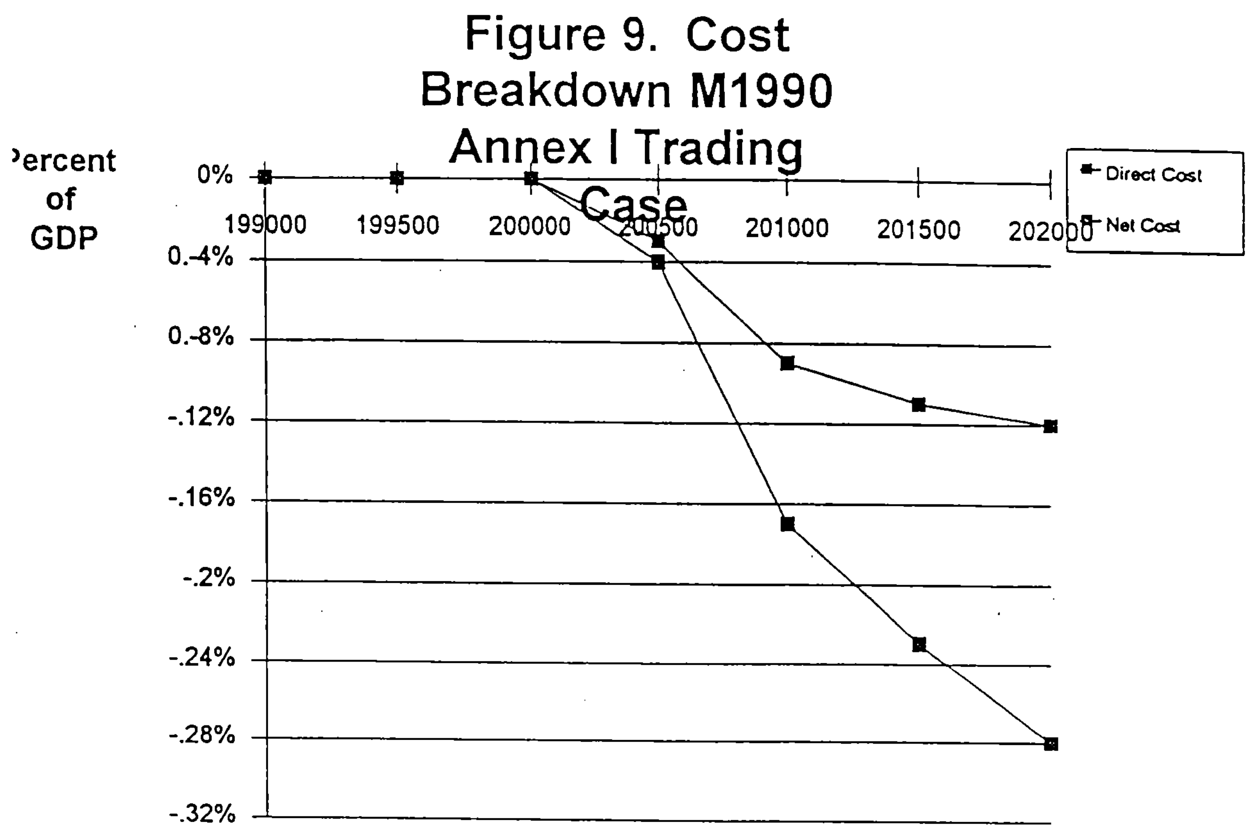


Figure 9. Cost Breakdown M1990 Annex I Trading Case
Percent of GDP
0%
0.-4%
0.-8%
-.12%
-.16%
-.2%
-.24%
-.28%
-.32%
199000
199500
200000
200500
201000
201500
202000
Direct Cost
Net Cost

Figure 10. Permit Prices under Alternative Permit Allocation Methods for EE & FSU: M1990 Annex I Trading Case

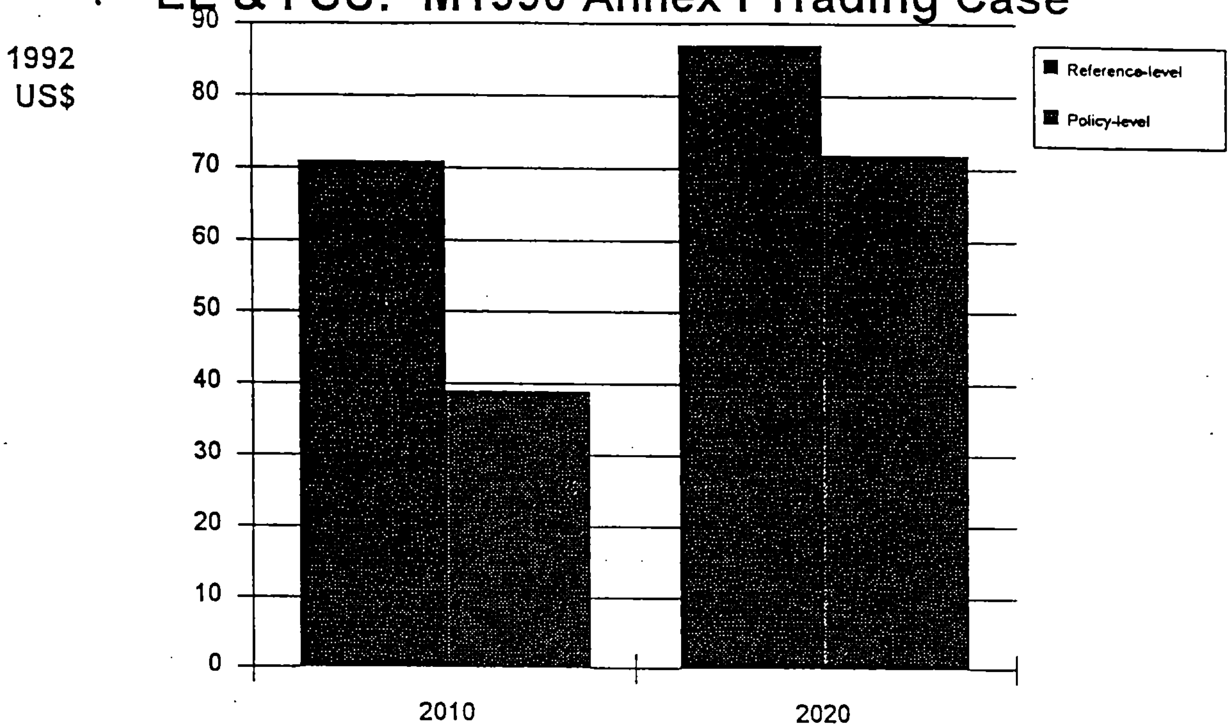
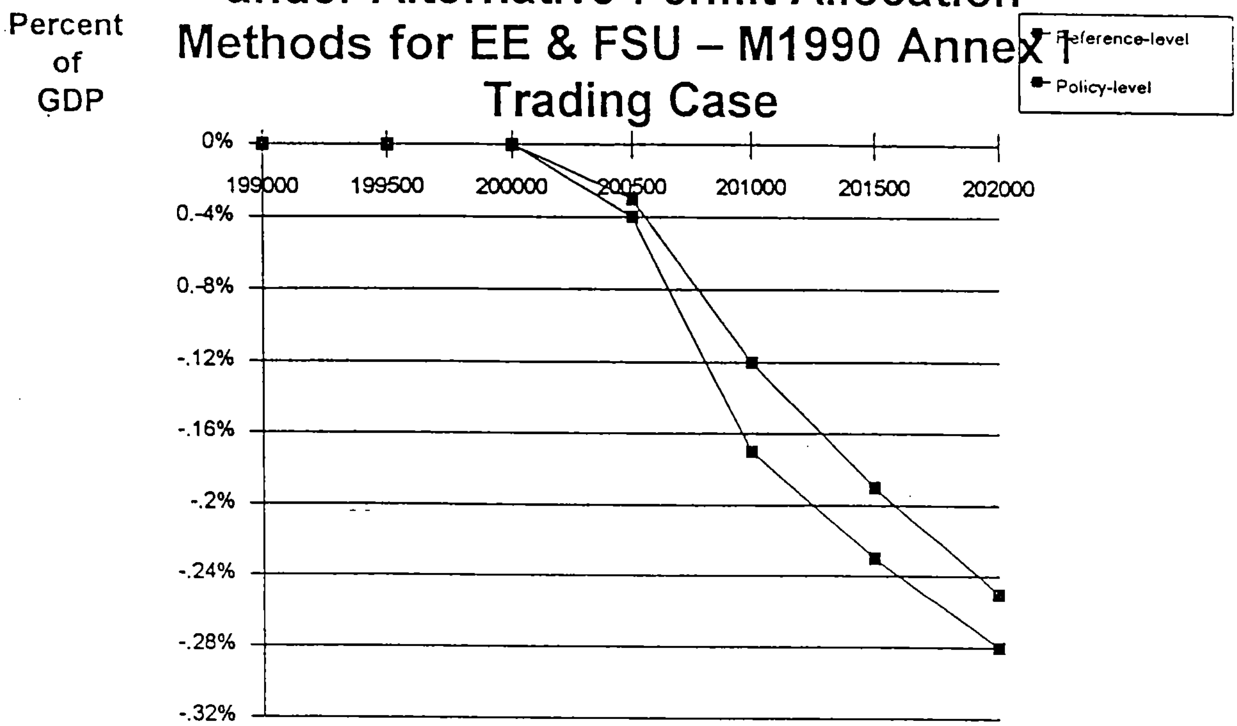


Figure 11. Cost of Emissions Mitigation under Alternative Permit Allocation Methods for EE & FSU – M1990 Annex 1 Trading Case



Ancillary Benefits

Research Briefs

RESOURCES FOR THE FUTURE

Impacts of Climate Change Mitigation on Other Environmental Problems

Mitigation policies for reducing the risks of climate change may have a variety of other effects on the environment. For example, policies to promote energy efficiency also are likely to reduce pollution associated with energy use, which can improve air quality and reduce harmful water pollution. Some effects could prove harmful, such as an increase in exposure to indoor radon from tighter buildings that may be constructed to improve energy efficiency or to avoid the effects of climate change. Similarly, wetlands could be damaged from the construction of floodwalls. Climate change may also alter baseline conditions for pollution risks -- that is, a warmer climate could enhance the formation of harmful pollutants under some conditions.

Building on recent research that has assessed pollution rates for specific industries and established the importance of regional characteristics in factoring the impact and costs of pollution, researchers at Resources for the Future (RFF) are examining this issue of co-control benefits. They are analyzing changes in the structure and regulation of the electric utility industry to provide a more comprehensive characterization of the benefits of different policies.

Several recent studies have employed dynamic computable general equilibrium models of the United States economy to estimate the compliance costs of various to reduce carbon dioxide (CO_2) emissions. An important aspect of these policies, says RFF's **Dallas Burtraw,** project coordinator, is the non-climate change benefits that may result. Preliminary research has looked at how these mitigation policies could affect emissions of pollutants other than CO_2 as well as possible economic benefits. But, says Burtraw, it has not accounted for regional profiles of emissions and their associated environmental impacts.

In the project's first phase, researchers are investigating how emissions of NO_x* and sulfur dioxide (SO_2) and concentrations of related pollutants associated with different CO_2 control policies are affected by restructuring in the U.S. electric industry. They are using the regional power trading and reduced form atmospheric transport components of PREMIERE (Primary Regional Environmental Model in Electricity Restructuring), a model developed at RFF to analyze the effects of increased inter-region power trading on regional air pollution as a result of restructuring.

In the project's next phase, researchers are creating a simulation model that takes selected results from CGE models, and adds a state or regional profile for projected changes in economic activity and associated emissions. This revised model will also include a library that shows geographic and demographic changes in population that are expected over time, and a reduced form atmospheric transport model to track concentrations of various pollutants, similar to the one constructed in PREMIERE.

Finally, researchers will use this model to incorporate RFF's health benefits model and other environmental models to construct a geographic and temporal profile of co-control benefits. Uncertainty will be explicitly modeled using a Monte Carlo analysis. The model will then be used in subsequent phases to investigate a variety of climate-related policy instruments. They seek to estimate their nonclimate-related benefits and test the validity of average estimates for economic benefits that have been used in previous studies. Researchers will pay special attention to co-control benefits in an international context, and, where possible, will develop new "rules of thumb" for transferring benefit estimates to other venues.

The project is part of RFF's Climate Economics and Policy Program, which aims to increase understanding and knowledge of the complex issues that must be addressed to design appropriate domestic and international climate change policies that are reliable and efficient.

# # #

* Many discussions of nitrogen-based air pollution refer to nitric oxide (NO) and nitrogen dioxide (NO_2) together as nitrogen oxides (NO_x). NO_2 is a brownish gas which is produced when NO emitted from power plants combines with oxygen already in the atmosphere. In the presence of sunlight and volatile organic compounds, NO_2 can contribute to the formation of ground-level ozone, or smog. NO_x can transform to nitrates in the atmosphere which, as a fine particulate, has effects on human health. Of the three electricity-related pollutants most responsible for current environmental damage -- NO_x, particulates, and sulfur dioxide -- NO_x currently merit the most immediate policy attention because emissions of NO_x are neither capped by environmental regulation nor controlled as effectively as particulates with current technology.

# # #

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FEATURE

The Kyoto Protocol: Unresolved Issues

By Raymond J. Kopp, Richard D. Morgenstern and Michael A. Toman

JANUARY 8, 1998 -- On December 10 1997, 160 nations reached an historic agreement in Kyoto, Japan on limiting emissions of carbon dioxide and other "greenhouse gases." The Kyoto Protocol calls for the industrialized nations — the so-called Annex I countries – to reduce their average national emissions over the period 2008-2012 to about five percent below 1990 levels. The U.S. pledged to reduce its emissions by seven percent below 1990, slightly less than the European Union and slightly more than Japan. The Protocol permits some industrialized nations to modestly increase their emissions and makes special provisions for the members of the former Soviet Bloc. None of the developing countries, including those with large and growing emissions such as India and China, is required to limit its emissions.

The protocol is broader than previous agreements in that it includes all the major greenhouse gases and takes into account emission changes resulting from changes in forest and land use patterns. The Protocol also contains the elements of a program for international trading of greenhouse gas emissions. Such trading would employ market incentives to help ensure that the lowest-cost opportunities for emissions reductions are pursued.

The Kyoto agreement is a significant victory for advocates who have sought to convince world leaders to address climate change. It is intended to signal to governments, businesses, and households that limits will be placed on future emissions of greenhouse gases, and that now is the time to begin developing the necessary technologies. Advocates also express the hope that acceptance by industrialized countries of binding emission limits would make developing countries more willing to take emissions-limiting actions appropriate to their own circumstances.

A protocol that is both workable in practice and capable of being ratified by the Senate must come to grips with three basic questions:

- Does it represent a sound framework for attaining long term global emission-reduction goals, and is it clear enough to serve as a sort of international contract to which parties can commit?
- How costly are the targets and timetables for greenhouse gas reduction agreed to by the U.S. and other Annex 1 countries – are they as affordable as the Administration says, or as burdensome as the fossil fuel industry has asserted?
- What measures would the U.S. deploy in order to achieve the goals laid out in the Protocol?

As we discuss in the balance of the article, the Protocol itself has significant gaps; the costs of meeting the stipulated targets are not tremendous but not trivial either; and there is a great deal still to settle with respect to the domestic policy agenda.

Unresolved Issues with the Protocol

The negotiators deferred action on several important but controversial elements to a subsequent meeting scheduled for the Buenos Aires in the fall of 1998. President Clinton has indicated that he will not send the Protocol to the U.S. Senate for ratification until more progress is made on these issues. We believe that, at a minimum, several issues must be addressed before ratification and implementation can occur:

The rules and institutions that will govern international trading of greenhouse gas emissions among Annex I countries must be better established. Article 6 of the Protocol provides for emissions trading, but only in the vaguest of terms. How the trading program is carried out greatly affects the capacity to hold down compliance costs. A program that establishes a freely functioning, largely private market in emissions permits, where private entities may execute trades with minimal bureaucratic red tape, will be the most efficient and will lead to the greatest cost savings. In contrast, a market permitting only trades by governments, or a market where private trades are hamstrung by overly restrictive rules, will sap the cost savings.

The rules and institutions governing joint implementation (the so-called Clean Development Mechanism) must be developed in detail. Under Article 12 of the Protocol, Annex I countries can jointly undertake projects with developing countries to reduce emissions in the latter countries, and count those reductions toward compliance with their own commitments, where it is possible to establish meaningful baselines against which reductions can be measured. Again, however, the Protocol does not address how such projects can be undertaken. A well supervised, but freely functioning market combined with credible certification and enforcement of reductions would yield real greenhouse gas reductions at lower cost. An overly restrictive and bureaucratic system would sap possible gains.

The criteria used to judge compliance, and any penalties for noncompliance, must be clearly articulated. The protocol contains a number of technical provisions for assessing national performance in measuring emissions and meeting emissions control objectives. These provisions build on previous efforts under the Framework Convention but are complicated by the more comprehensive nature of the new protocol. Beyond these technical questions, the fundamental issue is what actions, if any, would be taken if a country was found not to be in compliance. The emissions goals of Annex I countries are taken to be binding under international law, but the protocol itself contains no stipulations for sanctions in the event of noncompliance.

A binding agreement on the part of the major developing countries to limit their emissions at some specified point in the future must be obtained. The Framework Convention clearly states that developing countries do not bear the same obligations as developed nations for emissions control in the short term. Nevertheless, the Protocol could and should contain commitments from developing countries to limit their emissions *growth*. This can be achieved through the pursuit of "no regrets" measures that would be prudent to undertake in any case, and agreements to eventually cap emissions as countries' economic circumstances improve in exchange for assistance in adopting clean technologies. The lack of any early commitment by developing countries not only aggravates short-term concerns in the U.S. and other industrial countries about international competitiveness, but also raises the specter of developing countries becoming "locked in" to more fossil-fuel-intensive technologies.

To make longer-term objectives more credible, moderate but specific near-term goals should be set for Annex I countries and these countries should be able to use early emissions reductions to meet longer-term requirements. Other than a passing reference in Article 3 to the need for "demonstrable progress" in achieving commitments by 2005, the Protocol is silent on interim measures. Yet, without interim targets, prospects for achieving more ambitious longer-term goals become problematic, and the incentives to engage in long-term investments in new capital and technology are undercut. Incentives for cost-effective reductions before 2008 to meet long-term requirements also are limited since the Protocol makes no provision for emitters to "bank" such reductions.

__Raymond J. Kopp__ directs RFF's Quality of the Environment Division, where __Richard D. Morgenstern__ is a visiting scholar on leave from the U.S. Environmental Protection Agency. __Michael A. Toman__ directs RFF's Energy and Natural Resources Division.

Please rate the quality of the information contained in this article:

O Right on target O Useful O Somewhat useful O You lost me Submit weathervane

FEATURE

The Kyoto Protocol: The Realities of Implementation

By Raymond J. Kopp, Richard D. Morgenstern and Michael A. Toman

On December 10 1997, 160 nations reached a historic agreement in Kyoto, Japan on limiting emissions of carbon dioxide and other "greenhouse gases." The Kyoto Protocol calls for the industrialized nations — the so-called Annex I countries – to reduce their average national emissions over the period 2008-2012 to about five percent below 1990 levels. The U.S. pledged to reduce its emissions by seven percent below 1990, slightly less than the European Union and slightly more than Japan. The Protocol permits some industrialized nations to modestly increase their emissions and makes special provisions for the members of the former Soviet Bloc. None of the developing countries, including those with large and growing emissions such as India and China, is required to limit its emissions.

JANUARY 15, 1998 -- In the runup to Kyoto, a number of experts pointed out that both the environment and the economy might be served by following a slower path to emissions control than the Protocol stipulates, while developing the technologies for more aggressive and affordable emissions reductions later. Others disputed this view. In any event, the agreement reached in Kyoto sets the stage for discussion and for future debate in the Senate.

Some partisans have claimed that meeting the Protocol's targets ultimately will be inexpensive or even free because there is a large untapped reservoir of cheap energy-efficiency opportunities available today and new technologies will materialize in the near future. Other partisans predict economic collapse.

In our judgment, while neither extreme view is correct, there is a substantial likelihood that the proposed target and timetable will impose significant costs on the U.S. and the global economy, even after accounting for new technology stimulated by domestic policies. The limit agreed to by the U.S. implies a reduction of about one-third compared to what the U.S. Department of Energy estimates carbon dioxide emissions will be by the end of the next decade. Even with the flexibility to reduce emissions of other gases, achieving emissions reductions of such magnitudes in at most 15 years will lead to higher energy prices and thus costs that will be borne throughout the economy. These costs in turn will also give rise to serious debates about fairness. Recent public opinion polling indicates increased concern about climate change and some willingness to shoulder burdens to curb greenhouse gas emissions, but there is no compelling evidence that the public is ready to accept significant increases in energy prices or other costs. In light of these costs, it is an open question whether the Senate is willing to ratify the target and timetable stipulated in the Protocol.

A First Step Toward Implementation: Understand the Benefits and Costs

An important first step in fostering a productive debate nationally and in the Senate over the Protocol is better understanding of its benefits and costs. Advocates should dispense with the pretense that emissions reductions of the scale and speed proposed can be achieved at negligible or even negative cost, or that reductions necessarily doom the economy. To shine a brighter light on the costs and consequences of the Protocol requires an investment in better and more inclusive analysis and review of estimates, so that competing claims can be adjudicated and new ideas introduced.

Even after questions about the Protocol itself are settled, domestic policy options for achieving the targets and timetables require more thorough consideration. The U.S. deserves credit for advancing some specific measures. Still, the proposal the Administration offered in October – $5 billion in incentives for new technology – will not be enough to move the economy from where it is today to where it needs to be to meet the Kyoto goals.

Ultimately, if the U.S. is to even approach the Kyoto goals, energy prices must rise enough – especially for coal, the most carbon-rich fossil fuel – to induce enough conservation, energy efficiency, fuel switching, and the development and deployment of new technologies and energy forms. How large this price rise will have to be depends on what domestic policies are used. No agreement yet exists on this policy menu. Even if an efficient mechanism like emissions trading is used within the U.S., important questions of who gains and loses from the policy remain to be settled.

The Key to Cost-Effective Climate Policy: Market Incentives

To meet the Kyoto goals as cost-effectively as possible, the Clinton Administration should commit itself to the use of incentive-based market policies for domestic emissions control. Well-intentioned but costly proposals to mandate energy efficiency through rigid command-and-control measures must be avoided. In addition, policies aimed at encouraging the development and dissemination of low-emissions technology need careful scrutiny to avoid waste (for example, through an ill-focussed subsidy policy).

The institution of some modest interim measures to limit greenhouse gases would be important for establishing the credibility of longer-term reduction goals. A domestic emissions trading program with looser controls than are required by the Protocol is one example. Such a program would be combined with a "safety valve" that would cap the price of a tradable emissions permit at some prespecified level which would rise over time, with the government offering additional emissions permits as needed to maintain the price caps.

Such an approach is complementary to the policies the Administration already has announced and would provide valuable information about how emissions control policies work as well as their costs to the economy. It also would offer such near-term benefits as improved air quality from reduced conventional air pollutants and encouragement for the development of lower-emissions technologies. Even stronger incentives for early demonstrable progress would be provided if any early emissions reductions below an established baseline (for example, actual 1997 emissions levels) could be banked for use in meeting subsequent binding constraints.

Raymond J. Kopp directs RFF's Quality of the Environment Division, where Richard D. Morgenstern is a visiting scholar on leave from the U.S. Environmental Protection Agency. Michael A. Toman directs RFF's Energy and Natural Resources Division.

Please rate the quality of the information contained in this article:

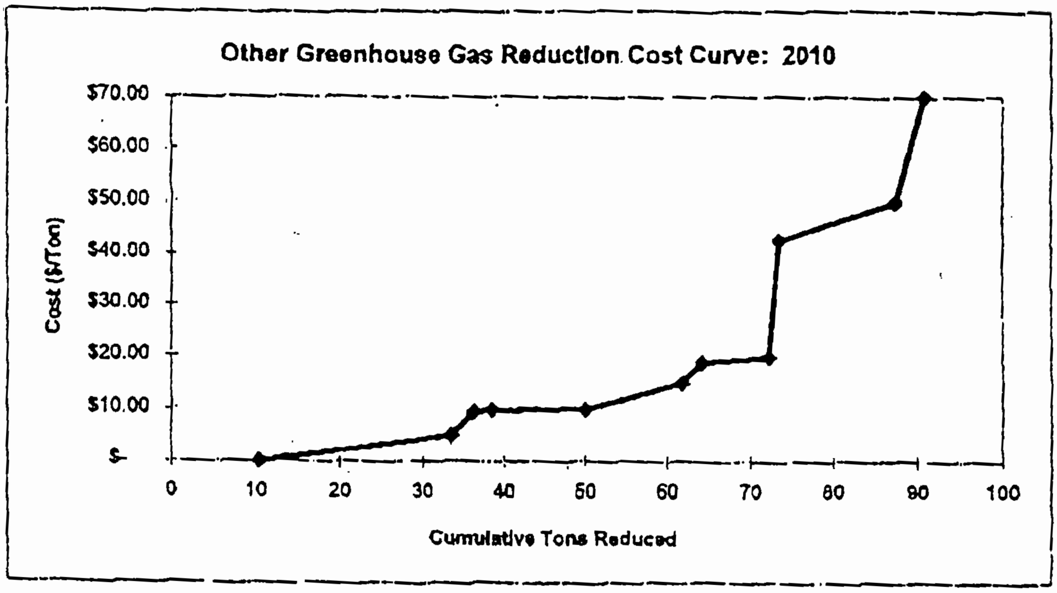
O Right on target O Useful O Somewhat useful O You lost me Submit

Costs of Reducing Non-energy Greenhouse Gas Emissions in 2010

N_2O

Cumulative Tons Reduced	Cost ($/ton)	MMTCE CH_4	MMTCE HFC/PFC	MMTCE Sinks	MMTCE NO_x	Total Tons Reduced
10	$ -	6.1			4.3	10.4
34	$ 5.00	1.4	21.8			23.2
36	$ 9.51			2.7		2.7
38	$ 9.86			2.2		2.2
50	$ 10.00	2.5	9.0			11.5
62	$ 15.00	3.6	8.1			11.7
64	$ 18.98			2.5		2.5
72	$ 20.00	2.4	5.6			8.0
73	$ 42.47			1.2		1.2
87	$ 50.00	7.8	6.2			14.0
91	$ 70.00	3.4				3.4
Total by Gas		27.1	50.6	8.7	4.3	

Average Cost = $18 Per Ton
Total Cost = $1.650 Billion
Total Reduction = 91 MMTCE



Note: $70/ton was selected as the cutoff because it was the average value from EMF-12

OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL # of pages ▶ 1

To Reed Harvey | From Bill Hohenstein
Dept./Agency OAR | Phone # 260-7019
Fax # 233-9569 | Fax # 260-6405

NSN 7540-01-317-7360 5099-101 GENERAL SERVICES ADMINISTRATION

Energy → Treasury →
CEA

Impact of different
carbon prices
on amount of
emissions

Not deliberative -
put #s into
black box & spit
out results

Problem: Assumes
high permit
prices

Table 62. Nitrogen Oxide Emissions from Electricity Generators by Region (million tons)

ricity Supply and Demand	2000	2004	2005	2006	2007	2006	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
. States	5.54	5.50	5.55	5.57	5.56	5.60	5.63	5.62	5.65	5.67	5.69	5.69	5.68	5.70	5.77	5.82	5.85	5.88
entral Area Reliability Coordination Agreement	1.35	1.37	1.37	1.37	1.38	1.39	1.39	1.38	1.38	1.37	1.38	1.37	1.36	1.36	1.41	1.44	1.44	1.46
ic Reliability Council of Texas	.42	.38	.38	.37	.34	.33	.33	.32	.33	.33	.33	.33	.33	.33	.33	.34	.35	.35
lantic Area Council	.26	.24	.24	.24	.25	.25	.26	.25	.26	.26	.26	.26	.26	.26	.27	.27	.27	.28
erica Interconnected Network	.47	.45	.45	.46	.46	.47	.47	.47	.47	.48	.48	.48	.48	.48	.48	.49	.49	.50
ntinent Area Power Pool	.36	.38	.38	.38	.38	.39	.39	.39	.39	.39	.39	.39	.39	.39	.40	.40	.40	.40
ast Power Coordinating Council/New York	.10	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.09
ast Power Coordinating Council/New England	.09	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.08	.09	.09
astern Electric Reliability Council/Florida	.26	.27	.28	.28	.27	.27	.27	.28	.28	.28	.28	.29	29	.30	.31	.31	.31	.31
astern Electric Reliability Council/Excl. Florida	.95	.97	.98	.99	.99	1.00	1.01	1.02	1.02	1.03	1.04	1.03	1.03	1.03	1.01	1.02	1.02	1.02
est Power Pool	.62	.63	.63	.63	.63	.63	.63	.64	.63	.53	.62	.62	.61	.61	.61	.61	.61	.61
n Systems Coordinating Council/NWP	.21	.22	.22	.22	.22	.23	.22	.23	.23	.23	.23	.23	.22	.23	.23	23	.23	.23
n Systems Coordinating Council/RA	.27	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.29	.29	.29
n Systems Coordinating Council/CNV	.17	.15	.16	.17	.17	.18	.18	.19	.19	.20	.20	.24	.24	.24	.25	.25	.26	.26

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Table 62. Nitrogen Oxide Emissions from Electricity Generators by Region (Million tons)

icity Supply and Demand	2000	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
States	5.54	5.38	5.43	5.45	5.45	5.09	4.76	4.48	4.38	4.41	4.33	4.43	4.42	4.35	4.43	4.48	4.51	4.49
ntral Area Reliability Coordination Agreement	1.33	1.33	1.33	1.34	1.36	1.24	1.13	1.05	.97	.93	.84	.85	.88	.87	.91	.94	.95	.95
c Reliability Council of Texas	.42	.38	.39	.37	.34	.32	.27	.22	.20	.20	.20	.23	.22	.22	.23	.23	.24	.24
antic Area Council	.27	.25	.25	.25	.25	.24	.24	.24	.24	.24	.23	.24	.24	.22	.26	.24	.24	.24
rica Interconnected Network	.48	.41	.41	.42	.42	.39	.35	.33	.33	.35	.33	.35	.35	.34	.34	34	.34	.35
tinent Area Power Pool	.35	.37	.37	.38	.39	.35	.34	.31	.32	.33	.32	.33	.34	.33	.33	.33	.33	.33
st Power Coordinating Council/New York	.10	.07	.07	.07	.07	.05	.05	.06	.06	.06	.07	.06	.07	.06	.06	.06	.06	.06
st Power Coordinating Council/New England	.09	.10	.10	.10	.09	.08	.07	.06	.06	.07	.06	.06	.06	.07	.07	07	.07	.07
stern Electric Reliability Council/Florida	.26	.26	.26	.26	.25	.23	.22	.22	.21	.22	.23	.24	.22	.22	.24	.24	.24	.24
stern Electric Reliability Council/Excl. Florida	.97	.99	1.01	1.02	1.02	.98	.96	.93	.93	.93	.94	.96	.95	.94	.95	.95	.96	.95
st Power Pool	.61	.60	.60	.59	.59	.56	.51	.48	.47	.49	.50	.51	.50	.47	.47	.47	.49	.48
Systems Coordinating Council/NWP	.17	.15	.15	.16	.17	.17	.17	.17	.17	.17	.17	.19	.19	.19	.19	.20	.20	.20
Systems Coordinating Council/RA	.21	.22	.22	.22	.22	.22	.20	.20	.19	.19	.19	.20	.19	.19	.19	.19	.19	.19
Systems Coordinating Council/CNV	.27	26	.27	.27	.27	.26	.24	.22	.23	.23	.24	.23	.22	.22	.22	.21	.21	.21

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Post-it® Fax Note 7671	Date 1/8/98 # of pages ▸ 2
To Randy Lutter	From Ray Squitieri
Co./Dept. CEA	Co.
Phone #	Phone #
Fax # 395-6870	Fax #

5:00 pm 1/7/98

Table 62. Nitrogen Oxide Emissions from Electricity Generators by Region (million tons)

Electricity Supply and Demand	2000	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
United States	5.54	5.50	5.55	5.57	5.56	5.60	5.63	5.62	5.65	5.67	5.69	5.69	5.68	5.70	5.77	5.82	5.85	5.88
East Central Area Reliability Coordination Agreement	1.35	1.37	1.37	1.37	1.38	1.39	1.39	1.38	1.38	1.37	1.38	1.37	1.36	1.36	1.41	1.44	1.44	1.46
Electric Reliability Council of Texas	.42	.38	.38	.37	.34	.33	.33	.32	.33	.33	.33	.33	.33	.33	.33	.34	.35	.35
Mid-Atlantic Area Council	.26	.24	.24	.24	.25	.25	.26	.25	.26	.26	.26	.26	.26	.26	.27	.27	.27	.28
Mid-America Interconnected Network	.47	.45	.45	.46	.46	.47	.47	.47	.47	.48	.48	.48	.48	.48	.48	.49	.49	.50
Mid-Continent Area Power Pool	.36	.38	.38	.38	.38	.39	.39	.39	.39	.39	.39	.39	.39	.39	.40	.40	.40	.40
Northeast Power Coordinating Council/New York	.10	.07	.07	.07	.07	.07	.07	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.09
Northeast Power Coordinating Council/New England	.09	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.08	.09	.09
Southeastern Electric Reliability Council/Florida	.26	.27	.28	.28	.27	.27	.27	.28	.28	.28	.28	.29	.29	.30	.31	.31	.31	.31
Southeastern Electric Reliability Council/Excl. Florida	.95	.97	.98	.99	.99	1.00	1.01	1.02	1.02	1.03	1.04	1.03	1.03	1.03	1.01	1.02	1.02	1.02
Southwest Power Pool	.62	.63	.63	.63	.63	.63	.63	.64	.63	.63	.62	.62	.61	.61	.61	.61	.61	.61
Western Systems Coordinating Council/NWP	.21	.22	.22	.22	.22	.23	.22	.23	.23	.23	.23	.23	.23	.23	.23	.23	.23	.23
Western Systems Coordinating Council/RA	.27	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.29	.29	.29
Western Systems Coordinating Council/CNV	.17	.15	.16	.17	.17	.18	.18	.19	.19	.20	.20	.24	.24	.24	.25	.25	.26	.26

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Table 62. Nitrogen Oxide Emissions from Electricity Generators by Region (million tons)

Electricity Supply and Demand	2000	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
United States	5.53	5.37	5.44	5.46	5.46	5.48	5.46	4.51	4.51	4.41	4.26	4.29	4.35	4.29	4.33	4.38	4.45	4.44
East Central Area Reliability Coordination Agreement	1.34	1.33	1.34	1.34	1.36	1.37	1.37	1.13	1.14	1.06	.97	.91	.89	.84	.87	.90	.91	.92
Electric Reliability Council of Texas	.42	.38	.38	.37	.35	.32	.32	.26	.23	.21	.18	.19	.20	.20	.21	.22	.22	.23
Mid-Atlantic Area Council	.26	.24	.25	.25	.25	.26	.26	.22	.23	.23	.23	.23	.23	.22	.23	.23	.24	.24
Mid-America Interconnected Network	.47	.41	.42	.42	.42	.43	.43	.31	.32	.33	.34	.33	.34	.34	.34	.34	.34	.34
Mid-Continent Area Power Pool	.36	.36	.37	.38	.38	.39	.39	.30	.31	.31	.29	.30	.33	.32	.32	.32	.32	.32
Northeast Power Coordinating Council/New York	.10	.07	.07	.07	.07	.08	.08	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06
Northeast Power Coordinating Council/New England	.09	.10	.10	.10	.10	.10	.09	.07	.07	.07	.07	.06	.06	.07	.07	.07	.07	.07
Southeastern Electric Reliability Council/Florida	.26	.26	.26	.26	.25	.25	.26	.21	.21	.20	.20	.21	.22	.23	.24	.24	.24	.24
Southeastern Electric Reliability Council/Excl. Florida	.97	.99	1.01	1.02	1.02	1.03	1.04	.92	.92	.89	.89	.91	.94	.94	.94	.94	.95	.95
Southwest Power Pool	.62	.60	.60	.59	.59	.59	.58	.44	.44	.45	.45	.46	.46	.47	.46	.46	.48	.47
Western Systems Coordinating Council/NWP	.21	.22	.22	.22	.22	.22	.22	.19	.19	.19	.19	.19	.19	.19	.19	.19	.20	.19
Western Systems Coordinating Council/RA	.27	.27	.27	.27	.27	.27	.27	.22	.22	.22	.22	.23	.23	.22	.22	.21	.21	.21
Western Systems Coordinating Council/CNV	.17	.15	.15	.16	.17	.17	.17	.17	.17	.17	.17	.19	.19	.19	.19	.20	.20	.20

fee100.d010698a run in /store2 on Tue Jan 6 16:11:25 EST 1998

Ray: This is preliminary 1/7/97 1 PM; It will probably change a little.

- No ramp on carbon fee. $100/ton carbon beginning in 2010
- fee begins in 2010 and remains flat
- advanced demand technologies; ref. supply technologies

Will rerun w/ 3 year ramp beginning in 2008

Andy

CO_2 only

energy-related CO_2

ANNEX 1 CARBON EMISSIONS (million metric tons)

	1990 emissions	2010 emissions
United States	1,337	1,721
Former Soviet Union	1,029	872
Western Europe	1,016	1,208
Eastern Europe	309	306
Japan	308	466
Canada	137	182
Australia/ New Zealand	100	127
	4236	4882

→ AEO98: 1803

Target 2010
4024 A1
7942 overall

DEVELOPING COUNTRIES (million metric tons)

	1990 emissions	2010 emissions
All other	904	1,811
China	625	1,523
India	159	421
Mexico	87	163
	17	3918
	6011	8800

1997 Internal Energy Outlook
EIA

FROM EIA

Descriptive material

To: Randy Lutter
Phone: 395-3142
FAX " 6870
From: Phillip Tseng
581-2892

Converting carbon value to energy price increases

Carbon "Value"	Natural Gas (mcf)	Gasoline (gallon)	Coal (ton)	Coal-fired* electricity ($/kwh)	Total* electricity ($/kwh)	Total** electricity ($/kwh)
$0.00	$0.00	$0.00	$0.00	$0.0000	$0.0000	$0.0000
$10.00	$0.15	$0.02	$5.46	$0.0026	$0.0016	$0.0017
$20.00	$0.30	$0.05	$10.92	$0.0053	$0.0033	$0.0034
$30.00	$0.45	$0.07	$16.38	$0.0079	$0.0049	$0.0050
$40.00	$0.60	$0.10	$21.84	$0.0106	$0.0066	$0.0067
$50.00	$0.75	$0.12	$27.30	$0.0132	$0.0082	$0.0084
$60.00	$0.89	$0.15	$32.76	$0.0158	$0.0099	$0.0101
$70.00	$1.04	$0.17	$38.22	$0.0185	$0.0115	$0.0118
$80.00	$1.19	$0.19	$43.68	$0.0211	$0.0131	$0.0135
$90.00	$1.34	$0.22	$49.14	$0.0238	$0.0148	$0.0151
$100.00	$1.49	$0.24	$54.60	$0.0264	$0.0164	$0.0168
$110.00	$1.64	$0.27	$60.06	$0.0290	$0.0181	$0.0185
$120.00	$1.79	$0.29	$65.52	$0.0317	$0.0197	$0.0202

* Calculation based on 1995 electricity generation, excluding Cogen.
** Calculation based on 1995 electricity Sales.

1995 Price and Consumption of Natural gas, Gasoline, Coal, and Electricity

	Price	Quantity	P*Q ($billion)
Natural Gas ($/mcf at wellhead, tcf)	$1.61	22.2	$35.71
Gasoline ($/gallon, mmbd/day)	$1.15	7.8	$137.45
Coal($/ton at electric utilities, mil short ton)	$27.01	847.0	$22.88
Electricity($/kwh end-use, bkwh)	$0.07	3,008.0	$213.57

EIA #3
Public info

October 9, 1997

Why 7% below Kyoto's "1990 levels" is no more than 3% below the President's proposal: a calculation

This paper compares the carbon numbers associated with the United States emissions commitment under the Kyoto Protocol with the commitment the President made in his October speech. The Kyoto Protocol and the President's speech differ both in the emissions budget and in the emissions accounting system that will determine the emissions that must be below the budget for compliance with the treaty, *so the targets cannot be compared directly*. The most significant differences between the two commitments are1:

(1) Under the Kyoto Protocol, each party has its choice of 1990 or 1995 as a base year for emissions of three greenhouse gases: HFC, PFC, and SF6. The U.S. had 13 MMTCE more emissions of these gases in 1995 than in 1990, making the option of a 1995 base year less restrictive.

(2) Under the Kyoto Protocol, the emissions budget is based only on gross emissions, not counting the carbon sequestered by forests in the base year (1990), the "sinks." The effect of this difference is to make the Kyoto budget less strict than it would have been using the President's assumption that the budget would be based on net emissions.

(3) Under the Kyoto Protocol, the emissions accounting system includes only certain land use changes and forestry activities in its calculation of sinks, rather than the carbon activity in all U.S. forests. The effect of this provision relative to the President's plan depends on the methodology developed to account for sinks under the Kyoto agreement. 2

The Kyoto Protocol

(A) The Kyoto Target

Emissions budget = 5 years × (1990 Emissions of CO_2, CH_4, N_2O + 1995 Emissions of HFC, PFC, and SF_6) × 93%

CEA Staff → JLY

Non-Deliberative Descriptive Document

1990 Emissions of CO2, CH4, N2O	=	1559 MMTCE
1995 Emissions of HFC, PFC, and SF6	=	37 MMTCE
Total baseline emissions	=	1596 MMTCE

Kyoto Emissions Budget, total for first budget period = 5 years × (1596) × 93%
= 7421 MMTCE

Annual Average Budget in 2008-2012 = 1484 MMTCE

(B) The Kyoto Accounting System

2008-2012 emissions = [Total emissions of CO2, CH4, N2O, HFC, PFC, SF6] - [net changes of carbon stocks "from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period"]

The President's Announcement

(A) The President's October Target

Under the President's October plan, the emissions target for the United States would be written:

Emissions Budget = 5 years × [(1990 Emissions of CO2, CH4, N2O and HFC, PFC, and SF6) - (net changes carbon stocks from all forests, including forest soils]

Note that the budget equation includes sinks, which all else equal makes the budget tighter for the United States, which experienced positive sequestration in forests in 1990.

1990 Emissions of CO2, CH4, N2O	=	1559	MMTCE
1990 Emissions of HFC, PFC, and SF6	=	24	MMTCE
Carbon activity in forests (sequestration)	=	-282	MMTCE
Net emissions	=	1301	MMTCE

President's Plan Emissions Budget = 5 years × (1301) = 6505 MMTCE

Annual Average Budget in 2008-2012 = 1301 MMTCE

(B) The President's October Accounting System

2008-2012 Emissions Calculation = [Total emissions of CO2, CH4, N2O, HFC, PFC, SF6 2] - [net changes of carbon stocks from all U.S. forests]

Comparison: How much lower is the Kyoto target than the President's plan?

Recall that the two plans entail different accounting systems for the emissions that must be within budget, *so the budgets of the two commitments (1484 and 1301) are not directly comparable*.

The Kyoto commitment:

[Total emissions of all six gases] - [net changes of carbon stocks from certain activities] < 1484

Since the sink accounting system under the Kyoto Protocol is not yet determined, we must make an assumption about the net changes of carbon stocks from the activities specified in the treaty. The U.S. has said that the accounting system for carbon sinks will not increase the emissions calculation under the Protocol, and may in fact offset our emissions. If we assume that sinks are zero, that is they neither offset U.S. emissions nor contribute to them, then the Kyoto commitment is:

[Total emissions of all six gases] - 0 < **1484**

President's plan:

[Total emissions of all six gases] - [net changes of carbon stocks from all U.S. forests] < 1301

The change in carbon stocks from all U.S. forests in 2010 is estimated by USDA and EPA to be about 227 MMTCE. If that figure is about average for the budget period, the President's commitment would be equivalent to:

[Total emissions of all six gases] - 227 < 1301, or equivalently,
[Total emissions of all six gases] < **1528** (the total of the budget plus offsets by sinks)

Then the comparison question is: **how much lower is 1484 than 1538?**

Algebraically, the percentage difference, x, can be expressed: 1484 = (1-x)1538
=> x = 1 - 1484/1538 = .03
=> **1484 is 3% below 1538.**

What if accounting for sinks under the Protocol offsets our emissions, as we expect they may do? Then the total emissions of all six gases can be *higher* than 1484 by the amount of carbon sequestered in the eligible land use activities. That makes the Kyoto Protocol even less than 3% more stringent than the President's plan.

Conclusion: The Kyoto agreement is no more than 3% more stringent than the Presidents plan.

#s from
Energy

Non-deliberative

possibly
public info

Trends in Energy-Related Carbon Dioxide Emissions

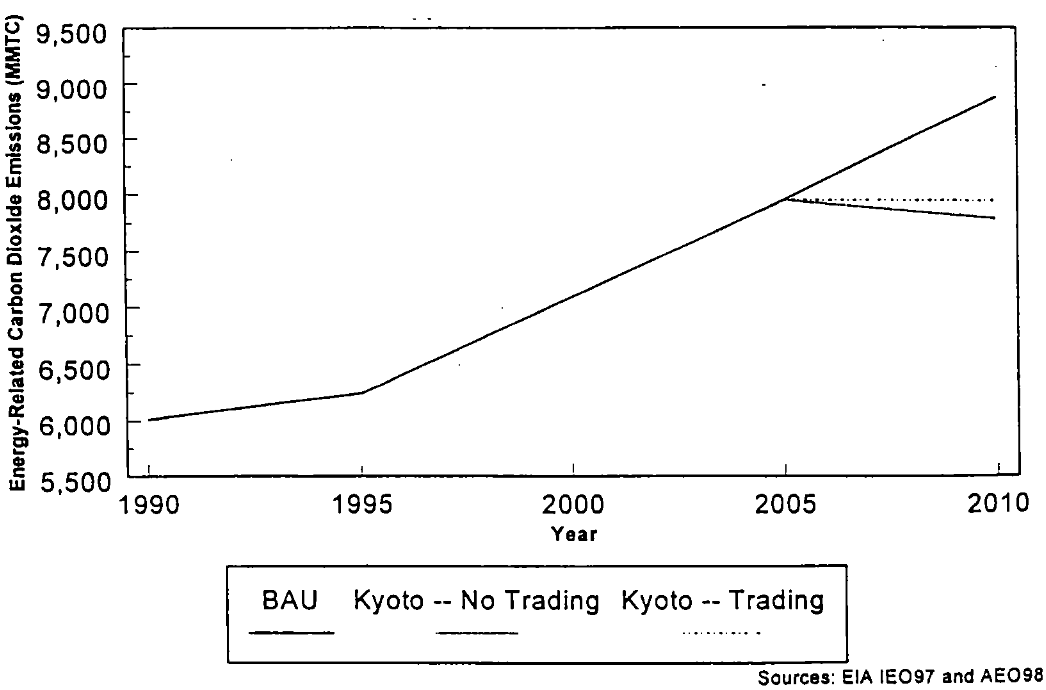
- To assess the implications of Kyoto on global greenhouse gas emissions, we had to make two simplifying assumptions because of data limitations. First, we assumed that energy-related carbon dioxide emissions could serve as an adequate proxy for greenhouse gas emissions (in the U.S., energy-related carbon dioxide emissions are more than 97% of all carbon dioxide emissions). Second, we assumed that Annex I countries will reduce their energy-related carbon dioxide emissions by the percentage cuts stipulated in Annex B of the Kyoto Protocol (in effect, we ignore any opportunities for what flexibility).

- Chart 1 illustrates the trend in world emissions under BAU and under two scenarios of Annex I emissions reductions. One scenario assumes no trading of emissions rights, which has lower total Annex I emissions because countries with paper tons would not be able to sell their excess rights. The other scenario assumes trading of emissions rights, so total Annex I emissions are higher.

- In 2010, both Kyoto scenarios have emissions slightly below 2005 BAU and a little more than 10% below global 2010 BAU. Because of the substantial growth in non-Annex I emissions, global emissions in 2010 under both Kyoto scenarios are approximately 30% above the global 1990 level.

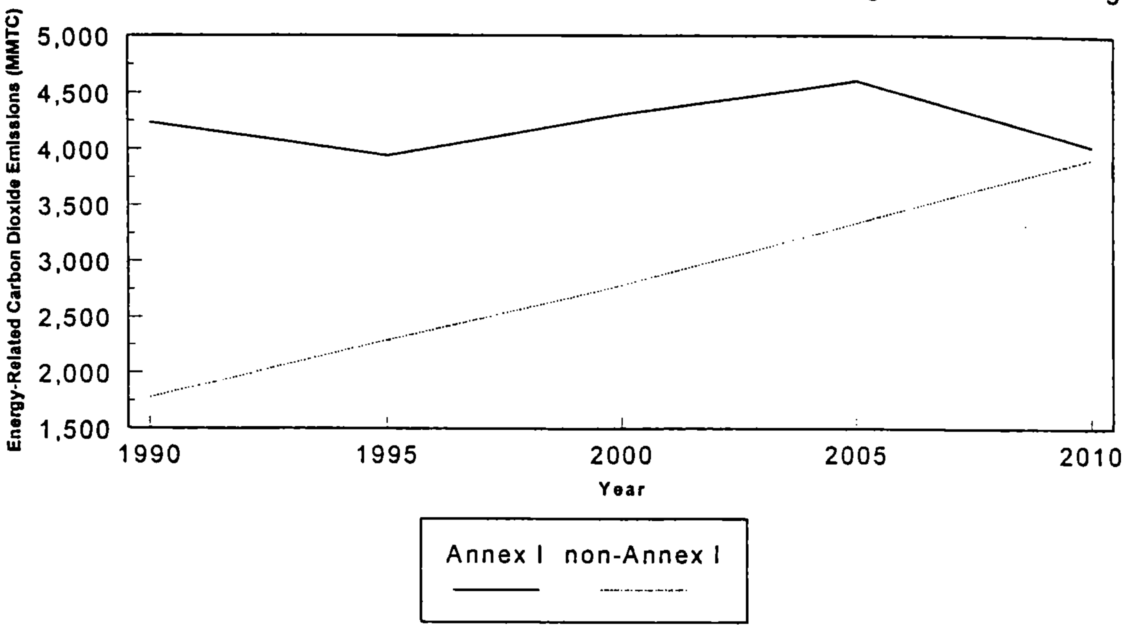
- Charts 2 and 3 illustrate the breakdown of emissions between Annex I and non-Annex I. Without international trading, non-Annex I emissions will surpass Annex I emissions in 2010. With international trading, non-Annex I emissions are slightly lower than Annex I emissions, but would likely pass Annex I emissions by the end of the first commitment period.

Chart 1: Trend in Global Energy-Related CO2 Emissions



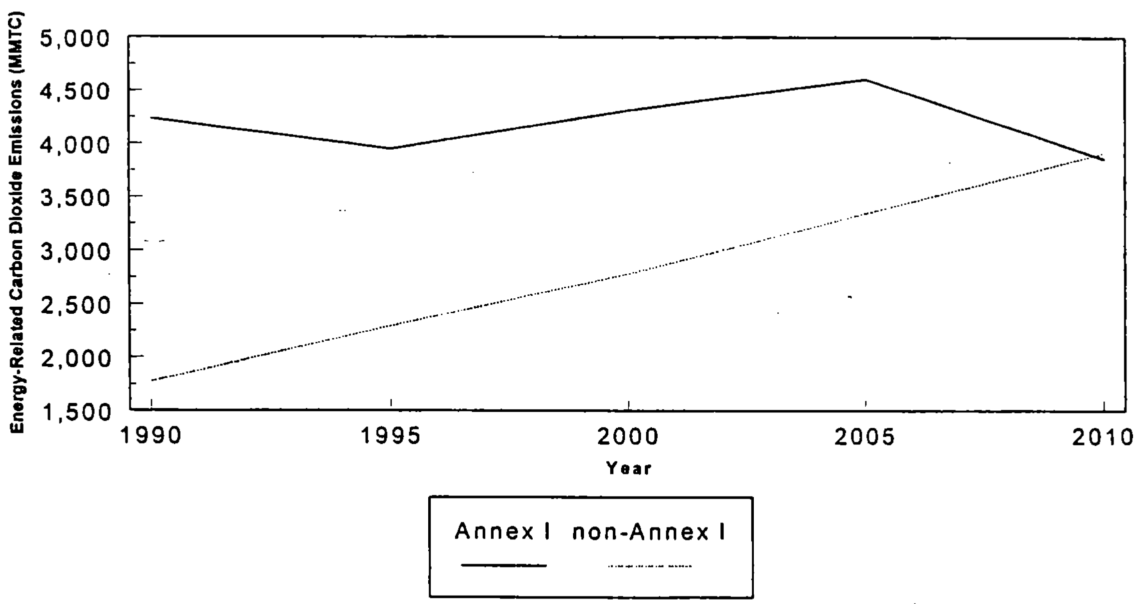
Sources: EIA IEO97 and AEO98

Chart 2: Trend in Energy-Related CO2 Emissions Assuming Annex I Trading



Sources: EIA IEO97 and AEO98

Chart 3: Trend in Energy-Related CO2 Emissions Assuming No Annex I Trading



Sources: EIA IEO97 and AEO98

EPA document

descriptive

Bill Hohenstein
1/98

The Structure of the Kyoto Protocol: US Efforts Needed to Meet Commitments

In October 1997, President Clinton proposed to return greenhouse gas net emissions to 1990 levels in 2008-2012. This target was premised on the long-standing US position of comprehensive coverage of all greenhouse gases (CO2, CH4, N2O, PFCs, HFCs, and SF6) and all sectors (including land use and forestry systems). Although comprehensiveness increased the tonnes of US reductions required to meet a given numerical target, we have pushed for it because it provides greater cost-effectiveness and increases the industrial support for the agreement,. The EU or Japanese wanted to exclude the synthetic gases and land use and forestry, making their targets several percentage points "easier" to achieve than if their proposals had been comprehensive.

The Kyoto Protocol assigns the US a 7% reduction below base period emissions. The U.S. accepted changes in calculation of the obligation for synthetic gases, forests and land use change that allowed the US to deepen its numerical target for the same level of effort. These changes simultaneously increased the level of effort required by the EU and Japan.

The U.S. also agreed to increase the strength of its obligation. The total of the accounting changes and increased strength result in the change of target to 7% below base period levels. Despite the accounting changes, the U.S. gained virtually comprehensive coverage during the commitment period of 2008 to 2012.

Synthetic Gases (HFC/PFC/SF6) → fastest growing gases

The President's proposal included the rapidly growing synthetic gases, using a base year of 1990. The US won inclusion of these gases, and accepted a 1995 base year for calculation of the commitment. The recalculation of base period emissions allowed the U.S. to adjust downward its numerical target by roughly 13 MMTCE, the amount by which the synthetic greenhouse gases grew between 1990 and 1995 (about 1% of the U.S. commitment). For the EU and Japan, which had not counted synthetic gases in their proposals, the broader coverage made their targets more difficult.

Exclusion of Forest and Land Use Change Category.

Forest carbon sequestration is a large, but declining offset to US emissions. U.S. estimates, using 1996 IPCC guidelines adopted by the Parties, indicate that US forest carbon sequestration is expected to decline by 55 MMTCE between 1990 and 2010.[1] Unlike emissions from energy use, emissions or removals in the base period cannot be continued indefinitely; emissions decline as available land is exhausted and removals decline as forest systems mature. Therefore,

[1] The US Climate Action Report estimated that US forest sinks would decline by 16 MMTCE. This estimate was updated to include soil carbon, to conform with the 1996 IPCC guidelines and the U.S. goal of comprehensive coverage.

including this sector in calculation of the GHG obligation penalizes those Parties with net removals in the base period and rewards Parties with net emissions. The Kyoto Protocol therefore, as standard practice, excludes LUCF from the base period emissions on which the GHG obligation is based, eliminating the "penalty" in the President's proposed target of 55 MMTCE of carbon (slightly more than 3% of our overall commitment). It had no effect on the EU or Japan, which had excluded the category from their target proposals.

In addition, the U.S. gained crediting of specific forest activities, limited to: afforestation, reforestation, and deforestation since 1990. While the U.S. was initially opposed to this approach due to its inherent accounting uncertainty, we believe that these credits may further reduce the level of effort needed for a given target by a significant but as yet unquantified amount.

Additional Reductions

The US accepted an additional -3 percentage points of real effort in order to get agreement with the European Union, Japan, and the G-77. The U.S. reached a target 7% below the base period emissions by combining the two changes in calculation of base period emissions, which made the President's proposal equivalent to -1 percentage points for synthetic gases plus -3 percentage points for forests and land use change, with the -3 percentage points of additional reductions.

3rd party

From WEB page

Final Draft of Kyoto Protocol to U.N. Climate Change
Convention
Issued Dec. 10, 1997

CONFERENCE OF THE PARTIES

Third session

Kyoto, 1-10 December 1997

Agenda item 5

FCCC/CP/1997/CRP.6

10 December 1997

ENGLISH ONLY

KYOTO PROTOCOL TO THE
UNITED NATIONS FRAMEWORK CONVENTION
ON CLIMATE CHANGE

Final draft by the Chairman of the Committee of the Whole

The Parties to this Protocol,

Being Parties to the United Nations Framework convention on Climate Change, hereinafter referred to as "the Convention",

In pursuit of the ultimate objective of the Convention as stated in its Article 2,

Recalling the provisions of the Convention,

Being guided by Article 3 of the Convention,

Pursuant to the Berlin Mandate adopted by decision 1/CP.1 of the Conference of the Parties to the Convention at its first session,

Have agreed as follows:

Article 1

For the purposes of this Protocol, the definitions contained in Article 1 of the convention shall apply. In addition:

1. "Conference of the Parties" means the Conference of the Parties to the Convention.

2. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.

3. "Intergovernmental Panel on Climate Change" means the Intergovernmental Panel on Climate Change established in 1988 jointly by the World Meteorological Organization and the United Nations Environment Programme.

4. "Montreal Protocol" means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended.

5. "Parties present and voting" means Parties present and casting an affirmative or negative vote.

6. "Party" means, unless the context otherwise indicates, a Party to this Protocol.

7. "Party included in Annex I" means a Party included in Annex I to the Convention, as may be amended, or a Party which has made a notification under Article 4, paragraph 2(g), of the Convention.

Article 2

1. Each Party included in Annex I in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(i) Enhancement of energy efficiency in relevant sectors of the national economy;

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation;

(iii) Promotion of sustainable forms of agriculture in light of climate change considerations;

(iv) Promotion, research, development and increased use of new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

(v) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and apply market instruments;

(vi) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;

(vii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector;

(viii) Limitation and/or reduction of methane through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9 of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant tO their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by six per cent below 1990 levels in the commitment period 2008 to 2012.

2. Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3. The net changes in greenhouse gas emissions from sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation, and deforestation since 1990, measured as verifiable changes in stocks in each commitment period shall be used to meet the commitments in this Article of each Party included in Annex I. The greenhouse gas emissions from sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

Δ since 90
or Δ in 2008-12 ?

4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide for consideration by the Subsidiary Body for Scientific and Technological Advice data to establish its level of carbon stocks in 1990 and to

enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how and which additional human-induced activities related to changes in greenhouse gas emissions and removals in the agricultural soil and land-use change and forestry categories, shall be added to, or subtracted from, the assigned amount for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods.

5. The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session, shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national communication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use a historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6. Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those in this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

QELROs
Average
2008-2012
vs. 1990

7. In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five.

HFCs... 1995

8. Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9. Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period mentioned in paragraph 7 above.

Trdg

10. For the purpose of meeting its commitments under this Article, any Party included in Annex I may participate in emissions trading. The Conference of the Parties shall define the relevant rules and guidelines for verification, reporting and accountability. Such trading shall be supplemental to domestic actions for

the purpose of meeting its commitments.

Trading

11. Any part of an assigned amount, or any emission reduction units, which a Party acquires from another Party in accordance with the provisions of paragraph 10 above or Article 6 shall be added to the assigned amount for that Party.

12. Any part of an assigned amount, or any emission reduction units, which a Party transfers to another Party in accordance with the provisions of paragraph 10 above or Article 6 shall be subtracted from the assigned amount for that Party.

13. Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 13 shall be added to the assigned amount for that Party.

Banking (no interim MY)

14. If the emissions of a Party included in Annex I during a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

15. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environment and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

Bubble ?

1. Any Parties included in Annex I that have agreed to jointly fulfil their commitments under Article 3 shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.

2. The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance, approval or accession. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.

3. The agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.

4. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing

new EU ?

commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purpose of those commitments under Article 3 that are adopted subsequent to that revision.

5. In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to such an agreement shall be responsible for its own level of emissions set out in the agreement.

6. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1. Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to his Protocol at is first session.

2. Methodologies for estimating anthropologic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision

3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to those commitments under Article 3 in respect of

any commitment period adopted subsequent to that revision.

Article 6

JI ?

Just among Annex I ?

(LDCs are Article 13)

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by so or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

(a) Any such project has the approval of the Parties involved;

Additionality

(b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;

(c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and

(d) The acquisition of omission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition of this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this paragraph is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1. Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2. Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3. Each Party included in Annex I shall submit the information required under paragraph I above annually, beginning with the first inventory due under the

Convention for the first year of the commitment period after this Protocol has entered into force for it. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of national communications by Parties included in Annex I adopted by the Conference of the Parties. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall also, prior to the first commitment period, decide upon modalities for the accounting of assigned amounts.

Article 8

1. The information submitted under Article 7 by each Party included in Annex I shall be reviewed by expert review teams pursuant to the relevant decisions of the Conference of the Parties serving as the meeting of the Parties to this Protocol under paragraph 4 below. The information submitted under Article 7, paragraph 1, by each Party included in Annex I shall be reviewed as part of the annual compilation and accounting of emissions inventories and assigned amounts. Additionally, the information submitted under Article 7, paragraph 2, by each Party included in Annex I shall be reviewed as part of the review of communications.

2. Expert review teams shall be coordinated by the secretariat and shall be composed of experts selected from those nominated by Parties to the Convention and, as appropriate, by intergovernmental organizations, in accordance with guidance provided for this purpose by the Conference of the Parties.

3. The review process shall provide a thorough and comprehensive technical assessment of all aspects of the implementation by a Party of this protocol. The expert review teams shall prepare a report to the Conference of the Parties serving as the meeting of the Parties to this Protocol, assessing the implementation of the commitments of the Party and identifying any potential problems in, and factors influencing, the fulfilment of commitments. Such reports shall be circulated by the secretariat to all Parties to the Convention. The secretariat shall list those questions of implementation indicated in such reports for further consideration by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the review of implementation by expert review teams taking into account the relevant decisions of the Conference of the Parties.

5. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, with the assistance of the Subsidiary Body for Implementation

and, as appropriate, the Subsidiary Body for Scientific and Technological Advice, consider:

(a) The information submitted by the Parties under Article 7 and the reports of the expert reviews thereon conducted under this Article; and

(b) Those questions of implementation listed by the secretariat under paragraph 3 above, a well as any questions raised by Parties.

6. Pursuant to its consideration of the information referred to in paragraph 5 above, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take decisions on any matter required for the implementation of this Protocol.

Article 9

LDCs can voluntarily join later

1. Any signatory or Party to this Protocol not included in Annex I may, at any time, notify the Depositary that it has opted to be bound by this Article. The Depositary shall inform the other signatories and Parties of any such notification.

2. Such notification, supported by an inventory of emissions of greenhouse gases not controlled by the Montreal Protocol, including for the historical base year or period chosen under subparagraph (a) below, and a projection of future emissions, shall include a formal declaration on the following points:

(a) Its chosen historical base year or period for the implementation of subparagraph (b) below; and

(b) The level of limitation or reduction of anthropogenic emissions of greenhouse gases listed in Annex A, as a basket, it is ready to undertake.

3. Where a notification has been made pursuant to paragraphs 1 and 2 above, the secretariat shall include it in the agenda for the following session of the Conference of the Parties serving as the meeting of the Parties to this Protocol which shall decide on the acceptance of such notification.

4. After its acceptance by the Conference of the Parties serving as the meeting of the Parties to this Protocol, a notification by a signatory shall enter into force on the date of entry into force of this Protocol for that State, and a notification by a Party to this Protocol shall enter into force on the ninetieth day after the acceptance of such notification. The commitment under paragraph 2(b) above of Parties acting under this Article shall be inscribed in Annex B.

Article 10

reviews

1. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall periodically review this Protocol in the light of the best available scientific information and assessments on climate change and its impacts, as well as relevant technical, social and economic information. Such reviews shall be coordinated with pertinent reviews under the Convention, in particular those required by Article 4, paragraph 2(d), and Article 7, paragraph 2(a), of the Convention. Based on these reviews, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall take appropriate action.

2. The first review shall take place at the second session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. Further reviews shall take place at regular intervals and in a timely manner.

Article 11

All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, without introducing any new commitments for Parties not included in Annex I, but reaffirming existing commitments in Article 4, paragraph 1, of the Convention, and continuing to advance the implementation of these commitments in order to achieve sustainable development, taking into account Article 4, paragraphs 3, 5 and 7, of the Convention, shall:

(a) Formulate, where relevant and to the extent possible, cost-effective national, and where appropriate regional programmes to improve the quality of local emission factors, activity data and/or models which reflect the socio-economic conditions of each Party for the preparation and periodic updating of national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties, and consistent with the guidelines for national communications adopted by the Conference of the Parties;

Policies & measures

Alternative A

(b) Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change;

(i) The programmes containing measures shall, inter alia, and to the extent possible and relevant, remove obstacles to the limitation or the abatement of increase of anthropogenic emissions by sources and to the enhancement of removals by sinks, enhance energy efficiency, emphasize market-oriented pricing, as appropriate encourage reforms in the energy sector and regulatory regimes, increase the use of renewable energy, make improvements in the transport and industrial sectors, promote the development and sustainable management of greenhouse gas sinks and reservoirs, improve the integration of climate change considerations into the agriculture and waste management sectors, promote voluntary arrangements with industry, and generally take actions to address climate change that, in the context of their national priorities, objectives and circumstances, are economically justified and can help address other environmental problems; and

(ii) The programmes containing measures shall, inter alia, and to the extent possible and relevant, deploy adaptation technologies and know-how, develop and implement integrated mountain area plans, develop and implement integrated coastal zone management plans, develop research on impacts of, and adaptation to, climate change, develop and implement related technical capacity building and awareness raising measures promote sustainable management plans for the conservation and enhancement of sinks and reservoirs and ecosystems and develop and implement plans for water resources and agriculture, particularly for countries affected by drought and desertification;

Alternative B

(b) Each developed country Party and each other developed Party included in Annex II to the Convention shall incorporate into its national programmes the quantified emission limitation and reduction objectives and related policies and measures under this Protocol, including details of measures undertaken by them to promote, facilitate and finance transfer of technology, provide new and additional financial resources and assist in meeting costs of adaptation in developing countries. Each developing country Party shall seek to include in its national communication, as appropriate, information on programmes which contain measures that the Party believes contribute to addressing climate change and its adverse impacts, including the abatement of increase in greenhouse gas emissions, and enhancement of and removals by sinks, capacity building and adaptation measures;

(c) Cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance access to, and transfer of, environmentally sound technologies;

(d) Cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives to reduce uncertainties related to the climate system, the adverse impacts of climate change and the economic and social consequences of various response strategies, and promote the development and strengthening of endogenous capacities and capabilities to participate in international and intergovernmental efforts, programmes and networks on research and systematic observation, taking into account Article 5 of the Convention;

(c) Cooperate in and promote at the international level, and, where appropriate, using existing bodies, the development and implementation of education and training programmes, including the strengthening of national capacity building, in particular human and institutional capacities and the exchange or secondment of personnel to train experts in this field, in particular for developing countries, and facilitate at the national level public awareness and public access to information on climate change. Suitable modalities should be developed to implement these activities through the relevant bodies of the Convention taking into account Article 6 of the Convention;

(f) Include in their national communications information on programmes and activities undertaken pursuant to this Article in accordance with relevant decisions of the Conference of the Parties; and

(g) Give full consideration, in implementing the commitments in this Article, to Article 4, paragraph 8, of the Convention.

Article 12

1. In the implementation of Article 11, Parties shall take into account the

provisions of Article 4, paragraphs 4, 5, 7, 8 and 9 of the Convention.

2. In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the operating entity or entities of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

Money to LDCs

(a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 11, subparagraph (a); and

(b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments in Article 4, paragraph 1, of the Convention that are covered by Article 11 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article.

The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply mutatis mutandis to the provisions of this paragraph.

3. The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 11, through bilateral, regional and other multilateral channels.

Article 13

"Clean Dev. mech."

1. A clean development mechanism is hereby defined.

2. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

3. Under the clean development mechanism:

(a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and

3 J 17.

(b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

4. The clean development mechanism shall be subject to the authority and

guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the Parties.

5. Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:

(a) Voluntary participation approved by each Party involved;

(b) Real, measurable, and long-term benefits related to the mitigation of climate change; and

(c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

6. The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

7. The Conference of Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

8. A share of the proceeds from certified project activities shall be used to cover administrative expenses as well as assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

9. Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10. Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 14

1. The Conference of the Parties, the supreme body of the Convention, shall Serve as the meeting of the Parties to this Protocol.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to it.

3. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be substituted by an additional member to be elected by and from amongst the Parties to this Protocol.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall:

(a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;

(b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;

(c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;

(e) Promote and guide, in accordance with the objective of the Convention and the provisions of this Protocol, and taking fully into account the relevant decisions by the Conference of the Parties, the development and periodic refinement of comparable methodologies for the effective implementation of this Protocol, to be agreed on by the Conference of the Parties serving as the meeting of the Parties to this Protocol;

(f) Make recommendations on any matters necessary for the implementation of this Protocol;

(g) Seek to mobilize additional financial resources in accordance with Article 12, paragraph 2;

(h) Establish such subsidiary bodies as are deemed necessary for the implementation of this Protocol;

(i) Seek and utilize, where appropriate, the services and cooperation of, and information provided by, competent international organizations and intergovernmental and non-governmental bodies; and

(j) Exercise such other functions as may be required for the implementation of this Protocol, and consider any assignment resulting from a decision by the Conference of the Parties.

5. The rules of procedure of the Conference of the Parties and financial

procedures of the Convention shall be applied mutatis mutandis under this Protocol, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

6. The first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of the entry into force of this Protocol. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held every year and in conjunction with ordinary sessions of the Conference of the Parties unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to this Protocol, or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8. The United Nations, its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof of observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to this Protocol as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Protocol and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to this Protocol as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure, as referred to in paragraph 5 above.

Article 15

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Protocol.

2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention on arrangements made for the functioning of the secretariat, shall apply mutatis mutandis to this Protocol. The secretariat shall, in addition, exercise the functions assigned to it under this Protocol.

Article 16

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve as, respectively, the Subsidiary Body for Scientific and Technologial Advice and the Subsidiary Body for Implementation of this Protocol. The provisions relating to the functioning of these two bodies under the Convention shall apply mutatis mutandis to this Protocol. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Protocol shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for

Implementation of this Convention.

2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Protocol, decisions under this Protocol shall be taken only by the Parties to this Protocol.

3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Protocol, any member of the Bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a party to this Protocol, shall be substituted by an additional member to be elected by and from amongst the Parties to this Protocol.

Article 17

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, as soon as practicable, consider the application to this Protocol of, and modify as appropriate, the multilateral consultative process referred to in Article 13 of the Convention, in the light of any relevant decisions that may be taken by the Conference of the Parties. Any multilateral consultative process that may be applied to this Protocol shall operate without prejudice to the procedures and mechanisms established in accordance with Article 18.

Article 18

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, approve appropriate and effective procedures and mechanisms to determine and to address cases of non-compliance with the provisions of this Protocol, including through the development of an indicative list of consequences, taking into account the cause, type, degree and frequency of non-compliance. Any procedures and mechanisms under this Article entailing binding consequences shall be adopted by means of an amendment to this Protocol.

Article 19

The provision of Article 14 of the Convention on settlement of disputes shall apply mutatis mutandis to this Protocol.

Article 20

1. Any party may propose amendments to this Protocol.

2. Amendments to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed amendment to this Protocol shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed amendments to the Parties and signatories to the Convention and, for information, to the Depositary.

3. The Parties shall make every effort to reach agreement on any proposed amendment to this Protocol by consensus. If all efforts at consensus have

been exhausted, and no agreement reached, the amendment shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted amendment shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

4. Instruments of acceptance in respect of an amendment shall be deposited with the Depositary. An amendment adopted in accordance with paragraph 3 above shall enter into force for those Parties having accepted it on the ninetieth day after the date of receipt by the Depositary of an instrument of acceptance by at least three fourths of the Parties to this Protocol.

5. The amendment shall enter into force for any other Party on the ninetieth day after the date on which that Party deposits with the Depositary its instrument of acceptance of the said amendment.

Article 21

1. Annexes to this Protocol shall form an integral part thereof and, unless otherwise expressly provided, a reference to this Protocol constitutes at the same time a reference to any annexes thereto. Any annexes adopted after the entry into force of this Protocol shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

2. Any Party may make proposals for an annex to this Protocol and may propose amendments to annexes to this Protocol.

3. Annexes to this Protocol and amendments to annexes to this Protocol shall be adopted at an ordinary session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. The text of any proposed annex or amendment to an annex shall be communicated to the Parties by the secretariat at least six months before the meeting at which it is proposed for adoption. The secretariat shall also communicate the text of any proposed annex or amendment to an annex to the Parties and signatories to the Convention and, for information, to the Depositary.

4. The Parties shall make every effort to reach agreement on any proposed annex or amendment to an annex by consensus. If all efforts at consensus have been exhausted, and no agreement reached, the annex or amendment to an annex shall as a last resort be adopted by a three-fourths majority vote of the Parties present and voting at the meeting. The adopted annex or amendment to an annex shall be communicated by the secretariat to the Depositary, who shall circulate it to all Parties for their acceptance.

5. An annex, other than Annex A or B, that has been adopted or amended in accordance with paragraphs 3 and 4 above shall enter into force for all Parties to this Protocol six months after the date of the communication by the Depositary to such Parties of the adoption or amendment of the annex, except for those Parties that have notified the Depositary in writing within that period of their non-acceptance of the annex or amendment to the annex. The annex or amendment to an annex shall enter into force for Parties which withdraw their notification of non-acceptance on the ninetieth day after the date on which withdrawal of such notification has been received by the Depositary.

6. If the adoption of an annex or an amendment to an annex involves an amendment to this Protocol, that annex or amendment to an annex shall not enter into force until such time as the amendment to this Protocol enters into force.

7. Amendments to Annexes A and B to this Protocol shall be adopted and enter into force in accordance with the procedure set out in Article 20, provided that any amendments to Annex B shall be adopted only with the written consent of the Party concerned.

Article 22

1. Each Party shall have one vote, except as provided for in Paragraph 2 below.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States which are Parties to this Protocol. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 23

The Secretary-Generl of the United Nations shall be the Depositary of this Protocol.

Article 24

1. This Protocol shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations which are Parties to the Convention. It shall be open for signature at United Nations Headquarters in New York from 16 March 1998 to 15 March 1999. This Protocol shall be open for accession from the day after the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization which becomes a Party to this Protocol without any of its member States being a Party shall be bound by all the obligations under this Protocol. In the case of such organizations, one or more of whose member States is a Party to this Protocol, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Protocol. In such cases, the organization and the member States shall not be entitled to exercise rights under this Protocol concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Protocol. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 25

Entry into force

1. this Protocol shall enter into force on the ninetieth day after the date on which not less than 55 Parties to the Convention, incorporating Parties included in Annex I which accounted in total for at least 55 per cent of the total

carbon dioxide emissions for 1990 of the Parties included in Annex I, have deposited their instruments of ratification, acceptance, approval or accession.

2. For the purposes of this Article, "the total carbon dioxide emissions for 1990 of the Parties included in Annex I" means the amount communicated on or before the date of adoption of this Protocol by the Parties included in Annex I in their first national communications submitted in accordance with Article 12 of the Convention.

3. For each State or regional economic integration organization that ratifies, accepts or approves this Protocol or accedes thereto after the conditions set out in paragraph 1 above for the entry into force have been fulfilled, this Protocol shall enter into force on the ninetieth day following the date of deposit of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by States members of the organization.

Article 26

No reservations may be made to this Protocol.

Article 27

1. At any time after three years from the date on which this Protocol has entered into force for a Party, that Party may withdraw from this Protocol by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, o on such later date as may be specified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Protocol.

Article 28

The original of this Protocol, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

Done at Kyoto this tenth day of December one thousand nine hundred and ninety-seven.

Annex A

Greenhouse gases

Carbon dioxide (CO_2)

Methane (CH_4)

Nitrous oxide (N_2O)

Hydrofluorocarbons (HFCs)

Perfluorocarbons (PFCs)

Sulphur hexafluoride (SF6)

Sectors/source categories

Energy

Fuel combustion

Energy industries

Manufacturing industries and construction

Transport

Other sectors

Other

Fugitive emissions from fuels

Solid fuels

Oil and natural gas

Other

Industrial processes

Mineral products

Chemical industry

Metal production

Other production

Production of halocarbons and sulphur hexafluoride

Consumption of halocarbons and sulphur hexafluoride

Other

Solvent and other product use

Agriculture

Enteric fermentation

Manure management

Rice cultivation

Agricultural soils

Prescribed burning of savannas

Field burning of agricultural residues

Other

Waste

Solid waste disposal on land

Wastewater handling

Waste incineration

Other

Annex B

Party	Quantified emission limitation or reduction commitments (percentage change from 1990)
Australia	(to be completed)
Austria	
Belgium	
Bulgaria*	
Canada	
Croatia*	
Czech Republic*	
Denmark	
Estonia*	
European Community	
Finland	
France	
Germany	
Greece	
Hungary*	
Iceland	
Ireland	
Italy	
Japan	
Latvia*	
Liechtenstein	
Lithuania*	
Luxembourg	
Monaco	
Netherlands	
New Zealand	
Norway	
Poland*	
Portgual	
Romania*	

Russian Federation*
Slovakia*
Slovenia*
Spain
Sweden
Switzerland
Ukraine*
United Kingdom of Great Britain and
Northern Ireland
United States of America
*Countries that are undergoing the process of transition to a market economy.

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FAO PRODUCTION YEARBOOK

LAND USE	Land Use Country Notes
IRRIGATION	Specific Country Notes
General Country Notes	

Land use (land cover)

It should be borne in mind that definitions used by reporting countries vary considerably and items classified under the same category often relate to greatly differing kinds of land.

Definitions of land use (land cover) categories are as follows:

11 Total Area 1000ha:
: the total area of the country, including area under inland water bodies. Data in this category are obtained mainly from the United Nations Statistical Division, New York. Possible variations in the data may be due to updating and revisions of the country data and not necessarily to any change of area.

31 Land Area 1000ha:
: total area excluding area under inland water bodies. The definition of inland water bodies generally includes major rivers and lakes. Data in this category are obtained mainly from the United Nations Statistical Division, New York. Possible variations in the data may be due to updating and revisions of the country data and not necessarily to any change of area.

51 Agricultural Area 1000ha:
: up to 1994, this element shows total of data under Elements 061 (Arable land and Permanent crops) and 131 (Permanent pastures).

61 Arable and Permanent Crops 1000ha:
: Arable land and land under permanent crops shows the total of data in Elements 071 (Arable land) and 121 (Permanent crops).

71 Arable Land 1000ha:
: land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for "Arable land" are not meant to indicate the amount of land that is potentially cultivable.

121 Permanent Crops 1000ha:
: land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber; this category includes land under flowering shrubs, fruit trees, nut trees and vines, but excludes land under trees grown for wood or timber.

131 Permanent Pasture 1000ha:
: land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). The dividing line between this category and the category "Forests and woodland"; is rather indefinite, especially in the case of shrubs, savannah, etc., which may have been reported under either of these two categories. In the year 1995 and onward there will be no data for this element.

141 Forests and Woodland 1000ha:
: land under natural or planted stands of trees, whether productive or not. This category includes land from which forests have been cleared but that will be reforested in the foreseeable future, but it excludes woodland or forest used only for recreation purposes. The question of shrub land, savannah, etc. raises the same problem as in the category "Permanent meadows and pastures". In the year 1995 and onward there will be no data for this element.

181 All Other Land 1000ha:
: up to 1994, this category includes any other land not specifically listed under elements 051

(Agricultural land) and 141 (Forests and Woodland). This element includes: built-on areas, roads, barren land, etc. for which no specific data are available.

191 Non arable and permanent crops 1000ha:

from 1995 this element includes any other land not specifically listed under elements 061 (Arable land and Permanent crops) i.e.: permanent pastures, forests and woodland, built on areas, roads, barren lands, etc.

LAND USE COUNTRY NOTES

The following are specific country notes pertaining to land-use (land-cover) categories:

Australia: Data on arable land include about 27 million hectares of cultivated grassland.

Greenland: "Total area" refers to area free from ice.

Mauritius: Data on total area exclude dependencies.

Russian Federation: Data on total area exclude the portion of land under the White Sea and the Azov Sea.

Switzerland: Data from 1992, with the exception of "Total area" are not comparable with those of the previous years because of a new statistical method recently applied by the country.

Ukraine: Data on total area exclude the portion of land under the Azov Sea.

USSR: Data on total area include the White Sea (9 million hec tares) and the Azov Sea (3.73 million hectares). Data on arable land and land under permanent crops and on permanent meadows and pastures refer to the land being used by agricul tural undertakings and farms, i.e. excluding State land reserves and areas belonging to nonagricultural undertakings.

Irrigation

051 Irrigated Area 1000ha:

Data on irrigation relate to areas equipped to provide water to the crops. These include areas equipped for full and partial control irrigation, spate irrigation areas, and equipped wetland or inland valley bottoms.

The following are specific country notes:

Cuba: Data refer to State sector only.

Hungary: Data exclude complementary farm plots and individual farms.

Japan; Korea, Republic of; Sri Lanka: Data refer to irrigated rice only.

GENERAL COUNTRY NOTES

Anguilla

Data for Anguilla are included with those of Saint Kitts and Nevis.

China

Data for China generally include those for Taiwan (Province of China).

Cyprus

As a result of the present situation in Cyprus, data refer to the governmentcontrolled area only, except for total area and Population where data refer to all Cyprus.

Czech Republic, Slovakia

Starting in 1993, these independent republics, formerly Czecho slovakia, are shown separately.

East Timor

Most data for recent years are included in those of Indonesia.

Eritrea, Ethiopia

Starting in 1993, Eritrea and Ethiopia, formerly Ethiopia PDR, are shown separately.

Independent republics of the USSR

Starting in 1992, the independent republics Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan are shown separately in Asia, while Belarus, Estonia, Latvia, Lithuania, Moldova, the Russian Federation and Ukraine are shown separately in Europe. However, they are not included in the continental totals. Data before 1992 are shown under USSR.

Independent republics of Yugoslavia SFR

Starting in 1992, the independent republics Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Slovenia, and the Federal Republic of Yugoslavia (Serbia and Montenegro) are shown separately. Data for the years prior to 1992 are shown under Yugoslavia SFR.

India and Pakistan

Data relating to KashmirJammu, whose final status has not yet been determined, are generally included under India and excluded from figures for Pakistan. Data for Sikkim are included under India.

Pacific Islands

This heading includes data for the Republic of the Marshall Islands, the Commonwealth of the Northern Mariana Islands, the Federated States of Micronesia and the Republic of Palau.

Saint Helena

Data for Saint Helena include those for Ascension and Tristan da Cunha.

Yemen

Data for the former Yemen Arab Republic and the former Yemen, Democratic, have been combined.

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LAND USE	Year					
LAND AREA (1000HA)	1990	1991	1992	1993	1994	1995
ALBANIA	2,740	2,740	2,740	2,740	2,740	2,740
AUSTRALIA	768,230	768,230	768,230	768,230	768,230	768,230
AUSTRIA	8,273	8,273	8,273	8,273	8,273	8,273
BEL-LUX	3,282	3,282	3,282	3,282	3,282	3,282
BULGARIA	11,055	11,055	11,055	11,055	11,055	11,055
CANADA	922,097	922,097	922,097	922,097	922,097	922,097
CZECHOSLOVAK	12,536	12,536	12,536			
DENMARK	4,239	4,239	4,243	4,243	4,243	4,243
ESTONIA			4,227	4,227	4,227	4,227
FINLAND	30,459	30,459	30,459	30,459	30,459	30,459
FRANCE	55,010	55,010	55,010	55,010	55,010	55,010
GERMANY	34,927	34,927	34,927	34,927	34,927	34,927
BOSNIA HERZG			5,100	5,100	5,100	5,100
GREECE	12,890	12,890	12,890	12,890	12,890	12,890
HUNGARY	9,234	9,234	9,234	9,234	9,234	9,234
CROATIA			5,592	5,592	5,592	5,592
ICELAND	10,025	10,025	10,025	10,025	10,025	10,025
IRELAND	6,889	6,889	6,889	6,889	6,889	6,889
ITALY	29,406	29,406	29,406	29,406	29,406	29,406
JAPAN	37,652	37,652	37,652	37,652	37,652	37,652
LATVIA			6,205	6,205	6,205	6,205
LIECHTENSTEN	16	16	16	16	16	16
LITHUANIA			6,480	6,480	6,480	6,480
NETHERLANDS	3,392	3,392	3,392	3,392	3,392	3,392
MACEDONIA			2,543	2,543	2,543	2,543
NEW ZEALAND	26,799	26,799	26,799	26,799	26,799	26,799
NORWAY	30,683	30,683	30,683	30,683	30,683	30,683
CZECH REP				7,728	7,728	7,728
POLAND	30,442	30,442	30,442	30,442	30,442	30,442
PORTUGAL	9,150	9,150	9,150	9,150	9,150	9,150
ROMANIA	23,034	23,034	23,034	23,034	23,034	23,034
RUSSIAN FED			1,688,850	1,688,850	1,688,850	1,688,850
YUGOSLAVIA			10,200	10,200	10,200	10,200
SLOVENIA			2,012	2,012	2,012	2,012
SLOVAKIA				4,808	4,808	4,808
SPAIN	49,944	49,944	49,944	49,944	49,944	49,944
SWEDEN	41,162	41,162	41,162	41,162	41,162	41,162
SWITZERLAND	3,955	3,955	3,955	3,955	3,955	3,955
UK	24,160	24,160	24,160	24,160	24,160	24,160

UKRAINE			57,935	57,935	57,935	57,935
USA	915,912	915,912	915,912	915,912	915,912	915,912
YUGOSLAV SFR	25,540	25,540				
EC (15)	313,183	313,183	313,187	313,187	313,187	313,187
E EUROPE	114,581	114,581	114,488	114,488	114,488	114,488

LAND USE	Year					
FOREST&WOOD (1000HA)	1990	1991	1992	1993	1994	1995
ALBANIA	1,045	1,050	1,051	1,048	1,048	0
AUSTRALIA	145,613	145,000	145,000	145,000	145,000	0
AUSTRIA	3,227	3,227	3,218	3,240	3,240	0
BEL-LUX	709	709	709	709	709	0
BULGARIA	3,345	3,348	3,348	3,348	3,348	0
CANADA	453,300	453,300	453,300	453,300	453,300	0
CZECHOSLOVAK	4,618	4,619	4,618			
DENMARK	417	417	417	417	417	0
ESTONIA			2,016	2,022	2,017	0
FINLAND	23,373	23,222	23,186	23,186	23,186	0
FRANCE	14,811	14,850	14,872	14,931	15,012	0
GERMANY	10,735	10,700	10,700	10,700	10,700	0
BOSNIA HERZG			2,100	2,000	2,000	0
GREECE	2,620	2,620	2,620	2,620	2,620	0
HUNGARY	1,675	1,701	1,712	1,719	1,719	0
CROATIA			2,074	2,076	2,076	0
ICELAND	123	120	120	120	120	0
IRELAND	500	570	570	570	570	0
ITALY	6,760	6,764	6,772	6,800	6,809	0
JAPAN	25,105	25,230	25,230	25,100	25,000	0
LATVIA			2,815	2,839	2,870	0
LIECHTENSTEN	3	3	3	3	3	0
LITHUANIA			1,983	1,983	1,983	0
NETHERLANDS	334	334	334	334	334	0
MACEDONIA			1,066	1,020	1,020	0
NEW ZEALAND	7,667	7,667	7,667	7,667	7,667	0
NORWAY	8,330	8,330	8,330	8,330	8,330	0
CZECH REP				2,629	2,629	0
POLAND	8,672	8,732	8,732	8,732	8,732	0
PORTUGAL	3,102	3,102	3,102	3,102	3,102	0
ROMANIA	6,685	6,680	6,682	6,682	6,680	0
RUSSIAN FED			767,693	768,436	765,912	0
YUGOSLAVIA			1,769	1,769	1,769	0
SLOVENIA			1,077	1,077	1,077	0

SLOVAKIA				1,989	1,989	0
SPAIN	15,807	15,858	15,915	16,137	16,137	0
SWEDEN	28,025	28,025	28,025	28,025	28,025	0
SWITZERLAND	1,186	1,186	1,186	1,186	1,186	0
UK	2,326	2,390	2,390	2,390	2,390	0
UKRAINE			9,239	9,239	9,239	0
USA	295,990	295,990	295,990	295,990	295,990	0
YUGOSLAV SFR	9,118	9,120				
EC (15)	112,746	112,788	112,830	113,161	113,251	0
E EUROPE	35,158	35,250	34,229	34,089	34,087	0

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CALIBRATION OF THE SECOND GENERATION MODEL

3rd Party Paper

Detailed ON SGM Model

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June 1993

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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:

$$RE_i = \alpha_i (1 - e^{r*\beta_i}) \tag{1}$$

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].

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[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:

$$Q_{0,s} = q_{0,s} + q_{-1,s} + q_{-2,s} + q_{-3,s} \tag{2}$$

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:

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

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.

$$P_0 = \frac{TO - IBT}{TO} \tag{6}$$

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:

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

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.,

$$\frac{\partial \pi_s}{\partial P_{i,s}} = - X_{i,s} \tag{8}$$

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,

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

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).

IIIc. 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:

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

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:

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

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

$$IBTrate_i = \frac{IBTtot_i}{TO_i - IBTtot_i} \tag{25}$$

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),

$$IBTrate_i = \frac{1}{P_0} - 1 \tag{26}$$

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:

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

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:

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

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:

$$Total\ government\ transfers = G0 * Population + G1 \qquad (29)$$

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:

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

where

β_{ss}	=	$\delta ss(-1/(m-1))$;
γ	=	$\mu/(\mu-1)$; 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.,

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

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:

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

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:

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

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

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

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.

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