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Greenhouse Gas Economics and Computable General Equilibrium

by

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ABSTRACT

This paper employs a new class of Computable General Equilibrium (CGE) models, developed in the context of energy-economy-environmental models to simulate the impacts on the EU economy of internal and multilateral instruments for regulation of greenhouse gases (GHGs) emissions.

Climate change due to emissions gases of greenhouse gases is a long-term global environmental problem. While specific impacts on different regions as well as their timing are yet uncertain. It is reasonable to suppose that unilateral voluntary action by individual countries to reduce their net emission of GHGs is unlikely. This is because significant reduction of net GHGs emissions by a single major net emitter, say, for example the EU, is unlikely to substantially slow down their rate of increase in concentration in the atmosphere because the emissions of GHGs worldwide is increasing rapidly with spreading industrialization. On the other hand unilateral changes in energy use patterns are widely perceived to have adverse effects on a country's economic growth, consumer welfare and trade competitiveness. This perception is shared by both developing (DCs) and industrialized countries (INCs).

Some major policy instruments have been assessed on the basis of experiments with the CGE model.

The use of each of the policy instrument for direct GHGs regulation is promising. The results of the above experiments seem to show, that first, emission standards accomplish significant decreases in net GHGs emissions with negligible relative GDP and Welfare index changes and without major distributional impacts in the sense of relative changes in factor rewards. They seem to work through major reduction in coal and natural gas use and slight overall reduction in the use of petroleum.

Second, auctioned tradeable permits also accomplish large decreases in net GHGs emissions, with, however a perceptible increase in the Welfare Index and significant distributional impacts in higher rewards to land owners and labour relative to capital owners. They appear to work primarily by expansion of the forest sector and associated increases offsets generation.

Third, the use of a GHGs tax on positive net emissions of GHGs by industries accomplishes large reductions in net GHGs emissions with significant increase in GDP and the Welfare Index. The relative changes in factor rewards are also important and favour land owners over labour and capital owners. This instrument too appears to work primarily through considerable expansion of the forest sector and consequent increases offsets generation.

Each of these instruments show sufficient promise as effective policy tools for GHGs reduction that it would be advisable to conduct further research in each case. The choice between standards on the one hand, and market based domestic regulatory instruments on the other, is not straightforward, if these results are verified through further analysis.

Key-words. Computable General Equilibrium, Global Pollution, Greenhouse Gases, Environmental Policy.

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PART 1

THEORY AND MODELS

GLOBAL POLLUTION AND COMPUTABLE GENERAL EQUILBRIUM

1 INTRODUCTION

For a wide range of global environmental issues highly disaggregated general equilibrium models offer effective arrangements to highly aggregative optimizing EEE models.

To begin with, they enable one to capture the simultaneous interactions among product and factor markets. In particular, they allow to evaluate the natural resource 'feedback' - the effects of changing conditions in the natural resource sectors on other sectors and on labour and capital markets. Partial equilibrium (PE) models, in contrast, often exogenously specify values for basic macroeconomic variables (the wage rate, the rental price of capital, the growth rate of GNP) and use these values to derive key magnitudes for the natural resource sectors. Although certain benefits derive from the partial equilibrium approach - data, estimation is simpler and model building requirements are fewer - the cost is that the natural resource feedback is ignored. Some studies, as subsequently mentioned, indicate that the feedback is important enough to justify the careful treatment of interactions between the natural resource markets and the rest of the economy.

A highly disaggregated general equilibrium analysis is also particularly useful for exploring the effects of changing natural resource conditions on economic growth. Since it incorporates interactions among all markets, it provides explicit connections between natural resource availability and commodity prices, between these prices and savings and investment decisions, and between these decisions and the growth of the economy.

A third attraction of multisector general equilibrium models is that they reveal the compositional effects of changing natural resource conditions. The impact of changes in the availability of natural resources may be dramatic for particular sectors even when the effects on aggregate economic variables are relatively minor. Highly aggregate models cannot bring out these compositional effects, and may lead one to conclude incorrectly that the change in natural resource conditions initiates few changes in the nature of economic output.

The most persistent difficulty in developing applied models was of a computational nature; the fundamental breakthrough came in the late sixties with a solution algorithm devised by Scarf (1967). This algorithm exploited fixed-point methods which had previously been employed in many of the existence proofs of competitive general equilibria. A most attractive feature of Scarf's algorithm was its guarantee of convergence to a solution under rather unrestrictive conditions. More recent fixed-point algorithms extend Scarf's work and offer improvements in computational efficiency and flexibility.

With the solution algorithms available today, it is possible to construct even very large applied general equilibrium models which can be solved at a reasonable cost.

The use of large equilibrium models in the natural resource area begins with the work of Hudson and Jorgenson (1974). These authors combined an interindustry production model containing price-responsive input intensities with a long-run model of aggregate demand. In the interindustry production model, Hudson and Jorgenson integrated a flexible production technology in which the per-unit use of intermediate inputs, as well as of primary factors, responded to price changes, with a standard input-output structure.

This was a significant methodological advance. In the first version of the Hudson-Jorgenson model, which appeared in 1974, the prices of labour and capital were determined independently of the relative factor demands in the interindustry model. Later versions of the model achieved a more complete integration of the interindustry and aggregate demand models. The version of the more recent Hudson-Jorgenson model contains a demand submodel quite different from the original one. In the current model, consumers are distinguished according to demographic and other characteristics based on an aggregation method first presented in Jorgenson, Lau and Stoker (1980). The current model also differs from the original with regard to production. A significant new feature is the incorporation of technical change as a function of changes in prices.

Another model of energy-economy interactions is Manne's ETA-Macro (1977). This model contains a detailed energy technology assessment module describing various energy activities available at different points in time. In contrast to the Hudson-Jorgenson models the representation of the interactions between the energy and non-energy sectors is quite simple.

Electric and non-electric energy are treated as inputs, along with capital and labour, into a single aggregate production function. Flexibility in adjusting to higher energy costs is governed by the elasticity of substitution between energy and value added. The production technology is of the putty-clay type. Unlike the Hudson-Jorgenson model, ETA-Macro deals explicitly with the energy resource base by assuming cumulative supply functions for primary energy. The solution of the model is based on intertemporal optimization, the maximization of social utility from the stream of future consumption, given the resource base and the available energy technologies. The model has typically been used to simulate the impact of technological or regulatory constraints on energy supply.

In the past few years several new economy-wide natural resource models have appeared. Although the structure and focus of these models differ widely, there is a general emphasis on interactions between the natural resource and non-natural resource sectors, and implicit confirmation of the value of general equilibrium approaches. The construction of these models is usually guided by prior theory, but the models' results sometimes induce a reformulation or revision of the theory on which they were based. The connection between theory and model development thus runs both ways. As a consequence of the natural resource modelling efforts of the past few years, the theoretical understanding of the interplay between natural resource prices and economic growth has improved. The effects of changed resource conditions on the production of, demands for and prices of other productive factors has been clarified. With this structure the model is able to explore a wide range of important policy issues. These include the welfare cost of higher natural resource prices and the deviations from steady-state growth produced by scarce energy, the economic implications of changes in the speed of adjustment by firms, the impacts on the domestic economy of different reinvestment patterns by resource exporting countries, and the effects of profits, taxes and import tariffs on economic efficiency and income distribution.

There are alternative but related approaches to modelling the environmental/ecological impacts of economic activities, including models which aim to assess resource use in developing countries. The traditional input-output framework has been extended since at least 1970 (Leontief, 1970) to model environmental pollution generation and abatement activity.

Three basic categories of such models are:

- generalized input-output models, which augment the technical coefficients matrix to include pollution generation and abatement (Leontief, 1970). Extensions of the input-output approach to modelling environmental impacts have included regional models aimed at identifying responsibility for pollution by industries (Chatterjee, 1975)
- commodity-by-industry models which express environmental factors as "ecological commodities" (Johnson and Bennet, 1981). These are non-marketable commodities which are either inputs to or outputs discharged from production processes in a commodity-by-industry input-output table.

- economic-ecologic models which extend the concept of inter-industry flows to record flows between the economy and "ecosystem sectors" (Isard, 1968; Forsund, 1985). The latter include environmental resources such as air and water, and the flows consist of pollutants and/or abatements.

The chief problem with this class of models is that they are unable to generate endogenous prices which result from market clearing. It is, accordingly, difficult to include in such models policy tools which work through market incentives.

The CGE approach does not suffer from this handicap. In addition, CGE models have the advantage to present a schematic framework for integrating economy-wide micro models including resource sectors with alternative macro models. An example of models that are highly interactive is the ETA-Macro model or the expanded Global 2100 model (Manne, 1977; 1991). For an overview with an up-to-date coverage I refer to Jorgensen and Wilcoxen (1993a).

In CGE models the link to "sustainability" in economic development is established through the equilibrium process of balancing production and resource sectors in the economy, and by imposing the requirement that long-run macroeconomic resilience will not be sacrificed at the expense of ecological degradation. Given the various, often inconsistent definitions and concepts of "sustainability" in economic development, see Pezzey (1989), we require that resource use should proceed at (sustainable) prices that assure long-run intertemporal and inter-generational preservation.

2 COMPUTABLE GENERAL EQUILIBRIUM MODELS

Policy analysis, and formulation, in both industrialized and developing countries, have frequently relied on multi-sector, economy-wide models. Such models furnish insights into linkages between production, demand, and trade, that are not captured by aggregated, macroeconomic models. Since the first formulation of disaggregated, economy-wide models there has been considerable theoretical and empirical development in the formulation of models which focus on important general equilibrium relationships. The widespread use of such models in policy analysis, has, in turn, fostered the collection of reliable data in both industrialized and developing countries. The chief characteristics of CGE models, distinguishing them from other modelling approaches, is price endogeneity for commodities and factors, and the incorporation of non-linear substitution possibilities by different economic agents who respond to market incentives.

The earlier models implicitly assumed command economies, and did not allow for situations where numerous agents in pursuit of their own welfare, jointly determine equilibrium outcomes.

All present economies, whether industrialized or developing countries, are, however, characterized by the prevalence of both state and decentralized sectors. In such 'mixed' economies much economic activity is not under the direct control of national planners, and market mechanisms play an important role in resource allocations between different sectors. In input-output or linear programming models, it is not possible to capture adequately the impacts of policy variables that operate through market mechanisms (Dervis et al, 1982) because the workings of factor and commodity markets are not explicitly modelled. In contrast, CGE models explicitly incorporate market processes through endogenous prices which determine consumer, government, intermediate, capital stock, and trade demands, and supply from domestic manufacture and imports. However, a significant weakness of many CGE models is that they have excluded command economy elements.

Another important distinction between the earlier multi-sector models and their newer CGE counterparts is the incorporation in the latter of non-linear relationships, allowing for substitutability between inputs (including non-produced factors), and between domestic and imported commodities.

Input-output models as well as linear programming models assume linear production relationships: inputs and outputs maintain fixed proportions to each other. This results in the inability of these models to realistically cover various substitution possibilities. The use of non-linear relationships imply, of course, that CGE models are more data intensive, and more demanding of computing resources than are linear models.

Recent advances in data gathering have ensured that adequate, reliable data is frequently available for constructing detailed CGE models. However, despite considerable progress in computer technology and software development, the feasible size and complexity of CGE models is still constrained by computing limitations. CGE models are not intended for simulating transient responses of an economic system over time-periods during which the economy adjusts to the application of policy instruments or to exogenous shocks.

This is because the solutions are always equilibrium solutions, and the adjustment path of the economy is not revealed. Further, CGE models are useful for predicting trends in sectoral structure, intersectoral terms of trade, income distribution, trade performance and government revenue.

By now, CGE models have been developed for a variety of purposes, including the modelling of trade policy, resource allocation and output effects of taxation policies, and the impacts of price shocks on the pattern of resource use. A well specified CGE approach would have several clear advantages over the earlier input-output approaches. One advantage is the ability of the CGE models to cover the effects of policy instruments which work through markets, on commodity and pollution outputs of different industries, including those emerging in abatement activities. A second advantage of CGE models is their ability to analyze possibilities of substitution between factors, and thus predict the distributive effects of different environmental policy instruments.

Finally, CGE models can capture substitution possibilities between domestic and import goods, and export and domestically used commodities, and thus simulate the effects of environmental regulation on trade and international specialization in production. In CGE models, in contrast to earlier linear general equilibrium models, final demand vectors of goods and services are linked to factor incomes implicit in the solution, through adjustment of prices. The earliest true CGE model (consistent with the above description), was formulated by Johansen (1960) in a study of the Norwegian economy. Johansen linearized the general equilibrium model by means of logarithms and was thus able to solve it by matrix inversion, to obtain growth rates of endogenous variables. Since then, with the increasing data availability, computing power and non-linear solution algorithms, there has been a proliferation of CGE models. At present, there exist four general classes of CGE models, defined in terms of the problems on which they focus (Scarf and Shoven, 1984; Bergman et al., 1990).

In the first category are models of national economies (INC's and DC's) which are concerned with issues of trade, economic structure, growth and income distribution. Selected examples include Taylor and Black (1974) for Chile (dealing with resource shifts under trade liberalization), Dervis (1975) for Turkey (concerning substitution, employment and intertemporal equilibrium), De Melo (1977) for Columbia (dealing with the impact of an equalization of the urban wage rate of qualified and unqualified labour, in the absence or presence of factor mobility), Whalley (1977) for the UK (dealing with economic impacts of the UK tax system) and Feltenstein (1980) for Argentina (relating to analysis of trade restrictions).

A second category are models of INCs focusing on issues in public finance theory. Examples are Shoven and Whalley (1974), relating to computation of competitive equilibria on international markets with tariffs, and Ballard et al. (1985), concerning the welfare costs of taxes in the US. The next category are multi-country, international trade models to study issues related to the volume and direction of trade, and its regional impacts. Examples are Petri (1976), dealing with Japanese-US trade, and Deardorff and Stern (1979), concerning the impacts of the Tokyo round of multilateral trade negotiations on the US and other industrialized countries.

Finally, there are several regional, national, and multi-country models focusing on energy and resource sectors (Boone et al., 1992). These include Hudson and Jorgenson (1978), Manne et al. (1980) and Despotakis and Fisher (1988). The first and last of these are described in some detail, below.

No parallel effort has yet been made with respect to the use of CGE models for market based domestic and international environmental pollution regulation and sustainable development, except for work covered by Jorgensen and Wilcoxen (1993b).

3 STRUCTURE OF CGE MODEL

The theoretical formulation of the model is general in the sense that it applies to developing countries as well as industrialized countries, for which the "small country" assumption in traded sectors holds. The economy modelled is an open, national economy, and a price-taker for imported commodities.

The assumptions on the supply side are as follows: industries produce domestic commodities, employing capital, labour and an aggregation of commodity inputs. Additionally, the agriculture and forest sectors also employ land. The different types of inputs in each industry may be smoothly substituted for each other through an industry-wide, neo-classical cost (or production) function. The specific functional form employed in this model is the Trans-Log (TL) cost function, for the reason that it permits different substitution elasticities between different pairs of inputs. The TL cost function collapses to the widely used Cobb-Douglas (CD) form in the case of unit substitution elasticities between input pairs, which is convenient. It is usual in CGE models to assume constant returns to scale for all industries, and this assumption is retained. Increasing or decreasing returns to scale are compatible with the CGE framework, but require the adoption of specific pricing rules (how non-marginal cost pricing is to be accomplished) for industries, which may be controversial.

It is assumed that commodity inputs are an aggregation of two types of inputs: namely aggregate materials and aggregate natural resources, accomplished separately for each industry by a Constant Elasticity of Substitution (CES) aggregation function, which too, collapses to the CD form for unit elasticity of substitution. The CES functional form is chosen for this aggregation because only two aggregate inputs are involved, and only one parameter estimate (substitution elasticity) is required.

Further, for each industry, different natural-resource commodity inputs are assumed to comprise aggregate materials in fixed proportions while other aggregate natural resources are composed of different resource sources, accomplished by means of an aggregation function which allows for smooth substitution between the various sources of natural resources. This last aggregation function is also assumed to be of the TL form, for reasons detailed above, collapsing to CD in the special case of unit substitution elasticities. The mix of different resource sources comprising aggregate resources is determined by cost minimization in resource use with the aggregation function constraining the choice.

Each industry produces a characteristic commodity but in addition, it may produce one or more marketed by-products, which in turn are the characteristic commodities of other industries. Thus, for example, the 'agriculture and food' industry may produce 'intermediates' as by-products. The quantities of the different products of each industry bear fixed proportions to each other, which are the elements of a "Make Matrix", and these are recovered from the primary data. Thus, in the above example, the quantities of 'agriculture and food products' and 'intermediates' per unit of gross output of the 'agriculture and food' industry are constant. The typical assumption in CGE models is that each industry produces a single commodity: the present modelling assumption enables the inclusion of greater detail on the supply side.

Industries maximize profit by choosing capital, labour and non-factor inputs. Additionally, while maximizing profit, they respond to whatever domestic regulatory regime for GHGs is operated by the government. The regulatory regimes considered here have the following characteristics.

- 1. Industrial emissions of GHGs due to intermediate energy use, and not emissions due to private (household) or public (government) consumption of fossil fuels, are regulated by environmental policy instruments.

- 2. Each industry is assigned a permit ("assigned tradeable permits") for GHGs emissions (expressed as equivalent tonnes of carbon per year), which is set equal to zero in the model. If this policy instrument is not employed industries may emit GHGs up to the quantity specified in the permit without penalty. These permits may be traded with other industries. Emissions in excess of the assigned permits must be offset or will be penalized as described below.

- 3. Government may auction tradeable permits ("auctioned tradeable permits") for GHGs emissions (in terms of carbon equivalent per year) to industries in a domestic market for quotas and offsets. If auctioned tradeable permits are not employed, the quantity of permits auctioned is set equal to zero in the model.

- 4. In addition to permits, industries may also purchase offsets for GHGs emissions from the forest sector in the domestic market for offsets and quotes (again expressed in equivalent tonnes of carbon per year).

- 5. The government may levy a tax ("GHGs tax") on the net GHG emissions of each industry, after giving credit for the permits and offsets traded in the domestic market or assigned by the government. If this instrument is not employed, the tax rate is set at zero in the model. If no emissions in excess of the permits and offsets available to or purchased by an industry are to be allowed, this tax rate may be conceptually considered as set equal to infinity.

- 6. Additionally, or as an alternative to the above devices, the government may impose industry wide emissions limits ("standards" or quantity restrictions on the net of GHGs emissions) which may not be exceeded. Again, this is conceptually equivalent to an infinitely large penalty for non-compliance.

In all cases it is assumed that the domestic regulatory regime can be effectively administered and that all taxes or penalties are collected at the time the GHGs are emitted.

3.1 Trade Sector

Since the economy is modelled as an open economy, the international trade sector must be included in a simple formulation, with the internationally traded and domestically utilized commodity assumed to be the same, for a small country, the domestic prices of commodities would be driven completely by world prices and tariff levels, and thus exogenous. Also, in such an approach, a good may be either imported or exported, but not both. In practice, this is not the case, and there is usually significant variation between domestic and world prices of commodities, which is not due to tariffs alone. Further, countries often engage in two-way trade in commodities of the same category.

A standard formulation that allows a way out, is to assume on the import side that domestically produced and imported commodities are imperfect substitutes (Armington, 1968). The domestic economy remains a price taker for imports, but these are combined with domestically produced commodities to yield a "composite" good for the domestic market. The composition is usually done by a constant elasticity of substitution (CES) aggregation function. This means that the users (consumers, government and industries) choose the mix of imports and domestic goods through cost minimization, subject to the substitution possibilities allowed by the aggregation function. The price of the composite good then becomes endogenous: a function of the import price, the domestic price, and the elasticity of substitution between the domestic and imported commodities.

The standard assumptions on the export side are as follows, exports face an export demand function, which, in general, is not infinitely (own price) elastic, due to the fact that traded goods in a given category are not perfect substitutes for those exported by other countries. Further, exports may differ in both quality and specific type of good within the broad category, from domestically used goods. Thus, industries are assumed to face a product transformation relationship between export goods and domestically demanded goods, and choose the mix of the two types by maximizing revenue for a given aggregate output. This transformation function is assumed to be the Constant Elasticity of Transformation (CET) form, analogous to the CES aggregation function.

3.2 Demand Side

The following assumptions are made on the demand side: Consumers derive income from factor payments, and from trading (windfall) profits. Additionally, they may receive subsidies from the government. Consumer demand for each (composite) commodity is determined by an economy wide Linear Expenditure System (LES) demand function. Government derives income from taxes of different types, including tariffs, direct and indirect taxes and pollution penalties, as well as from international trade in the national GHGs endowment, and domestic auctions of GHGs quotas to industries. It is assumed that shares of government expenditure (public consumption) on different commodities are fixed; these shares may constitute a policy instrument. Government itself does not own any factors of production. This assumption is based on the premise that all purchases of land or capital assets by government are made through market borrowings, and not from current revenues. State Owned Enterprises (SOEs) are thus, no different from other firms, because government in effect, rents the factors of production for SOEs. Alternative assumptions would be more data intensive. and are unlikely to yield qualitatively different insights.

Households pay direct taxes and receive subsidies and transfers, while industries pay indirect taxes such as excise and sales taxes on domestic commodity outputs and also pay emissions penalties. All agents (industries, consumers and the government,) pay tariffs for imports. Foreign buyers pay tariffs on exports. Quantity restrictions (QRs) on imports may yield windfall profits (rent) to importers, adding to housing income, while similar restrictions on exports may yield windfall profits to exporters. Consumers and government save a portion of their income, the fraction of income saved by each being exogenous, a standard CGE modelling assumption. Savings, together with the exogenous foreign capital inflow, equals gross investment. The (constant) shares of gross investment in each industry are exogenous in the model. These shares may constitute a policy choice, where Governmental Central Planning or industrial licensing is available as a policy instrument. The remainder of the income is spent on consumption of composite (of imports and domestic goods) commodities.

The fraction by value of each commodity comprising (incremental) fixed investment is assumed to be in fixed proportion to the value of (incremental) fixed investment in each industry. These fixed proportions are the elements of the "capital composition matrix". Further, the part of gross investment comprising "change in stocks" is, for the economy as a whole, assumed to be in fixed proportion by value to the gross investment for each commodity. These are standard assumptions in the CGE literature.

3.3 Market Clearance

In this model, long-run equilibrium changes are intended to be simulated, through empirical comparative statics analysis. Thus, all inputs to each industry may be varied, and the supply of each factor is updated in each time-period, for multi-period runs. The supply of land is, however, fixed in the model, and initial capital stock and labour supply are exogenous. The increment to capital in each time period is endogenous, and in the case of labour supply, the rate of increase in available labour is exogenous. Labour-leisure tradeoffs are not modelled, so the labour supply in each period is fixed: this is a standard CGE modelling practice.

Capital and labour are assumed to be mobile across all industries, though in the case of capital, the real cost varies across industries due to differing rates of replacement of fixed capital. In the case of labour, institutional factors result in different wage levels across industries. These wage level differences are assumed to be related by fixed ratios, which are exogenous Land is fungible between its use in agriculture and forestry, and the rental rates are identical in these two sectors. Each factor market is balanced in the GE model to yield market clearing endogenous factor prices.

The overall demand for domestic commodities results from the domestic content of composite goods (determined by cost minimization constrained by the Armington CES function referred to above) demanded by consumers, government, and industries, for consumption, intermediate inputs, fixed investment, change in stocks, and for exports. Domestic supplies result from the outputs of industries. The demand for imported commodities is also determined by cost minimization on the Armington function. A balance between demand and supply for domestic commodities prevails in each commodity market, from Walras' law it is not necessary to write a balance equation for (any) one factor or commodity market in the CGE model. The particular equation emitted may be chosen from the point of view of computational convenience.

A foreign exchange balance prevails through costs of imports equalling revenues from exports, (including trade in offsets), together with net foreign exchange inflow. The exchange rate is endogenized by means of this balance. Finally, the price level is determined through equating to unity the weighted (endogenous) domestic prices of domestically used commodities. The weights employed are the proportions by quantity of each Armington commodity in the private consumption vector in the calibration year.

3.4 Model Closure

One problem in the design of CGE models is that, given exogenous levels of real investment and public consumption, if factors are paid their marginal revenue product, full employment of factor is not possible. If the system is to be mathematically determined, it is necessary to choose between alternative macroeconomic consistency rules, called "closures". For an open economy, with a floating exchange rate, as in the present model, the choice lies between the following: (a) Keynsian closure: the absence of full labour employment or rigidity of the nominal wage, (b) Johansen closure: the endogenity of public consumption or savings so as to equate total savings to the exogenously given real investment, (c) Kaldorian closure: where factors are not paid according to their marginal revenue product and (d) Classical closure: the level of real investment becomes endogenous and adjusts to the total available savings. The present model adopts two versions of the classical closure rule, since there is no empirical evidence clearly favouring any of the alternatives. In the base case, it is assumed that household and public savings rates are exogenous (called "Normal" closure). The variant employed in sensitivity analyses (called "Variant" closure) is that real public expenditure rather than the public savings rate is exogenous. This is policy relevant and plausible since the government may find it politically expedient to maintain unchanged the real level of public expenditure, and allow the government to run a deficit, financed by borrowings from households, or a surplus, where the government becomes a net lender to households.

Policy Relevant Endogenous Variables: Three endogenous variables of policy interest which are extracted from the equilibrium solution of the GE model are: GDP, an index of consumer welfare changes, and the ratios of wages of unskilled rural labour to the interest rate or the land rental rate to the interest rate. These latter ratios are termed: "class indexes".

The GDP is simply the sum of the factor incomes of the economy, together with patriation of foreign exchange from trade in the net national emissions quota, which is the return to a resource endowment of the economy.

The construction of the Welfare Index is accomplished as follows: the change form the calibration year value of the Paasche real consumption expenditure index is a lower bound on consumer welfare change, while the change in the corresponding Laspeyres index is an upper bound. If we assume a single representative consumer in the economy and that the underlying utility function is homothetic (Samuelson and Swamy, 1974). Our Welfare Index is defined as the arithmetic average of the Paasche and Laspeyres real consumption expenditure indexes. Changes in this Welfare must be interpreted with caution. Since (under the assumptions of the model) the Welfare Index is simply the midpoint of the lower and upper bounds of actual consumer welfare, small changes in the Welfare Index in either direction are consistent with small consumer welfare changes in the reverse direction. Only if the change in the Welfare Index is large would it be safe to conclude that a change in actual consumer welfare in the same direction as the change in Welfare Index has occurred. Moreover, the Welfare Index captures only one aspect of societal welfare, neglecting other important dimensions, for example savings and investment.

It is important to note that the CGE model constructed as above is not a true Walrasian GE model in Pareto optimal equilibrium. This is because of the inclusion of government as an agent, and the presence of a distortionary tax structure in the initial state. Neither is GDP maximized in the initial (or any given equilibrium) state given the factor endowments of the economy. The application of policy instruments, including those in the nature of additional constraints on the economy, may therefore result in increases or decreases in welfare or GDP General equilibrium theory does not furnish any restrictions on such outcomes.

This completes the verbal description of the CGE model, which is employed below to perform comparative statics simulations of the effect of various policies, and of exogenous shocks on the economy.

4 SPECIFICATION OF CGE MODEL

We start with some notation. Industries are subscripted by 'a' and commodities by 'c', except where otherwise specified. Different natural resources are subscripted 'nr'. These indexes are also employed as superscripts when not serving to define operations over sets. Each industry is associated with a characteristic commodity whose name it bears. All other terms are defined when they first appear.

Production Relationships

A neo-classical cost function for each industry may be written as

$$C^a = F^a(W_K^a, W_L^a, W_{LA}^a, P_Q^a, X^a) \tag{1}$$

where K is fixed capital employed, L is labour employed, LA is land employed, Q is an aggregation of intermediate inputs comprising aggregate 'materials' M and aggregate resources NR, X is the gross output of the industry, and comprises of the marketable products of the industry, aggregated in the manner shown below. F(.) is the industry cost function.

The W's are effective factor prices (which are industry specific), and P_Q is the 'price' of aggregate non-factor inputs faced by the industry.

The actual cost function employed is the Trans-log (TL) cost function, which is of the form

$$\begin{aligned} \ln C(P,X) &= a_o + a_X \ln X + b_{XX} (\ln X)^2 \\ &+ \sum_i a_i \ln P_i + (1/2) \sum_i \sum_j b_{ij} \ln P_i \ln P_j \\ &+ \sum_i b_{X_i} \ln X \ln P_i \end{aligned} \tag{2}$$

where the a's and b's are fixed parameters for each industry, i,j subscript different inputs. Restrictions on parameter values required for homogeneity in degree one in all prices are:

$$\begin{aligned} &\Sigma a_i = 0, \ \sum_i b_{X_i} = 0 \\ &\sum_i b_{ij} = \sum_j b_{ji} = 0 \\ &b_{ij} = b_{ji}, i \neq j \end{aligned} \tag{3}$$

For constant returns to scale technology, assumed in the model for all industries: $a_x = 1$, $b_{xx} = 0$, $b_{Xi} = 0$ for all i. These restrictions result in a simplification of the cost function to:

$$\begin{aligned} \ln C(P,X) &= a_o + \ln X + \sum_i a_i \ln P_i \\ &+ (1/2) \sum_i \sum_j b_{ij} \ln P_i \ln P_j \end{aligned} \tag{4}$$

and $\sum_i a_i = 0, \ \sum_i b_{ij} = \sum_j b_{ji} = 0, \ b_{ij} = b_{ji}, \ i \neq j$

Cost share of each input (from Shephard's lemma) is then given by

$$s_i = a_i + \sum_j b_{ij} \ln P_j \Rightarrow a_i = s_i \sum_i b_{ij} \ln P_j \tag{5}$$

where the s_i's are the cost shares of different inputs.

The Allen-Uzawa substitution elasticities between inputs are given by

$$\sigma_{ij} = (b_{ij} + s_i s_j)/s_i s_j \Rightarrow b_{ij} = (\sigma_{ij} - 1) s_i s_j, \ i \neq j \tag{6}$$

$$\sigma_{ij} = (b_{ii} + s_i(s_i - 1))/s_i^2 \Rightarrow b_{ii} = - \sum_j b_{ij}, \ i \neq j \tag{7}$$

where the σ's are the Allen Uzawa substitution elasticities. If all σ's are unity, the TL cost function becomes identical to the cost function derived from the CD production function.

Equations (5), (6) and (7) enable one to recover constant returns to scale TL cost function parameter values, given data on substitution elasticities, cost shares, and input prices, and assuming average cost pricing. (It is convenient to assume that all domestic commodity prices in the calibration year are unity, which changes the scale of measurement for quantities of commodities but has no effect in real terms).

The general advantages of TL cost functions are first flexibility: differing substitution elasticities between different pairs of inputs can be accommodated in the model. Further, intermediate inputs may be aggregated by an aggregation function which allows for smooth substitution between aggregate materials and non-renewable resources.

$$Q^a = F^a \, (M^a, NR^a) \tag{8}$$

where F(.) is an aggregation function of intermediate inputs. The CES functional form is adopted for accomplishing this aggregation. Generically, for two inputs, the CES aggregation function is written as

$$Y = A\,[\delta\, X_1^{-\rho} + (1-\delta)\, X_2^{-\rho}]^{-\frac{1}{\rho}} \tag{9}$$

where Y is the output (or aggregated commodity), X_1, and X_2 are 'inputs' (or components of the aggregation), δ is the 'share parameter', and ρ is the 'elasticity parameter'. The parameter A is a scaling factor.

It is convenient to recover a value for A so that the price of Y is unity (under the assumption of average cost pricing for the composite) when the prices of X_1 and X_2 are also unity (details not shown). The (direct as well as Allen-Uzawa) substitution elasticity is given by $\sigma = 1/(1+\rho)$.

In the special case of unity substitution elasticity the CES function collapses to the CD form:

$$\log Y = \log A + \delta \log X_1 + (1 - \delta) \log X_2 \tag{10}$$

First order conditions for cost minimization by choosing X_1 and X_2 to produce a given 'quantity' of Y yields:

$$X_1/X_2 = (P_{X_2}/P_{X_1})^{\sigma}\ (\delta/(1-\delta))^{\sigma} \tag{11}$$

where P_{X1} and P_{X2} are the prices of X_1 and X_2, respectively.

The δ or 'share parameter' is recovered, given cost shares of the components, and the substitution elasticity between them, by:

$$\delta = 1/(1 + (s_2/s_1)^{\frac{1}{\sigma}}) \tag{12}$$

where the σ's are the cost shares. The above relationships also apply to the composition of imports and domestic commodities.

The case of Constant Elasticity of Transformation (CET) composition of outputs is analogous. The CET function is represented generically (for two commodity outputs) as:

$$Q = B[\gamma\ Q_1^{\phi} + (1-\gamma)\ Q_2^{\phi}]^{\frac{1}{\phi}} \tag{13}$$

where Q is the 'composite' output, Q_1 and Q_2 are individual commodity outputs, γ is the 'share parameter', ϕ is the 'elasticity parameter' related to the (constant) elasticity of transformation between Q_1 and Q_2 by $\eta = 1/(1-\phi)$ where η is the transformation elasticity. The constant parameter B is a scaling parameter, recovered in a manner analogous to the scaling parameter of the CES aggregation function.

In the choice of output mix from given inputs, firms are assumed to maximize revenue, leading to the following relationship:

$$Q_1/Q_2 = (P_1/P_2)^{\eta}\ ((1-\gamma)/\gamma)^{\eta}$$

The share parameter, γ , is recovered, given revenue shares s_1 and s_2, and the transformation elasticity, η, by

$$\gamma = 1/\left(1+(s_1/s_2)^{\frac{1}{\eta}}\right) \tag{15}$$

The CET functional form is used to model product transformation between export and domestically used commodities.

It is assumed that in the time-frame of analysis 'materials' are an aggregation of commodities, not being resource sources in fixed proportions

$$M_{ca} = \alpha_{ca} M_a \tag{16}$$

where M_{ca} is the quantity of non-NR commodity c included in one unit of aggregate materials input of industry 'a', and α_{ca} is a fixed parameter, derived from the 'Use Matrix' of input-output analysis.

Further, it is assumed that 'aggregate resources', NR, are an aggregation of different energy sources, (petroleum, coal, natural gas, and electricity) allowing for limited but smooth substitution between different sources:

$$NR^a = NR^a(NR_1^a, NR_2^a, \ldots, NR_e^a) \tag{17}$$

where NR_e^a is the quantity of resource of type e used by industry 'a'.

It is assumed that the aggregation is accomplished by a TL aggregation function (described above), with,in general, differing substitution elasticities between each source pair, and constant returns to scale.

The 'output' in this case is the quantity of aggregate NR, and the 'cost' is the sum of effective costs of each NR source to each industry. In the special case of unit substitution elasticities, the TL aggregation takes the CD form.

Finally, aggregate output is a fixed coefficients aggregation of different marketed commodities

$$XD_{ac} = \mu_{ac} X^{a} \tag{18}$$

where XD_{ac} is the output of domestic commodity of type c produced by industry a, and μ_{ac} is a fixed coefficient, determined from the 'Make Matrix' of the input-output literature. The above assumptions enable one to model substitution (or complementarities) in production between different factors and (aggregated) commodity inputs.

GHGs Emissions by Industries: The present research is aimed at constructing a CGE model for simulating GHGs emissions due to energy use, CO2 and N20. GHGs such as chlorofluorocarbons (CFCs) and methane (CH4), which originate from sources other than energy use or consumption are not considered in the present model.

It may be noted that, given present technology, CO2 and N20 emissions are not feasibly abated, in the sense of being converted to environmentally benign products, or even to other types of pollutants, by industrial processes. It is thus assumed that each type of energy used results in emissions of CO2 and N20 in fixed proportions by quantity of each. This assumption conforms to standard technical practice, based on the chemical law of constant proportions.

$$GHG_{e,g} = \eta_{e,g} EN_{e} \tag{19}$$

where EN_e is the quantity of energy type e employed, and η is a non-negative technical parameter for each energy source, e and each GHG, g.

The same quantities of different GHGs have differing impacts on the greenhouse effect, related by a technical parameter Ω for each GHG, called the "carbon equivalent" for that GHG.

$$CO2EQ_{g} = \Omega_{g} GHG_{g} \tag{20}$$

where $CO2EQ_g$ is the quantity of carbon dioxide equivalent in greenhouse impact to a quantity GHG of emission of type g.

An expression for the gross GHGs emissions by each industry, in terms of equivalent carbon, is:

$$CO2EMS^{a} = \sum_{e} \sum_{g} \eta_{eg} \, \Omega_{g} EN_{ea} \tag{21}$$

where $CO2EMS^{a}$ is the gross emission of GHGs in carbon equivalent terms, of industry a.

Additionally, offsets are assumed to be generated by the forest sector alone, in proportion to the total land area under forest cover.

$$OFFSET^{FOREST} = \Phi \, . \, LA^{FOREST} \tag{22}$$

where OFFSET is the total offsets generated LA^{FOREST} is land area under forest cover, and Φ is a technical parameter denoting the offsets generated per unit forest area.

An industry level balance for GHGs is furnished by :

$$CO2NET^{a} = CO2EMS^{a} \cdot OFFSET^{a} \cdot CO2INP^{a} \cdot CO2PERI \tag{23}$$

where $CO2NET^{a}$ is the net emissions of GHGs in carbon equivalent terms of industry a. $OFFSET^{a}$ is the quantity of offsets generated by the industry (zero for all but the forest sector). $CO2INP^{a}$ is the quantity of quota or offsets for GHGs in carbon equivalent terms purchased in the domestic market, and $CO2PERMIT^{a}$ is the GHGs quota in carbon equivalent terms assigned to the industry by the government.

Pricing Rules for Industries: The constant returns to scale, price taking and profit maximization assumptions for industries enable one to specify an "average cost pricing rule" for each industry, which is formally identical to a "marginal cost" pricing rule. Under conditions of balance of each commodity market, this will result in an endogenous price for each domestic commodity in the economy. The average cost form of the price rule is mathematically simpler in the context of multiple products, emissions penalties, and offsets purchases (or sales):

$$\sum_{e} (PD_c\ XD_{ac}) / (1 + Td_c^{-}) = \sum_{f} P_{af} F_{fa} + \sum_{c} P_c\ Q_{ca} \\ PG \cdot CO21NP_a + (CO2NET^{a} \cdot CO2TAX \ / \ CO2NET^{a} > 0) \tag{24}$$

where PD_c is the domestic price of commodity c (composite of domestic goods exported and used domestically, see below). Td^{-}_c is the indirect (ad-valorem) tax rate on c. P_{af} is the effective price of factor input f (capital, labour, land) to industry a. F_{fa} is the quantity of input f used in industry a. P_c is the price of Armington composite c. Q_{ca} is the quantity of intermediate Armington commodity input c to industry a. PG is the domestic price of GHGs offsets and quotas, and CO2TAX is the tax rate on net positive GHGs emissions.

The "effective price" of each input for each industry is as follows

For capital services

$$P_{Ka} = R + k_a \tag{25}$$

where P_{ka} is the effective price of capital per time period. R is the real interest rate in the economy (assumed to be the same for all sectors), and k_a is the "replacement fraction" (real depreciation) for fixed capital, for industry a

For labour

$$P_{La} = w_a\ P^{*} \tag{26}$$

where P_{La} is the wage level for industry a. w_a is the ratio of the average industry wage rate to the wage rate for one specified category (unskilled rural labour, in the present case), and P^{*} is the wage rate of the specified labour category.

For each energy source

$$P_{ea} = P_e - \left(\sum_{g} \eta_{e.g} \Omega_g\ PG\right) \tag{27}$$

where P_{ea} is the effective price of energy of type e for industry a. PG is the domestic price of GHGs offsets per unit (in carbon equivalent terms), and P_e is the price of the Armington composite of imports and domestic types of energy of type e.

The effective price for each industry for each type of non-energy material input equals the Armington composite price.

Import Equations: It has been already noted that all commodities used in the domestic market, whether for private or public consumption, intermediate use, fixed investment, or change in stocks, are assumed to be Armington composites of imports and domestically produced commodities, composed by employing the CES functional form furnished in equations (9) to (11).

The price of an imported commodity in the domestic market is given by

$$PM_c = PW_c \ (1 + Tm_c) \ ER + WINDM_c, \ WINDM_c \geq 0 \tag{28}$$

where PM is the price of the import commodity in a chosen currency unit (CU), PW is the world price in \$. Tm is the import tariff rate, and ER is the exchange rate, Cu per \$. $WINDM_c$ is the "windfall profit" accruing to importers from quantity restrictions (QRs) on imports. The imported quantity of a commodity cannot exceed the QR on imports of that commodity.

$$Q_c^m \leq QRM_c \tag{29}$$

where QRM is the QR for imported commodities and Q^m is the quantity of commodity imported. Quantity restrictions on trade are not included in the PE model, and thus windfall profits are assumed to be zero.

The Treatment of Exports: The assumption of imperfect substitutability between exports of different countries of the same category of goods leads one to specify an export demand function for each exported commodity for the economy.

$$Q_c^E = Q_c^{Eo} \ (\Pi_c / PE_c)^{v_c} \tag{30}$$

where $Q^E{}_c$ is the quantity of commodity c exported, $Q^{Eo}{}_c$ is a parameter for each commodity, Π_c is a weighted average of the world price of the commodity in \$. PE_c is the export price of each commodity in \$, and v_c is the price elasticity of exports of c, a data parameter. Given data on the price elasticity of exports of each commodity, taking Π_c as unity in the calibration year, and calculating PE_c from data on export tariffs (with domestic prices of exports as unity in the calibration year), it is trivial to recover $Q^{Eo}{}_c$.

Further, the assumption of product differentiation between exports and domestically used goods of the same category leads to CET transformation relationships between them, as described in equations (13) and (14). The price fetched by export commodities in the world market in $ is given by

$$PE_c = (PDE_c(1 + Te_c) + WINDE_c \; / \; ER \tag{31}$$

where PDE_c is the domestic price of export goods in Cu, and Te_c is the ad-valorem export tariff rate for export commodity c, and $WINDE_c$ is the windfall profit on exports accruing to exporters, due to a QR on exports of each commodity allowed to operate as a policy instrument

$$Q_c^E \leq QRE_c \tag{32}$$

where QRE_c is the QR on exports of c.

Incomes: The Gross Domestic Product, GDP, is the sum of factor payments, together with windfall profits from trade and international sales of national emission quotas (NEQ)

$$\begin{aligned} GDP = {} & (\textstyle\sum (w_a L_a + P_{Ka} \, K_a + r L_a) + \\ & \textstyle\sum (Q_c^m \; WINDM_c + Q_c^E \; WINDE_c) + PGW \; CO2TRADE \cdot ER \end{aligned} \tag{33}$$

where PGW is the exogenous world trading price of GHGs per carbon equivalent unit in $, and CO2TRADE is the quantity of GHGs traded (exports positive).

In the present formulation, we assume that there is only one type of household, which owns all factors of production. Households derive income from factor payments, including windfall profits on imports or exports which are restricted by QRs. In addition, they may receive direct government subsidies. These assumptions imply that government owns no factors in the net, and that subsidies directly affect consumer behaviour, but industry behaviour only indirectly through changes in demand. Consumers pay direct taxes, which, it is assumed, do not affect factor supplies, and save a portion of their net income after direct taxes. This (marginal) propensity to save is assumed to be constant and exogenous. An expression for net household income is thus

$$HHINC = (GDP - PGW \cdot CO2TRADE \cdot ER) \; (1 - Tx) + GDP{\cdot}S_s \tag{34}$$

where HHINC is the household income. Tx is the direct tax rate, and s_s is the subsidy rate as a fraction of the GDP, a policy parameter.

Net household expenditure is given by

$$HHCEX = HHINC(1 - s_H) \tag{35}$$

where s_H is the marginal propensity to save of households, assumed constant and exogenous.

The government derives income from direct and indirect taxes, tariffs, trading in NEQ exogenous foreign exchange inflow negotiated as part of a GHGs protocol linked to past (lack of) emissions and from emissions taxes and domestic sales of GHGs quotas

$$\begin{aligned} GINC = {} & (GDP \cdot PGW \cdot CO2TRADE \cdot ER)\ Tx \\ & + \sum_{c} (PW_c \cdot Q_c^M (1 + Tm_c) \cdot ER + PDE_c \cdot Q_c^E (1 + Te_c)) \\ & + \sum_{a} \sum_{c} (X_{ac} \ldots PD_c (Td / (1 + Td))) \\ & + PGW \cdot CO2TRADE \cdot ER + PG \cdot CO2SALE \\ & + \sum_{a} Tg\ CO2NET_a / CO2NET_a > 0) \\ & + FCO2\ ER \end{aligned} \tag{36}$$

where GINC is the gross government income $CO2NET_a$ is the net GHGs emissions by industry a. CO2SALE is the domestic sales of GHGs quota (negative for purchasers), and FCO2 is the negotiated exogenous flow of foreign exchange which is part of the GHGs protocol.

Further, under the Normal Closure rule, the government saves a portion of its gross income, determined by policy considerations and exogenous to the model, and also transfers subsidies to consumers. The public consumption expenditure is given by

$$GEX = GINC\ (1 - s_G)\ - s_s\ GDP \tag{37}$$

where s_G is the savings rate of the government which may be negative. Alternatively, under Variant Closure, the level of public expenditure is exogenous and the government savings rate becomes endogenous. A simple rearrangement of equation (37) yields the endogenous government savings rate in this case. Note that in this model, the government is not required to execute a balanced budget. The level of gross investment in the economy adjusts to equal the net of government and household savings and exogenous foreign capital inflow.

Armington Commodity Demands: Commodity demands for Armington composites arise from consumption demands by consumers (private consumption) and the government (public consumption), intermediate demands by industries, investment demands for fixed capital, and demand due to change in stocks. Each of these demand categories is detailed below.

Consumer Demand: The Linear Expenditure System (LES) is standard in the CGE literature. It is based on the assumption of additive separability of the underlying preference function, and results in simplicity of the functional form of demand equations. This form is adopted in the present model. Generically, the LES demand system is written as

$$C_c = \gamma_c + (\beta_c / P_c)\,(Y - \sum_c P_c\,\gamma_c) \tag{38}$$

where C_c is the consumer demand for good c, P is the price of good c, Y is total consumer expenditure, and γ and ß are parameters called the "subsistence minima" and "marginal budget share", respectively of each good.

Parameters of the LES demand equations are recovered as follows. The Engel aggregation condition requires that the marginal budget shares summed over all commodities equal unity

$$\sum_c \beta_c = 1 \tag{39}$$

Further, given estimates of expenditure elasticities and average budget shares, ß's are given by

$$\beta_c = \epsilon_c\, a_c \tag{40}$$

where the ϵ's are the expenditure elasticities and the a_c's are the average budget shares.

Another parameter ϕ called the "Frisch parameter" (see Dervis et al 1982. p. 483) and interpreted as elasticity of the marginal utility of income with respect to income, is defined by

$$\phi = -Y/\,(Y-\sum_j P_j\,\gamma_j) \tag{41}$$

The Frisch parameter values are estimated from the primary data, which furnish average household expenditures and levels of consumption considered as "subsistence level". All these equations relating to consumer demand hold for the PE model also.

Public Consumption: The public consumption function is assumed to be of the form

$$C_{cG} = g_c \cdot GEX / P_c \, , \sum_c g_c = 1 \tag{42}$$

where C_{cG} is the quantity of commodity c in public consumption. The g's are expenditure shares for each commodity, exogenously chosen by government in a policy determination, and thus a policy instrument in the model.

Investment Demands by Industries: The value of total investment equals the sum of savings by household and the government, and exogenous foreign exchange inflow

$$TINV = HHINC \cdot s_H + GINC \; s_G + F \cdot ER \tag{43}$$

where TINV is the total investment demand for all commodities together and F is the exogenous foreign capital inflow. This expression corresponds to the Normal model closure rule adopted

The fixed investment demand for each industry is given by

$$FIX_a = \theta_a \cdot TINV, \; \sum \theta = 1 \tag{44}$$

where the θ's are the shares of fixed investment by industry, and FIX_a the fixed investment in industry a. The θ's are policy instruments in Centrally Planned Economies, or in some developing countries where industrial licensing is practised.

The fixed investment demand by commodity is given by

$$Z_c = \sum_a k_{ca} \cdot FIX_a / P_c, \; \sum k = 1 \tag{45}$$

where Z_c is the fixed investment demand by commodity, the k's are the capital composition coefficients, the fraction by value of each commodity contained in the fixed investment in each industry, and P_c is the price of the composite Armington commodity c.

Change in Stocks: The simplest, yet plausible, assumption regarding the category of demand is that the value of change in stocks of each commodity in the whole economy, is in constant ratio to the total investment

$$CHSTK_c = X_c \; TINV / P_c \tag{46}$$

where $CHSTK_c$ is the change in stocks of each commodity and the X's are fixed parameters for each commodity, recovered from the calibration year data. This equation holds only for the commodity outputs and inputs of the focussed industry. Since total investment consists of fixed investment and change in stocks, the following balance must hold for each Armington commodity

$$TINV_c = FIX_c + CHSTK_c \tag{47}$$

where $TINV_c$ is the total investment in commodity c. This balance relationship enables the recovery of value of X's from calibration year data.

Intermediate demands for Armington composite materials commodities are given by equations (16) and (11), and for energy by equation (17).

Balance Equations for Market Equilibria: A balance equation for Armington composites is written as

$$Y_c = C_c + C_{cG} + FIX_c + CHSTK_c + \sum_a Q_{ca} \tag{48}$$

where Y_c is the quantity of Armington composite in the whole economy, and Q_{ca} is the quantity of intermediate input (material or energy) for each industry.

A domestic commodity balance is given by

$$\sum_a XD_{ac} = CET^a \; (Q_c^E , Q_c^d) \tag{49}$$

where Q^d_c is the quantity of domestic commodity in the Armington composite, and Q^E_c is the quantity of commodity exported. Equations (9), (10), (11), (13) and (14) help determine their values. The aggregation of domestically demanded domestic commodities and exports is accomplished by a CET function, as described above. A foreign exchange may be written as

$$\sum_c PW_c \, Q_c^M - \sum_c PE_c \, Q_c^E \; PGW \; CO2TRADE - F = 0 \tag{50}$$

where PGW is the exogenous world price of offsets in \$, and CO2TRADE is the quantity of offsets of NEQ traded internationally (exports positive), a policy variable. The foreign exchange balance endogenizes the exchange rate, even though the term ER does not explicitly appear in the above equation.

A national balance equation for GHGs is written as

$$\begin{aligned} &\sum_a CO2EMS^a + \sum_c \sum_g \eta_{e.g}\, \Omega_g\, (C_c + C_{cg}) \\ &- \sum_a CO2OFF^a + CO2TRADE \le NEQ \end{aligned} \tag{51}$$

The GE model is closed by specifying market equilibria for factors.

Labour markets are assumed to clear

$$\sum_a L_a = L \tag{52}$$

where L is the exogenous labour supply.

Capital markets are assumed to clear

$$\sum_a K_a = K \tag{53}$$

where K is the exogenous total fixed capital in the economy, and

$$\sum_a LA_a = LA \tag{54}$$

where LA is the total land availability in the present model. It is assumed that only the agriculture and forest sectors employ land.

Since by Walras law, the clearance of all but one market ensures clearance of the last market, it is not necessary to specify clearance of (any) one of these markets. In the empirical version we omit the foreign exchange market balance, being a common practice for reasons of computational advantage,

Price Normalization: A price index is constructed by

$$\sum_{c} \pi_{c} \cdot PD_{c} = PRCLEVEL \sum_{c} \pi_{c} = 1 \tag{55}$$

where the π's are chosen weights, and PRCLEVEL is the price level. In this model the π's are specified as the relative quantities of Armington commodities demanded in the economy in the calibration year. This price index serves as numeraire.

This completes the mathematical description of the independent equations of the CGE model. The model is a square system of equations, with as many endogenous variables as independent equations, and convexity, so that a unique solution is possible by employing an appropriate solution algorithm. The total number of independent equations or endogenous variables in the CGE model are $2N^2 + 47N + 16$, where N is the number of sectors/commodities. Additionally, various endogenous variables of policy interest may also be extracted as follows.

Policy Relevant Endogenous Variables: Some endogenous variables of policy interest which may be extracted from the equilibrium solution of the CGE model are GDP, an index of consumer welfare changes, and the ratio of wages of unskilled rural labour to the interest rate, or rental rate to interest rate as "class conflict indexes". Expressions for each of these are as follows.

Index of Consumer Welfare Change. The change in the Paasche index of real consumption expenditure is a lower bound on consumer welfare change, while the change in the corresponding Laspeyres index is an upper bound. If we assume a single representative consumer in the economy, and subject only to the condition that the underlying utility function is homothetic (Samuelson and Swamy, 1974), designating the situations before and after the policy change by superscripts "1" and "2" respectively, the change in the Paasche index of real income is given by (see Dervis et al (1982) p 242-243).

$$\Delta\, Paasche = \sum_{c} P_{c}^{2}\, C_{c}^{2} - \sum_{c} P_{c}^{2}\, C_{c}^{1} \tag{56}$$

where P_c is the price, and C_c is the quantity consumed of Armington composite of c in the relevant period. The change in the corresponding Laspeyres index is given by

$$\Delta\, Laspeyres = \sum_{c} P_{c}^{1}\, C_{c}^{2} - \sum_{c} P_{c}^{1}\, C_{c}^{1} \tag{57}$$

We construct a Welfare Index as the arithmetic average of the Paasche and Laspeyres indexes. This index conveys only very limited information, since small changes in the index in either direction are consistent with small changes in consumer welfare in the reverse direction. Only significant changes in the index may be considered to be indicative of consumer welfare change in the same direction. Further, the index relates only to changes in consumer welfare and other dimensions of overall societal welfare, for example investment or public consumption are not included in this measure.

The Class Conflict Index for Labour and Capital is simply the ratio of (endogenous) wage of a particular category (we choose the wage of rural unskilled labour) and the (endogenous) interest rate

$$CCRLK = [w_{AGRIL^2} / i^2] \;/\; [w_{AGRIL^1} / i^1] \tag{58}$$

where CCRLK is the Class Conflict Index for Labour and Capital, and for clarity, it is normalized with respect to the value in the calibration year. The Class Conflict Index for Land and Capital is defined analogously as the ratio of rental rate to the interest rate.

5 TECHNIQUES FOR COMPUTING MODEL SOLUTION

Obtaining a solution for a general equilibrium model involves finding a vector of prices allowing all markets to clear. Clearly the complexity of finding a general equilibrium solution increases with the degree of model disaggregation, that is, with the number of factors, produced goods and consuming agents distinguished by the model. These difficulties once prevented the implementation of large-scale general equilibrium models. But as a result of advances in computational methods over the last decade, it is now possible to employ even very large models.

Most algorithms for solving applied general equilibrium models apply a variant of the tatonnement procedure introduced theoretically by Walras (1874). These algorithms first announce an initial vector of prices. On the basis of these prices factor supplies and incomes can be calculated, consumer demands can be evaluated, and firms' production techniques, factor demands and supplies of goods can be determined. The total supplies and demands for each good or factor can then be derived and excess demands evaluated. If all markets do not clear -- that is, if some excess demands are non-zero -- a new vector of prices is announced by the algorithm and a new iteration begins.

Because so many price vectors are possible, the attainment of a solution requires that the new vector of prices at each iteration be selected in some logical fashion on the basis of information about the excess demands from previous price vectors.

The solution algorithm employed in the models proposed is Merrill's (1972) algorithm. The basic characteristics of this algorithm are described next.

We know that fixed-point theorems, in particular Brouwer's theorem for an exchange economy and Kakutani's theorem for an economy with production, have provided an especially fruitful approach to proving the existence of competitive general equilibria under relatively unrestrictive conditions. These theorems show that a general equilibrium exists so long as market excess demand functions satisfy Walras' Law and are continuous and homogeneous of degree zero in prices. If p is the vector of prices and E (p) is the vector of market excess demands, then p^* will be a solution if $E_i(p^*) = 0$ for all i. In this notation, Walras' Law is written as $p'E(p) = 0$ for any price vector p.

It would be desirable to have a solution algorithm which is as general as the conditions for proving existence of general equilibria, that is, which can be employed under the same unrestrictive conditions as those required to prove existence. It would also be advantageous if the algorithm could be guaranteed to find a solution, that is, to converge to a solution in a finite number of iterations. The first algorithm to attain both of these attractive properties was developed by Scarf (1967). Its development was based on some of the steps found in the proofs of fixed-point theorems. Merrill's algorithm is an extension and improvement of Scarf's. Given information about the net excess demands corresponding to any price vector, Merrill's algorithm searches efficiently for a solution until all excess demands are as close to zero as desired.

Merrill's algorithm works with prices that lie on the unit simplex: that is, each vector of prices $(p_1, p_2 \ldots, p_n)$ must be such that $\Sigma p_i = 1$. Given the zero homogeneity of the demand functions, this normalization does not change the solution. A grid is specified, consisting of price vectors within the unit simplex which will subdivide into smaller simplices, each defined by having its vertices correspond to the points in the grid. Each of these simplices must not have any of the points in the grid as an interior point. This means that the intersections of any two simplices is either the empty set or the full face of each simplex.

The algorithm starts with one (arbitrarily specified) simplex and assigns a label to each of its vertices. Since each vertex corresponds to a price vector, there is a vector of excess demands associated with it. The algorithm labels the vertex by assigning to it the index of the largest excess demand. For example, if p is the price vector represented by a given vertex of the simplex, the vertex will be labelled with index 2, if $E_2(p) \geq E_j(p)$, $j \neq 2$. In this way the algorithm labels each vertex on the simplex. For each of the simplices defined by the grid, there will be a set of labels associated with it, consisting of the labels of its vertices. Under these conditions it is possible to prove, using Sperner's lemma (Scarf, 1982), that there exists a simplex with distinct labels (not necessarily unique, i.e. there may be more than one simplex with distinct labels). This simplex is said to be fully labelled. It is desirable to identify the fully labelled simplex because, as will be discussed shortly, its vertices correspond to price vectors which approximate the equilibrium vector of prices.

The algorithm uses a method to find the fully labelled simplex in a finite number of iterations. It starts with an arbitrary simplex defined by the grid and computes all its labels. If they all happen to be distinct, then the fully labelled simplex has been found. Otherwise, the algorithm moves to an adjacent simplex by dropping one of the vertices with a repeated label and introducing a new vertex. The process is repeated for the new simplex: if there exists a pair of vertices with the same label, one of these will again be removed, however, the vertex removed must not be the one just introduced. This assures that the algorithm will never return to a simplex that has already been visited. Since the grid defines a finite number of simplices, by proceeding in this way, the algorithm will always identify the fully labelled simplex in a finite number of iterations. This is why the algorithm will always converge. As can be shown, any of the vertices of the fully labelled simplex represent an approximation to the general equilibrium solution. The closeness of the approximation depends on the fineness of the grid. One way to achieve a close approximation is to employ a very fine grid throughout the algorithm's search procedure.

In general, however, a close approximation can be found more efficiently by starting with a coarse grid and moving to a finer grid whenever a fully labelled simplex is found. Proceeding in this way, for each fine grid, a simplex with distinct labels will be determined. Since the unit simplex is compact, there exists a sequence of fully labelled simplices the vertices of which converge to the single point p^*. It remains to show that p^* is the solution to the general equilibrium problem.

For a fully labelled simplex, the largest element in the excess demand vector will be different from vertex to vertex. In other words, for the vertex labelled 2, $E_2(p) \geq E_j(p), j \neq 2$, but for the vertex labelled 3, $E_3(p') \geq E_j(p')\ j \neq 3$. As the vertices of the simplices converge with fine grids to the single point p^*, it must be the case that $E_i(p^*) \geq E_j(p_j^*), j \neq i$, for all i and j. This can only be true if the elements of the excess demand vector are all equal to some common value, c, that is, $E_i(p^*) = c$ for all i. However, using Walras's Law, it is straightforward to show that c must be zero, Walras's Law, i.e. $\Sigma\, p_i^*\, E_i(p^*) = 0$, implies that $c\Sigma_i\, p_i^* = 1$ which implies that c is zero, since $\Sigma_i\, p_i^* = 1$ by normalization . Since the excess demands are all zero, p^* is indeed a general equilibrium solution.

6 CONCLUSIONS AND EXTENSIONS

The CGE model developed in this paper is intended to simulate the long-run impacts of proposed policies for regulation of net GHGs emissions, on the general equilibrium of a national or international economy. The strengths of the model are

1. The model is founded on received mainstream microeconomic theory, which has been applied on numerous occasions to analytical and empirical models in both GE and PE frameworks. The specific assumptions of the model are routine in the empirical modelling literature, and the core relationships in the model are typical of the CGE class of models, of which specific instances have been subjected to empirical validation.
2. The model is empirically demonstrated to be robust in the sense that significant changes in the values of key parameters or model assumptions do not qualitatively alter the conclusions of experiments involving the use of different policy instruments.

The possibility nevertheless remains that the model may not predict the general equilibrium impacts of exogenous shocks with any acceptable degree of reliability. The reasons for such possible failure include the fact that a model is after all, a simplified, stylized depiction of really important causal relationships may have been overlooked in the construction of the model. Alternatively, some assumptions in the model may not be realistic. Further, adequate theory still does not exist to explain some important aspects of the economy.

A long-run model of this type suffers from an inherent limitation with respect to direct empirical validation. This is why, in practice, the "long-run" of the model is perhaps a decade or longer. If the predictions of the model are to be verified, a plethora of exogenous variables are required to remain essentially undisturbed. These exogenous variables include world prices, besides levels of policy variables and factor endowments. Such a stringent prerequisite to verification cannot be ensured.

In the case of the present model, besides the conventional CGE core, there is an overlay of policy instruments, for national and international level GHGs regulation. The predictive power of the model with respect to this class of policy instruments cannot even in principle be validated until such regulatory schemes are actually implemented.

It is possible, however, in principle to undertake a partial validation of the CGE model developed here by recasting the same as a dynamic model consisting of a series of short-runs (during which the capital stock remains fixed in each industry). Such a procedure would require the model to be updated at the end of each time period by the changes in factor endowments, level of policy variables, and of other exogenous variables. If the model successfully replicates the actual changes in the general equilibrium of the economy over a period during which assumed parameter values may be assumed to be constant, perhaps five years, the level of intuitive confidence in the model would be greatly improved. This process is however, resource and time intensive, and for that reason, outside the scope of the present framework.

Categorical scientific answers to the questions of whether or not increasing concentrations of GHGs in the atmosphere will have severe environmental impacts, and if so the timing and distribution of such impacts in different global regions are probably some years away. So too are substantive discussions on a treaty for limiting net GHGs emissions worldwide.

It has been noted above that the present CGE model is not susceptible to direct empirical validation for two reasons. The first reason, is that it focuses on long-run impacts of exogenous shocks, which may span a decade or more, during which all other exogenous variable and parameters are required to remain unchanged. The second is that the predicted impacts of GHGs regulatory instruments, which are the chief focus of the model, cannot be empirically verified unless such instruments are actually adopted. However, a partial validation may indeed be conducted, of a dynamic version of the core CGE model, consisting of a series of short-runs. These are required to be updated after each time period by the changes in exogenous variables (including policy variables) which occurred in that period, and changes in factor endowments, of which capital stock would be endogenous, and stocks of labour and land exogenous. The predicted changes in general equilibrium may then be compared with he actual changes that have occurred. This process may be repeated for several years, say five, during which parameter values may reasonably be assumed to be constant. If the deviations are small, this form of the model may be considered as validated. Such an exercise would considerably enhance the intuitive appeal of the model as a whole, and would enable the policy analyst to be less circumspect, in making policy recommendations based on considerations of economic impacts revealed by the model simulations.

Extensions of the model may be based on the consideration that complex as the CGE model is, it yet neglects important aspects of reality, and does not furnish several types of policy relevant information. The first, and most obvious type of extension is disaggregation of industry/commodity sectors. The results reported are for a 10 sector model, which is a level of aggregation which policy makers may find restrictive. This is because, first, aggregation quite obviously results in loss of information. Second, aggregation blunts some of the policy instruments that may be employed. For example import tariffs or excise taxes may be employed on "steel", rather than the entire set of "intermediates", of which steel is a member. In the aggregated model. A second type of disaggregation relates to types of households. The CGE model assumes a single, representative household. In practice, of course, numerous household types may be identified. These may differ in family size, and composition, location urban or rural, and patterns of factors ownership and (relative) income levels. All of these differences would be reflected in differences in tastes (different demand function parameters), besides savings rates. A related question is that of functional forms employed to model demand. The LES functional form is restrictive, though it has the advantage of requiring relatively few parameter estimates. More detailed and theoretically stronger demand functions, applied to disaggregated household classes may be expected to yield greater accuracy both of quantities demanded, as well as more sophisticated measures of consumer welfare.

An important dimension in which the present CGE model may be extended is the inclusion of renewable energy sources. These energy sources, which include wind, biomass, solar thermal and solar photovoltaic sources are benign as regards pollution, including GHGs emissions, while their potential flows are extremely large in magnitude. These technologies are still not viable, in competition with conventional energy sources in terms of commercial financial appraisals. However, if the long term social costs of pollution impacts of fossil fuel use are accounted for in a benefit-cost calculus, some of the renewable energy technologies may prove to be efficient. The use of the CGE approach may help identify policies which facilitate the adoption of such renewable energy technologies through creation of appropriate market incentives.

Since the greenhouse effect may span several human generations, it is important that global CGE models be able to simulate interemporal impacts of regulatory policies. This would require the formulation of multiperiod long-term models, each period constituting an economic long-run. These models would have to take into account intertemporal changes, in particular technological change.

While technological change has several dimensions, for example, relating to energy supplies, production techniques, new products, transportation modes, and information and communications techniques, it is important to distinguish between two distinct modes of such change. One mode is the gradual accumulation of technical knowledge that lead to incremental improvements in efficiency in the engineering sense. A second mode is the discontinuous, quantum leaps in techniques which are difficult to anticipate in their precise timing or specific technical characteristics. Both modes of technical change are possible, indeed likely, in the context of energy supply and use. Thus, the first mode may be typified by gradual changes in energy use efficiencies of existing processes and types of equipment, or in factor use associated with given engineering or thermodynamic efficiencies in energy use. Increased fuel efficiencies for automobiles, and higher recoveries of process heat through co-generation of electric power are examples of such gradual technical change. Instances of the second mode are the introduction of "ADV-HC" and "ADV-LC" technologies (Manne and Richels, 1989), the terms referring respectively to high and low cost advanced non-carbon based electricity generation technologies, for example advanced solar technology, and advanced nuclear technology with passive safety features.

While gradual technological change may be incorporated in intertemporal models by (continuous) time dependency of industry cost or production function parameters, the inclusion of discontinuous change is more problematic. Various modelling strategics may need to be devised in the latter case, possibly involving interactions with subjective expert judgements. Alternative scenarios would have to be postulated in such cases, since such changes are only roughly predictable. Yet the planning of technical innovation constitutes an important set of policy choices. Intertemporal global CGE models may be able to furnish insights into whether and how, if proposed research efforts bear fruit, the world, in time, would be a different place.

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PART TWO

GLOBAL POLLUTION AND CGE MODELLING FOR THE EUROPEAN COMMUNITY

1 INTRODUCTION

This paper employs a new class of Computable General Equilibrium (CGE) models developed in the context of energy-economy environmental models (Gottinger, 1993a) to simulate the impacts on the EC economy of internal and multilateral instruments for regulation of greenhouse gases (GHGs) emissions.

Climate change due to emissions of greenhouse gases is a long-term global environmental problem. While specific impacts on different regions as well as their timing, are yet uncertain. It is reasonable to suppose that unilateral voluntary action by individual countries to reduce their net emissions of GHGs is unlikely. This is because significant reduction of net GHGs emissions by a single major net emitter, say for example, the USA, is unlikely to substantially slow down their rate of increase in concentration in the atmosphere[1] because the emissions of GHGs worldwide is increasing rapidly with spreading industrialization. On the other hand, unilateral changes in energy use patterns are widely perceived to have adverse effects on a country's economic growth, consumer welfare, and trade competitiveness. This perception is shared by both developing (DCs) and industrialized countries (INCs).

It is likely therefore, that if the scientific evidence for major adverse environmental impacts of global net emissions of GHGs becomes strong, negotiations for an eventual international treaty to limit or reduce net GHGs emissions would gain momentum. Countries would be hardly likely, however, to relinquish their independence in the matter of domestic control over policies for compliance with the negotiated terms of such a protocol, in favour of a supranational regulatory body.

Significant changes in net GHGs emissions in any country will have to focus on energy use patterns, as well as on afforestation. This is because the most important of GHGs which result from anthropogenic activities, CO_2, and another GHG, N_2O, largely result from fossil fuel use. Further, the major offset to GHGs (since on the issue of climate change, different GHGs are fungible in their damage potential) is forests, which sequester carbon from CO_2. Thus regulation of net GHGs emissions is also related to the use of land, an important natural resource and primary factor input.

Energy is a ubiquitous input in production. Different energy sources are substitutable

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[1] The U.S. in the late eighties contributed 25 per cent of world wide emission of CO_2, the most important of GHGs (Barnes and Gottinger, 1993).

for each other and in the aggregate in the long run with other inputs capital, labour, land and materials. Policy instruments designed to alter energy and land use patterns (assuming fungibility of land between forestry and other industries such as agriculture) may therefore be expected to also impact on the use of other inputs and carry over to the whole economy, through inter-industry linkages and changes in factor incomes. If the economy is open, there are likely to be changes in trading patterns as well. Since these second order effects of the use of policy instruments cannot be captured by partial equilibrium (PE) or other similar approaches, a general equilibrium (GE) framework is advisable for policy analyses of this type, particularly if it can be demonstrated that there are indeed, appreciable differences between the results of GE and PE models.

Theoretical, disaggregated GE approaches to such questions are virtually non-existent in the literature (see below). Typically, the analytical mathematics are intractable in such problems, at least for "realistic" models which allow for disaggregation among commodities and more than two or three sectors. Empirical GE models offer a way out of these difficulties, and are able to capture higher levels of disaggregation, and besides, simulate the impacts of more finely tuned policy instruments than would be possible in analytical GE models.

The main features of the CGE model, employed are summarized in the Appendix. The CGE model which has been developed in the course of related work (Gottinger, 1993) constitutes a new class of CGE models incorporating market based regulatory instruments for internal and multilateral regulation of pollution (GHGs).

2 TYPES OF POLICY INSTRUMENTS

Some of the policy instruments which have been discussed in the literature for regulation of pollution emissions including GHGs emissions are likely to be classified as follows.

2.1 National Level Policies

Direct regulatory devices for environmental regulation have traditionally included emissions standards (quantity restrictions) as well as pollution taxes (or fees), and subsidies for reducing pollution.

The results cited in each case have evolved through PE analyses, and theoretical GE analyses in this field and are conspicuously low. Those which exist[2] are highly aggregated and typically neglect trade as well as industry interdependence for commodity inputs and outputs.

On the other hand, it is well understood by economists that "almost anything can happen in a general equilibrium model under particular assumptions about factor proportions and elasticities" (Hartwick and Olewiler, (1986), p.414). It may be noted that a GE model which includes government as an economic agent, and has an existing (distortionary) taxation structure, does not correspond to a Pareto optimal Walrasian equilibrium. In such cases, there is no indication from GE theory whether a new regulatory structure will decrease or increase welfare or GDP.

Pollution Tax: A tax on pollution can internalize an externality. If it is set equal to the marginal damage caused by pollution at the point where marginal damages equal marginal benefits. However, if real incomes are to be maintained at pre-tax levels, those facing the tax must be subsidized. When the marginal costs of abatement of pollution differ among firms, a tax minimizes the total costs of abatement (Gottinger, 1993).

A government trying to achieve an optimal amount of pollution through the use of taxes or fees that reflect individuals willingness to pay for pollution reduction will, however, have difficulty determining the optimal tax. This is because of the "free-rider" problem. Individuals have an incentive to reveal valuations less than their true preferences, if they think that others are being honest, and the level of pollution resulting from the use of taxes or fees determined on the basis of such revelations will be more than is optimal.

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[2] See References in Part One.

Standards: Emissions standards (quantity restrictions) on pollution can also internalize the externality, but typically entail higher enforcement costs than an optimal tax. When the marginal costs of abating pollution differ among firms, a standard will maximize the costs of abatement.

Subsidies for Abatement: A subsidy to firms to reduce pollution, will in the long, lead to increased entry into the polluting industry and lead to increase in pollution over time. An equivalent tax will lead to exit from the industry and reduce aggregate pollution.

Marketable Permits: Tradeable permits have been proposed by economists as a means of achieving aggregate pollution standards at potentially lower cost than standards imposed on each polluter. Such marketable permits of which several varieties have been proposed eliminate uncertainty about aggregate economy-wide emissions levels, and in the case of auctioned permits the need to determine initial emissions endowments, assuming that the policy is effectively administered.

All these policy devices may be employed by national governments for regulating GHGs emissions.

2.2 Multilateral Policy Instruments

A long-term solution to the global problem of GHGs emissions will require a multilateral agreement on overall net emissions criteria for apportionment of emissions rights between countries and verification provisions. While one can state with certainty that such an agreement must provide for independent national procedures for compliance, little else can be stated with confidence at present regarding other possible terms.

In principle, international variants of pollution taxes, standards, auctioned permits, assigned (negotiated) permits and subsidies for abatement, administered by a multilateral body, may all be adopted for regulation of global pollution. Political economy considerations would, however, eliminate several of these. Thus, for example, the auction of tradeable permits by some internationally authorized body to sovereign states is infeasible in the multilateral context. This is because industrialized countries (INCs) with greater resources will be perceived to have the ability to form buyer cartels at such auctions to the detriment of developing countries (DCs) which have fewer resources, and are more numerous and heterogenous. Even if such a market were competitive, equity considerations would preclude assigning emissions rights to countries on the basis of existing national incomes. Further, the disbursement of revenues collected through such auctions would involve major international political problems. This would also be true of revenues accruing from pollution taxes while subsidies would raise the question of raising resources which, in the international area, has until now been largely voluntary and unreliable.

This leaves standards and assigned (negotiated) tradeable permits as potential international regulatory instruments. The Montreal Protocol (1988) on Potential Ozone Depletors (PODs) emissions is the sole precedent of an international agreement on a long-term global atmospheric pollution problem, which may furnish insights into which types of international pollution control instruments are feasible. While the response to the protocol is still unsatisfactory with only 53 countries (out of then 129) in the UN system) having acceded, one may identify aspects of the Protocol about which no serious reservations have been expressed and regarding which, it may accordingly be assumed that there is international consensus. These include the idea of international regulation of global pollutants, mandatory national quotas, fungibility in damage potential between different pollutants and trading regimes for such quotas.

The international regulatory regime postulated in the present model, derives from these generally acceptable features of the Montreal Protocol. In brief, it includes net national emissions quotas for GHGs (with fungibility between different GHGs and offsets based on their greenhouse potential) and trading in net national emissions quotas, a form of assigned tradeable permits. The actual level of net national emissions quotas and financial flows between signatory States linked to past emissions (the application of a "polluter pays" principle which has been urged by several DCs), which are the two controversial aspects of the Montreal Protocol, may be chosen in different simulations of the model.

Net national emissions quotas, being tradeable, and financial flows would represent real resource endowments and countries may be expected to agitate strongly for allotment schemes that would ensure for them the largest share of such endowments.

2.3 Experiments, Terminology and Conventions

The specific policy instruments whose impacts are simulated using the CGE model, and the results reported here are listed below;

- Standards quantity restrictions on net GHGs emissions by each industry

- Auctioned tradeable permits for net GHGs emissions for the economy as a whole
- GHGs tax on positive net emissions of GHGs by industries
- Net national emissions quota internationally tradeable negotiated national emissions quota with an exogenous (assumed) world trading price for the same

The rationale for selection of each of these policy instruments is discussed below.

In each case, industries are able to offset their emissions of GHGs by purchase of offsets from the forest sector, in order to respond to the application of regulatory instruments. The GHGs tax, if employed, is levied on the positive net GHGs emissions by each industry (GHGs emissions which are not accounted for by permits or offsets).

It has been noted above that relevant disaggregated, theoretical results in a GE framework are not available, in their absence it becomes imperative to develop a body of empirical results on the general equilibrium impacts of the use of such policy instruments. The experiments reported make a start in this direction.

Initial Conditions: In 1989 a domestic regulatory scheme for GHGs was in existence. For the present experiments, it is postulated that in 1989 assigned permits were available to each industry at a level equalling the gross GHGs emissions by that industry. Further assumptions are that the level of auctioned GHGs quotas available in the economy equalled but was opposite in sign to the quantity of GHGs offsets generated in that year, and that the level of GHGs tax was zero. The object of specifying such initial conditions is to set up a hypothetical market for GHGs quotas and offsets in 1989 which clears at a zero domestic price for quotas, without disturbing the general equilibrium in the economy in that year. It is then possible to set up experiments designed to simulate the impacts of changes in policy instruments from (postulated) initial levels. Alternative assumptions of initial conditions are possible, but are not considered here.

3 THE USE OF COMMAND AND CONTROL INSTRUMENTS: EMISSIONS STANDARDS

From a strictly administrative standpoint, emissions standards or quantity restrictions on (net) emissions may be easier to operate than market based instruments. For example, the government may mandate, assuming that the legal basis for such a fiat exists, that all thermal electricity generation (in new or replacement plants) be accomplished by employing natural gas or nuclear energy, which generate little or no GHGs, rather than coal or oil, which are intensive GHGs emitters. This policy would be administratively easier to enforce, for example, than an alternative of assigning tradeable permits to electricity utilities up to the level of overall GHGs emissions allowed, and monitoring emissions (by auditing the use of different energy sources) at each plant, as well as trade in the domestic offsets market. A strong theoretical result in the PE framework for a single industry with a number of firms having different marginal abatement costs, is that emissions standards result in higher total abatement costs for any specified level of abatement than pollution taxes or tradeable permits. If a similar loss in efficiency due to the use of standards is not shown to obtain in the GE framework, the choice between standards and alternative (market based) regulatory instruments would no longer be straightforward.

Tables 1 and 2 present the results of an experiment involving the use of (net) emissions standards, together with sensitivity analyses. In this experiment, each industry is required by fiat to reduce its net emissions of GHGs by 1 per cent from 1989 levels. Industries may accomplish this by altering either their energy use patterns or by purchase of GHGs offsets/quotas in the domestic market for these or a combination of both. It is assumed that all industries will comply with the directive even though no specific penalty is prescribed in the simulation specification.[3] The results are, as above, reported as percentage changes from 1989 levels, or elasticities for the various endogenous variables of policy interest.

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[3] This is equivalent to setting an infinitely large penalty which is imposed with certainty on all violators.

Table 1: Effect* of Employing a Command Instrument for Reduction of Net GHGs Emissions by Each Industry on Endogenous Variables of Interest: Base Case: GE Simulations

Endogenous Variable		Percentage Change 100 or Elasticity of Response 100		
1. Gross Domestic Product:		0.042		
2. Welfare Index:		0.080		
3. Gross GHGs Emissions:		87.95		
4. GHGs Offsets**:		6.892		
5. Class Conflict Ratios:				
Interest/Wages:		-0.009		
Interest/Land Rent:		-0.096		
6. Exchange Rate:		1.654		
Commodity/Industry:	**Domestic Price**	**Value Added**	**Traded Quantities** **Imports**	**Exports**
1. Forest:	2.256	2.254	0.450	0.900
2. Coal:	107.15	1.476	20.22	0.251
3. Petroleum:	0.213	0.169	2.161	2.161
4. Electricity:	0.064	0.064		
5. Natural Gas:	349.35	0.015		
6. Agriculture & Food:	0.0	0.0	3.307	3.307
7. Intermediates:	0.003	0.008	0.546	-2.484
8. Durable and Capital Goods:	0.045	0.023	0.402	-2.413
9. Other Consumption Goods:	0.006	0.005	1.240	-2.482
10. Services & Transport:	0.0	0.0		3.307
Patterns of Energy Use: Industry:	**Coal**	**Petroleum**	**Electricity**	**Natural Gas**
1. Forest:	101.68	1.700	2.190	
2. Coal:	102.45	0.921	1.412	
3. Petroleum:	103.69	0.341	0.149	
4. Electricity:	103.84	0.491	0.0	337.54
5. Natural Gas:		0.540	0.0	337.54
6. Agriculture & Food:	103.91	0.555	0.064	337.56
7. Intermediates:	103.90	0.552	0.062	337.55
8. Durable and Capital Goods:	103.85	0.500	0.009	
9. Other Consumption Goods:	103.90	0.552	0.062	
10. Services & Transport:	103.91	0.555	0.064	337.56
Consumption:				
1. Private:	102.09	0.336	0.069	
2. Public:	101.55	0.234	0.183	

*: The experiment consists of reducing net emissions of GHGs emission by 1 per cent of gross emissions of that industry in 1989 by government fiat. Industries may effect such net reduction either by reducing their gross emissions, or by purchasing GHGs offsets, or a combination of both.

**: The percentage changes are with respect to gross emissions of GHGs in terms of their carbon equivalent from all sources in 1989.

The major result of the experiment, in the base case, evident from Table 1 is that there is a considerable reduction in gross GHGs emissions together with large increase in GHGs offsets. Together they indicate that nearly 0.95 per cent of the gross GHGs emissions in the economy are reduced in the net for a decreed net reduction in GHGs emission of 1 per cent of gross emissions of industries in 1989. This net reduction in economy wide emissions of GHGs is accompanied by only slight changes in GDP and the Welfare Index (which is too small to be categorically interpreted as a change in actual welfare). Prima-facie, therefore, if one does not consider distributional impacts the employment of this command instrument is attractive from the policy viewpoint, since significant net reductions in economy wide GHGs emissions take place without major (adverse) societal impacts. Another empirical result is that there is a slight increase in wages and rentals relative to interest while the increase in GDP is sufficient to suggest that the interest rate increases as well.

Note that increase in GDP (or welfare) despite imposition of an additional constraint on the economy (quantity restrictions on net GHGs emissions by each industry), does not violate any theoretical results. The initial non-Walrasian general equilibrium in the economy arises from the uncoordinated actions of numerous agents who maximize their own welfare, and jointly determine a unique equilibrium. There is no theoretical reason why this general equilibrium, which includes distortionary policy instruments should be optimal in terms of GDP or welfare for the given resource endowments of the society. Only a strictly Walrasian general equilibrium is Pareto optimal.

There are major increases in the domestic prices of coal and natural gas, and an appreciable increase in the price of forest products. The domestic price of petroleum increases significantly but all other prices including that of electricity, undergo little change. There are large increases in the value added in the forest and coal industries, a tangible increase in value added in the petroleum sector, but little change or slight change in the case of each of the others. There is a sharp decline in imports of coal and smaller percentage decreases in imports of agriculture commodities and food petroleum, other consumption goods, intermediates and durable and capital goods. Imports of forest products show a perceptible increase. Exports of forest products show a significant percentage increase, but that of all other exported commodities show perceptible or large percentage decreases.

The reduction in net GHGs emissions is primarily accomplished by a sharp fall in the use of coal, and a slight reduction in the use of petroleum by the major energy using industries, and similar reductions in their consumption, both private and public. There is also a major reduction in natural gas use by all user industries, and while natural gas is not an intensive GHGs emitter, the large percentage decrease in its use results in a tangible contribution to reduction gross GHGs emissions. The change in electricity use is variable. The (near) identical changes in energy use patterns in different industries may be explained by the fact that the assumed substitution elasticities between different energy sources are identical (unity).

One may attempt to derive intuition for this result as follows. Each industry is required by policy to reduce its net GHGs emissions and may do so either by purchasing offsets/quotas in the domestic market, or by altering its energy use patterns, or both. If offsets purchase is the preferred option, the forest sector would have to increase its use of land (since this input has a fairly high substitution elasticity with labour of unity) whose rental would rise resulting in increased demand for labour by the agriculture and food sector, and a general rise in wages. The increase in wage rate and rental would both feedback to the forest sector and one may expect that there would be a rise in the price of forest products and/or of offsets. A price rise for forest products actually occurs.

On the other hand, if reduction in use of GHGs intensive energy sources is pursued, two processes occur simultaneously. The first is the reduction in energy in the aggregate and its substitution by other inputs in particular those which have high substitution elasticities with energy and/or high value shares in the industry cost functions. In some sectors, agriculture and food and services and transport labour is the chief alternative input to energy, while the former sector is land intensive as well. There would be increased demand for land by the agriculture and forest sectors in order to substitute the same for labour which is now more expensive, with a consequent increase in the rental rate. The forest sector would face increased costs for both land and labour, but would be unable to recover these costs from higher offsets prices, since the supply of offsets has increase from other industries. An increase in the price of conventional forest products is necessary to recover its increased costs. This process thus reinforces the impacts of increasing offsets generation, and an increase in wages and rentals relative to interest is manifested.

The second process involves substitution of GHGs intensive energy sources by other inputs, such shifts, would however, depend on relative effective prices of each energy source. To see how the process might work, consider that each industry faces an optimization problem with profit as the objective and the net GHGs that it may emit as a binding constraint. At the optimization point, the shadow price of each energy source must equal the effective price which is the Armington price together with the cost of offsets which are equivalent to the gross GHGs contained per Armington unit of the energy source. Reduction in GHGs emissions would imply high shadow prices of energy sources which are substituted out, and if offsets prices are low this would be accomplished by increase in Armington price of GHGs emitting energy sources. The Armington prices of coal and natural gas are driven by domestic prices, while that of petroleum is relatively insensitive to domestic price, because of a high trade substitution elasticity (15 per cent) and a significant (approximately 30 per cent) share of imports to domestic production. Increases in Armington prices of coal and natural gas are accomplished by reduction in domestic supply, while this route is not feasible in the case of petroleum. Domestic prices of coal and natural gas, accordingly, escalate, and this results in sharp reductions in their use by all industries. The relatively higher change in the case of natural gas is explained by the fact that it is a minor energy source, and small quantity changes in its use accordingly result in large percentage changes. Increases in value added for the coal and natural gas sectors is not inconsistent with supply reduction, because aggregate energy and materials are also production inputs, and these may be cut back instead of factor inputs.

Both an increase in offsets generation and a decrease in GHGs generation appear to occur in the economy, though the latter dominates. The domestic offsets price, initially set at zero through specification of initial conditions remains essentially zero. This is because of the extremely small exogenous shock administered as well as the fact that industries are enabled to supply unused tradeable permits to the domestic offsets/quotas markets, because offsets reduce their GHGs emissions.

Table 2 furnishes the results of the sensitivity simulations

Table 2: Comparison of Results of Sensitivity Analysis Simulations Effect of Employing a Command Instrument for Reduction of Net GHGs Emissions by Each Industry on Endogenous Variables of Interest

Endogenous Variables:	Percentage Change 100 or Elasticity of Response 100 Base Case	Sensitivity Analysis: (1)	(2)	(3)	(4)
Economy Level Variables:					
1. Gross Domestic Product:	0.042	0.0	0.0	0.010	0.0
2. Welfare Index:	0.080	-0.001	0.0	0.010	0.0
3. Gross GHGs Emissions:	-87.95	-96.25	-95.26	-95.63	-96.25
4. GHGs Offsets:	6.892	0.001	0.403	0.0	0.001
5. Class Conflict Ratios:					
Interest/Wages:	-0.009	-0.008	0.014	0.005	0.109
Interest/Rental:	-0.096	-0.003	0.027	0.006	0.109
6. Exchange Rate:	1.654	-0.010	0.028	0.048	0.025
7. Public Savings Rate:					0.001
Industry Level Variables: Intermediates					
1. Energy Use:					
Coal:	103.90	132.64	120.98	120.19	132.57
Petroleum:	0.552	0.111	0.136	0.029	0.008
Electricity:	0.062	0.089	0.080	0.0	0.002
Natural Gas:	337.56	0.0	202.80	227.45	0.001
2. Value Added:	0.008	0.001	0.005	0.003	0.057
3. Factor Use:					
Capital:	0.034	0.0	0.0	0.0	0.0
Labour:	-0.025	0.0	0.003	0.001	0.001
Consumption of Energy:					
1. Private:					
Coal:	102.09	129.88	118.46	117.72	129.87
Petroleum:	0.336	0.004	0.0	0.001	0.006
Electricity:	0.069	0.001	0.0	0.006	0.0
2. Public:					
Coal:	101.55	129.94	118.51	117.74	129.87
Petroleum:	0.234	0.030	0.004	0.029	0.006
Electricity:	0.183	0.0	0.0	0.007	0.002

*: The sensitivity analysis conducted are as follows:

(1) Trade substitution elasticities are reduced by 10 per cent from the base case level for all commodities.

(2) Cost function (Allen Uzawa) substitution elasticities are reduced by 10 per cent from the base case for all sectors for all inputs pairs.

(3) Energy sources substitution elasticities (Allen Uzawa) are reduced by 10 per cent from the base case for all energy pairs for all sectors.

(4) Variant Closure rule is adopted in place of the base case assumption of the Normal Closure Rule.

The sensitivity analyses as before demonstrate that the response of the model to the policy change is generally stable. The percentage decrease in gross GHGs emissions is always of the same order, and while the percentage change in GHGs offsets is variable, it never changes sign. The GDP and Welfare Index change either negligibly, or increase very slightly. Changes in the class conflict ratios are too small to be taken into account, except under Variant Closure when the relative factor rewards changes perceptibly in favour of labour and land over capital.

In this simulation too, we trace the impact of the policy change on the factor use, energy use, and value added in the intermediate sector. There is always a major reduction in the use of coal while the change in petroleum use is a much smaller variable, and negligible in the case of Variant Closure. The same is true of the use of electricity, in the case of natural gas use there is, however, more variability. While natural gas use declines sharply in the base case as well as under reduced cost function and reduced energy sources substitution elasticities, there is no change under the assumption of reduced trade substitution elasticities or Variant Closure. Sharp changes in percent terms of natural gas use are because of comparatively small actual levels of use even though about 47 per cent of total natural gas use is in the intermediate sector.

Both private and public consumption of coal decline sharply, and by approximately the same percentage magnitude as in the case of the intermediate industry sector, in each of the simulations. Changes in the consumption of petroleum or electricity are much less marked. The results of the different simulations do not contradict the overall finding of the base case, that major reductions in net GHGs emissions are accomplished with only minor societal impacts.

4 THE USE OF AUCTIONED TRADEABLE PERMITS

Auctioned tradeable permits are a particular type of tradeable net emissions permits in which tradeable permits are initially auctioned by the government in the domestic market for quotas and offsets for GHGs. Industries may trade these permits among themselves subsequently in a theoretical PE model with perfect competition in the offsets/quotas market. Cost minimizing abatements occur as firms (industries) purchase the auctioned tradeable permits until at equilibrium the marginal abatement costs of all firms (industries) equal the domestic offsets price and economic efficiency results in the GE framework. It is possible that second order effects may overwhelm such efficiency gains.

Table 3 presents the results of the base case for the experiment involving the use of this market based regulatory instrument in this experiment, the postulated level of auctioned tradeable GHGs permits in 1989 are reduced by 1 per cent of the gross GHGs emission by all industries in that year. The levels of all other policy instruments are unchanged from the (postulated or actual) 1989 levels.

In sharp contrast to the previous experiment where emissions standards were employed, in the case of the use of auctioned tradeable permits, the base case simulation shows virtually the entire change in net GHGs emissions in the economy accounted for by the increase in GHGs offsets generated, rather than decrease in gross GHGs emissions due to energy use. There is no change in GDP and a perceptible increase in the Welfare Index of a sufficient order that one may believe that an actual welfare increase has occurred. The class conflict ratios change tangibly in favour of wages over interest, and markedly in favour of land rent over interest. Thus except for the distributional consequences of this policy, major reductions in net GHGs emissions are accomplished without adverse societal impact.

At the sectoral/commodity level, there is a major increase in the internal price of forest products, but inconsequential changes in the internal prices of each of the other commodities including energy sources. There is a large increase in the value added in the forest sector, and slight or negligible declines in value added in each of the other industries. Imports as well as exports of forest products increase by considerable percentages and there is a marked decline in the percentage of imports of agricultural products and food. Except for significant increase in the imports of coal and perceptible increases in the case of petroleum and durable and capital goods, there is little else by way of change in the trading pattern.

Table 3: Effect of Employing a Market Based Instrument (Auctioned Tradeable GHGs Permits) for Reduction of Net GHGs Emissions by Each Industry on Endogenous Variables of Interest: Base Case: GE Simulations

Endogenous Variables:		**Percentage Change 100 or Elasticity of Response 100**		
1. Gross Domestic Products:	0.0			
2. Welfare Index:	0.117			
3. Gross GHGs Emissions:	0.011			
4. GHGs Offsets[**]:	89.57			
5. Class Conflict Ratios:				
Interest/Wages:	0.844			
Interest/Rental:	2.047			
6. Exchange Rate:	0.045			
Commodity/Industry:	**Domestic Price**	**Value Added**	**Traded Quantities**	
			Imports	**Exports**
1. Forest:	29.31	29.31	21.99	44.07
2. Coal:	0.043	-0.278	2.424	-0.135
3. Petroleum:	0.023	-0.251	0.102	0.0
4. Electricity:	0.039	-0.261		
5. Natural Gas:	0.014	-0.275		
6. Agriculture and Food:	0.001	-0.221	16.27	0.0
7. Intermediates:	0.003	0.276	0.0	0.0
8. Durable and Capital Goods:	0.001	0.166	0.485	0.0
9. Other Consumption Goods:	0.006	0.175	0.0	0.0
10. Services and Transport	0.001	0.264		0.0
Patterns of Energy Use: Industry:	**Coal:**	**Petroleum**	**Electricity**	**Natural Gas**
1. Forest:	29.32	29.34	29.31	
2. Coal:	0.041	0.024	-0.040	
3. Petroleum:	0.103	0.017	0.015	
4. Electricity:	-0.002	0.032	0.0	0.024
5. Natural Gas:		0.024	0.0	0.0
6. Agriculture and Food:	0.041	0.007	-0.039	0.0
7. Intermediates:	0.035	0.0	0.033	-0.008
8. Durable and Capital Goods:	0.023	0.011	-0.021	
9. Other Consumption Goods:	0.138	0.172	0.140	
10. Services and Transport	0.041	-0.007	-0.039	-0.014
Consumption of Energy:				
1. Private:	0.151	0.132	0.148	
2. Public:	-0.412	-0.294	-0.418	

[*]: The experiment consists of the government reducing the level of auctioned tradeable permits by 1 per cent of the gross emissions of all industries in 1989.

[**]: The percentage changes are with respect to gross calculations of GHGs in terms of their carbon equivalent from all sources in 1989.

The forest sector significantly increases its inputs of coal, petroleum and electricity by virtually the same percentage in each case. However, since the forest sector is not a major user of any of the energy sources, the resultant effect on gross GHGs emissions are slight. Expansion of output by the forest sector is reflected in the greatly increased generation of GHGs offsets and the offsets/quotas price remains close to the initial value of zero. Coal use in each of the other sectors declines slightly, while the percentage change in use of petroleum is variable, as are those of electricity and natural gas. In no other instance, however, are these percentage changes large enough to have a major impact on gross GHGs emissions. The private consumption of each type of energy shows a marginal increase, and that of public consumption, a slight decrease.

Intuition for these results may be developed as follows: the economy as a whole is required to respond to the reduction in available permits, but no additional constraint is imposed on individual industries. The economy responds by expansion of the forest sector and consequent increased generation of offsets resulting in increased demand for land, whose rental relative to interest increases sharply. The relative wage rate also rises because the agriculture and food sector, which is both land and labour intensive, substitutes land with labour. Industries are, however, under no direct compulsion to reduce net GHGs offsets either by reducing GHGs emissions, or by purchasing offsets/quotas and thus the only change in energy use by industries is owing to second order price effects. The increased rental and wage rates experienced by the forest sector are captured in a sharply higher domestic price of forest products, which also induces increased imports of forest products, since the world price remains unchanged and there is little impact on the exchange rate. The domestic market is, however, unable to absorb the entire increased output of the forest sector, and thus exports too rise sharply. (This is possible because the domestic and export prices are separable, and there is a fall in the export price of forest products (not tabulated above), which suffices for the increase in forest products exports because of high own price elasticity (3.0) for exports).

Table 4: Comparison of Results of Sensitivity Analysis Simulations: Effect of Employing a Market Based Instrument (Auctioned Tradeable GHGs Permits) for Reduction of Net GHGs Emissions by Each Industry on Endogenous Variables of Interest

	Percentage Change 100 or Elasticity of Response 100				
Endogenous Variables:	**Base Case**		**Sensitivity Analysis:**		
		(1)	**(2)**	**(3)**	**(4)**
Economy Level Variables:					
1. Gross Domestic Products:	0.0	0.0	0.0	0.0	0.0
2. Welfare Index:	0.117	0.117	0.115	0.117	0.117
3. Gross GHGs Emissions:	0.011	0.011	0.013	0.012	0.002
4. GHGs Offsets:	89.57	89.57	89.57	89.57	89.56
5. Class Conflict Ratios:					
Interest/Wages:	-0.844	-0.844	-0.845	-0.844	-0.928
Interest/Rental:	-2.047	-2.047	-2.048	-2.047	-2.157
6. Exchange Rate:	-0.045	-0.046	-0.102	-0.048	0.032
7. Public Savings Rate:					1.080
Industry Level Variables: Intermediates					
1. Energy Use:					
Coal:	0.035	0.035	-0.043	-0.036	-0.031
Petroleum:	0.0	0.002	0.015	0.0	-0.026
Electricity:	0.033	0.033	-0.040	-0.034	-0.032
Natural Gas:	0.008	0.008	-0.012	-0.008	-0.044
2. Value Added:	0.276	0.276	-0.265	-0.276	-0.334
3. Factor Use:					
Capital:	0.0	0.0	0.0	0.0	0.0
Labour:	0.289	0.289	-0.263	0.289	-0.264
Consumption of Energy:					
1. Private:					
Coal:	0.151	0.151	0.145	0.152	0.148
Petroleum:	0.132	0.131	0.144	0.133	0.115
Electricity:	0.148	0.148	0.145	0.148	0.151
2. Public:					
Coal:	0.412	0.411	-0.424	-0.414	-0.036
Petroleum:	0.294	0.295	-0.286	-0.294	-0.024
Electricity:	-0.418	0.417	-0.429	-0.420	-0.037

*: The sensitivity analyses conducted are as follows:

(1) Trade substitution elasticities are reduced by 10 per cent from the base case level for all commodities.

(2) Cost function (Allen-Uzawa) substitution elasticities are reduced by 10 per cent from the base case for all sectors for all inputs pairs.

(3) Energy sources substitution elasticities (Allen-Uzawa) are reduced by 10 per cent from the base case for all energy paris for all sectors

(4) Variant Closure rule is adopted in place of the base case assumption of the Normal Closure rule.

In each of the simulations, there is no change in the GDP and very little in the Welfare Index. The base case result, that virtually the entire substantial decline in net GHGs emissions is attributable to an increase in GHGs offsets, is retained in each of the simulations. Further the class conflict ratios also show remarkable uniformity, and the relative in land rental over interest is appreciable in each case.

At the level of the intermediates sector, the pattern of change in energy use shows little variation between simulations, including the case of Variant Closure. Value added in the sector declines tangibly in each case. There is no change in capital use but always a slight decline in the use of labour.

The pattern of change in private consumption of energy shows appreciable stability in each of the simulations including the case of Variant Closure, increasing perceptibly for each energy source in all cases of Normal Closure, while the decrease in the case of Variant Closure is of lesser degree. This result may be explained by the fact that the level of public consumption expenditure is maintained at the initial level in Variant Closure with fixed value shares for each commodity. Change in public consumption patterns, including of energy sources occurs due to relative price change alone. On the other hand, in Normal Closure, the level of public consumption expenditure itself is allowed to change, and public consumption patterns are impacted by this aspect in addition to relative price changes.

In this experiment too, the base case result that major net reduction in GHGs emissions are effected through increased generation of offsets, is retained in each sensitivity analysis simulation. So too, is the result that such reductions in net GHGs emissions entail little Welfare Index or GDP change, but involve a significant increase in the rewards to land owners, relative to those of capital owners.

5 THE USE OF "GHGs" TAX

A "GHGs Tax" is a pollution tax on net emissions of GHGs by each industry, based on the overall carbon content of the emissions, less permits, quotas and offsets purchased or assigned. Unlike in the previous experiments reported above, where the exogenous shock consisted of a small (1 per cent) change in the (postulated) value of the policy instrument from the calibration year. In the present experiment, the exogenous shock is the actual institution of a GHGs tax, where none was postulated in the calibration year. The rate of GHGs tax imposed is at a rate per (metric) tonne of carbon so that if the entire carbon equivalent of GHGs emissions of fuels were taxed, it would amount to 1 per cent of the average EC price of petroleum in 1989. This rate is equivalent to 10.3 per cent of the EC price of coal or 4.9 per cent of the EC price of natural gas, in 1989. One may therefore consider the exogenous shock as significant, rather than small.

This specification of the GHGs tax rate is purely *ad hoc*, since no actual proposals have been made yet, at least in the EC context regarding possible rates of GHGs tax. A change in level of another policy instrument from initial conditions is necessary, in order that industries respond to the imposition of a GHGs tax, the initial level of assigned GHGs permits to industries is reduced to zero. Alternative changes in initial conditions are, of course, possible but are not considered here. Strictly speaking, this experiment involves institution of a GHGs tax as well as change in the level of assigned tradeable permits.

Table 5 furnishes the results of an experiment involving the use of GHGs tax, with base case parameter and closure assumptions. Note that in this case the percentage changes are reported at actual levels, are not rescaled.

Table 5: **Effect of Employing a Market Based Instrument (GHGs tax) for Reduction of Net GHGs Emissions by Each Industry on Endogenous Variables of Interest: Base Case: GE Simulations**

Endogenous Variables:	**Percentage Change 100 or Elasticity of Response 100**
1. Gross Domestic Products:	0.2383
2. Welfare Index:	0.2721
3. Gross GHGs Emissions:	-0.0679
4. GHGs Offsets[**]:	89.50

Table 5 Continued

5. Class Conflict Ratios:	
Interest/Wages:	0.0206
Interest/Land Rent:	-1.454
6. Exchange Rate:	0.8760

Commodity/Industry:	**Domestic Price**	**Value Added**	**Traded Quantities**	
			Imports	**Exports**
1. Forest:	26.27	19.72	-8.312	-4.493
2. Coal:	-1.895	-1.823	-0.842	-3.986
3. Petroleum:	-0.051	0.003	-1.375	-1.375
4. Electricity:	0.005	0.005		
5. Natural Gas:	1.126	1.126		
6. Agriculture and Food:	0.0	0.0	-1.729	-1.729
7. Intermediates:	0.0171	0.017	-0.293	-1.325
8. Durable and Capital Goods:	0.473	0.490	-0.0995	-0.595
9. Other Consumption Goods:	0.495	0.508	-0.282	-0.595
10. Services and Transport	0.084	0.084		-1.565

Patterns of Energy Use: Industry:	**Coal:**	**Petroleum**	**Electricity**	**Natural Gas**
1. Forest:	2.181	2.513	2.180	
2. Coal:	1.828	2.161	1.827	
3. Petroleum:	0.060	0.399	0.059	
4. Electricity:	0.001	0.340	0.0	0.256
5. Natural Gas:		1.467	1.113	-0.877
6. Agriculture and Food:	0.005	0.345	0.005	0.252
7. Intermediates:	0.001	0.351	0.001	0.246
8. Durable and Capital Goods:	0.460	0.119	0.461	
9. Other Consumption Goods:	0.477	0.136	0.478	
10. Services and Transport	0.078	0.261	0.079	0.336
Consumption of Energy:				
1. Private:	0.462	-0.071	0.215	
2. Public:	0.400	-1.221	-1.442	

Price of GHGs offsets (Units: ECU/Tonne of carbon): 6.546

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*: The experiment consists of imposition of a GHGs tax on net GHGs emissions by each industry, at a rate per tonne of carbon. See text for the basis. Assigned GHGs permits to industries are reduced to zero.

**: The percentage changes are with respect to gross emissions of GHGs in terms of their carbon equivalent from all sources in 1989.

The striking result of the simulation in the base case is that there is a substantial increase in generation of GHGs offsets, together with a small decrease in GHGs emissions in the economy. Thus, there is a large decrease in net GHGs emissions, as a percentage of initial gross GHGs emissions. Coupled with this result, is a large increase in GDP, and a parallel increase in the Welfare Index, of a level sufficient to suggest that actual increase in welfare has taken place. Prima-facie, this policy instrument appears to be effective in reducing net GHGs emissions and while doing so, increases GDP and consumer welfare. There are, however, some noticeable distributive effects. There is a significant change in the ratio of interest to land rent in favour of land, while the change in the ratio of interest to wages is comparatively minor and in favour to labour. The changes in relative factor rewards, place land owners at a significant advantage relative to labour or capital owners.

The CGE model employed deviates from Walrasian (Pareto optimal) equilibrium in that government is an agent in the economy, and a distortionary structure of taxes is in place in the calibration year. There are no theoretical GE results which would suggest that the institution of a GHGs tax under these circumstances cannot result in a welfare increase.

The increase in generation of GHGs offsets is accompanied by a sharp increase in the value added in the forest sector, as well as in its domestic price. Coal and natural gas prices decrease very significantly, that of petroleum declines to a smaller extent, and there is a minor increase in the case of electricity. Domestic prices of intermediates decrease slightly, while for agriculture and food products it is unchanged. Prices increase perceptibly for the remaining commodities. The value added in each of the energy sectors decrease in line with their prices. Value added in the case of agricultural products is unchanged, and for the other sectors there are increases, generally in line with the change in prices, with the exception, that for the intermediates sector there is a tangible increase in value added despite a fall in price. Imports and exports of forest products decline appreciably. For all other commodities, there are significant or slight declines in both imports and exports.

The change in energy use patterns is variable. Coal use decreases in the forest, energy sources, agriculture and food, and intermediates sectors, and increases in the remaining sectors. Changes in petroleum and electricity use parallel that of coal use, except that there is a significant decrease in petroleum use by the services and transport sector. The use of natural gas increases in all sectors except the natural gas sector itself. There are significant increases in private and public consumption of coal, a relatively minor decline in private consumption of petroleum but a large decrease in its public consumption. Electricity use increases perceptibly in private consumption, but decreases substantially in public consumption.

On the whole, the changes in the patterns of energy use are consistent with a decline in gross GHGs emissions. The increase in value added in the forest sector is consistent with increase in GHGs offsets. The market price of GHGs offsets is surprisingly low, only about one sixth of the rate of carbon tax. The reason for this appears to be that the forest sector produces marketable, indeed traded goods, and offsets are generated only as a by-product. Further, higher domestic prices for the main product of the forest sector seem to capture a significant part of the increased land rent, which is evidenced by a sharp increase in the ratio of interest to land rent coupled with a clear increase in GDP.

Intuition for these results is furnished as follows; the imposition of a GHGs tax together with elimination of assigned tradeable permits for all industries, result in sharp increase in demand for offsets/quotas to offset GHGs emissions which would otherwise be taxed. This increased demand can be met solely by increased generation of offsets by the forest sector since the government has not increased the level of auctioned tradeable permits. Land rent rises owing to expansion of the forest sector, and this is manifest as significantly reduced interest/rental ratio. The higher land rent is captured in the case of the forest sector by higher domestic price for forest products, as well as a positive price for offsets. It is not possible to trace intuitively the possibility of increased demand for forest products which enables the higher domestic price to prevail, since they are employed as material inputs in several industries, as well as figure in private and public consumption, and are traded both ways.

One may expect that higher land rent would induce an increase in the wage rate as well because of substitution of labour for land in the agriculture and food sector, which is intensive in both inputs. However, since the offsets price is positive, the effective price of GHGs intensive energy sources would be higher. Inducing substitution of capital for aggregate energy in the sectors which are both energy and capital intensive and leading to higher interest rates as well. Thus, the interest/wage ratio changes, not in favour of wages, but in favour of interest, albeit slightly.

Because this policy (GHGs tax together with elimination of assigned tradeable permits) works through the creation of an offsets/quotas markets, the results in this case differ substantially from those relating to the use of indirect taxes, which do not rely on such markets, but work directly through price effects. Note that the level of GHGs tax acts as an upper bound on the price of offsets, since were the price of offsets to exceed the exogenous level of GHGs tax, industries would find it advantageous to pay the tax instead of purchasing offsets.

Table 6 presents the results of sensitivity analysis for the same experiment.

Table 6: **Comparison of Results of Sensitivity Analysis Simulations: Effect of Employing a Market Based Instrument (GHGs Tax) for Reduction of Net GHGs Emissions by Each Industry on Endogenous Variables of Interest**

	Percentage Change 100 or Elasticity of Response 100				
Endogenous Variables:	**Base Case**		**Sensitivity Analysis:**		
		(1)	**(2)**	**(3)**	**(4)**
Economy Level Variables:					
1. Gross Domestic Products:	0.2383	0.2583	0.2401	0.1297	0.2298
2. Welfare Index:	0.2721	0.2859	0.2739	0.1838	0.3099
3. Gross GHGs Emissions:	-0.0679	0.0336	-0.0456	-0.3761	-0.1184
4. GHGs Offsets:	89.50	89.53	89.52	89.54	89.48
5. Class Conflict Ratios:					
Interest/Wages:	0.0206	0.0556	0.0196	-0.241	0.088
Interest/Rental:	1.454	1.436	-1.455	-1.588	-1.612
6. Exchange Rate:	0.876	0.703	0.834	0.224	6.358
7. Public Savings Rate:					2.954
Industry Level Variables: Intermediates					
1. Energy Use:					
Coal:	0.011	0.004	0.019	-0.121	0.481
Petroleum:	0.351	0.295	-0.343	-0.054	1.911
Electricity:	0.010	0.025	-0.001	-0.130	0.154
Natural Gas:	0.246	0.344	0.235	-0.440	1.580
2. Value Added:	0.017	0.030	0.026	-0.020	0.027
3. Factor Use:					
Capital:	0.011	0.011	0.005	0.0285	0.0361
Labour:	0.038	0.024	0.030	1.442	0.199
Consumption of Energy:					
1. Private:					
Coal:	0.462	0.526	0.506	0.020	0.971
Petroleum:	0.071	0.006	0.059	0.042	-1.166
Electricity:	0.215	0.226	0.221	0.168	0.307
2. Public:					
Coal:	0.400	0.436	0.422	0.154	2.916
Petroleum:	1.222	1.272	1.222	0.476	-1.359
Electricity:	1.442	1.594	1.445	0.494	0.046
Units: ECU Tonne of carbon:					
1. Price of GHGs offsets:	6.546	7.131	6.542	2.226	8.947

*: The sensitivity analyses conducted are as follows:

(1) Trade substitution elasticities are reduced by 10 per cent from the base case level for all commodities.

(2) Cost function (Allen-Uzawa) substitution elasticities are reduced by 10 per cent from the base case for all sectors for all inputs pairs.

(3) Energy sources substitution elasticities (Allen-Uzawa) are reduced by 10 per cent from the base case for all energy paris for all sectors

(4) Variant Closure rule is adopted in place of the base case assumption of the Normal Closure rule.

Except for the case of reduced energy sources substitution elasticities, the results of the sensitivity simulations may be summarized as follows.

There is remarkable uniformity in the changes in GDP and Welfare Index. Gross GHGs emissions decline in all cases, the extent of the decline being greater in the case of Variant Closure. There is uniformity in the large increase in the generation of GHGs offsets, and in each case, there is a major decrease in net GHGs emissions as a percentage of gross GHGs emission. The changes in class conflict ratios are also quite uniform, both direction and magnitude are preserved in changes in both ratios and on the whole, the base case result that land owners gain relative to capital owners and labour is preserved.

At the level of intermediates sector, changes in the patterns of energy use show some variation. Coal use declines slightly in the base case and with reduced trade substitution elasticities and increases slightly or significantly in the other cases. Petroleum use decreases throughout the percentage decrease in the case of Variant Closure being the most significant. Changes in electricity use almost parallel the change in coal use, except that with reduced cost function substitution elasticities, there is a very slight decrease in the case of electricity. Natural gas use increases in all cases.

The value added in the sector increases by the same percentage order of magnitude in all cases. Capital use decreases slightly in all cases. Labour use too, decreases in all cases of Normal Closure. There is, however, a significant increase in labour use in the case of Variant Closure.

There is a nearly uniform increase in private consumption of coal. There is a slight to significant decline in private petroleum consumption of all cases. Private electricity consumption always increases. Changes in public consumption of energy are even more uniform across the sensitivity analyses. Coal consumption always increases and petroleum and electricity consumption always decrease. The sole exception is that there is a small increase in electricity consumption in the case of Variant Closure.

The price of GHGs offsets in the domestic GHGs markets is almost always of the same order of magnitude, one sixth to one fourth of the GHGs tax.

There are several divergences from these results in the case of sensitivity analysis with reduced energy substitution. In that case, the extent of increase in GDP and Welfare Index is lower than in other sensitivity analysis simulations. The decline in gross GHGs emissions is greater. There is a reversal of sign in the case of the ratio of interest to wages in the case of the intermediates sector, there is an increase in the use of electricity, while in the other cases of Normal Closure, there is a decline. On the other hand, in the case of natural gas use by this sector, there is a decline, unlike in other cases. Further, the offsets price is significantly smaller in the case of reduced energy substitution elasticities.

The key to explaining the divergences between the results of the simulation with reduced energy sources substitution elasticities and the others is to note that wages increase relative to interest in this case. Labour intensive industries which are also less intensive in energy use, gain a cost advantage over energy and capital intensive industries. The latter are in this simulation less able to substitute away from GHGs intensive energy sources, and undergo a contraction in terms of value added. The result overall, is greater decrease in net GHGs emissions, and significantly lower demand for offsets, whose price is lower in this simulation.

In this experiment all the sensitivity analyses retain the base case result that large net decrease occurs in GHGs emissions, almost the whole of the change being attributable to increased offsets generation by the forest sector. While there are also significant increases in GDP and Welfare Index, there are significant gains in factor rewards to land relative to capital or labour. The domestic price of GHGs offsets remains only a fraction of the GHGs tax levied.

6 USE OF INTERNATIONAL REGULATORY INSTRUMENTS: NET NATIONAL EMISSIONS QUOTA

The model developed in the present research is partly motivated by the need to fashion a policy analytical device to help policy makers formulate negotiating positions at multilateral negotiations intended to evolve a global regime for GHGs regulation. The levels of net national emissions quotas (NNEQ) with an international trading scheme, and of financial flows linked to past emissions, are the two significant negotiable dimensions. At present, no detailed proposals exist on which actual policy analyses may be carried out. The simulations carried out in the following experiment are intended to be illustrative of the way the impact of one of these negotiable instruments net national emissions quota may be evaluated. Since such quotas are intended to be tradeable and the world trading price is exogenous in the model, an assumed international trading price (specified as ECU 3 per tonne of carbon equivalent of GHGs), of the same order of magnitude as the domestic price of GHGs offsets yielded in the experiment described above involving the use of a GHGs tax is assumed. Further, in the case of developing countries, the case is likely to be made for net GHGs quotas higher than existing net emissions levels, rather than lower.

The experiment presented below simulates the impacts of a postulated increase in the net national emissions quota above the 1989 level. As an initial condition of this experiment, the net emissions quota is assumed to equal the actual net GHGs emissions. In this experiment, for convenience, it is assumed that a domestic regulatory scheme for GHGs exists, with initial levels of use of each instrument unchanged from those postulated for the experiments involving tradeable permits. Table 7 presents the results of the base case simulation.

Table 7: Effect of Employing an International Regulatory Instrument (Negotiated Net National Emissions Quota) on Endogenous Variables of Interest: Base Case: GE Simulations

Endogenous Variables:	**Percentage Change 100 or Elasticity of Response 100**
1. Gross Domestic Products:	0.049
2. Welfare Index:	0.039
3. Gross GHGs Emissions:	0.070
4. GHGs Offsets[**]:	0.0

Table 7 Continued

5. Class Conflict Ratios:	
Interest/Wages:	0.004
Interest/Land Rent:	0.006
6. Exchange Rate:	1.580
7. Trade in Offsets**	99.92

Commodity:	Domestic Price	Value Added	Traded Quantities Imports	Exports
1. Forest:	0.192	0.0	1.329	0.0
2. Coal:	0.002	0.003	3.453	0.0
3. Petroleum:	0.126	0.083	2.181	0.0
4. Electricity:	0.0	0.003		
5. Natural Gas:	0.024	0.005		
6. Agriculture and Food:	0.047	0.002	2.573	0.0
7. Intermediates:	0.107	0.003	0.0	0.0
8. Durable and Capital Goods:	0.026	0.002	0.278	0.0
9. Other Consumption Goods:	0.206	0.003	0.0	0.0
10. Services and Transport	0.040	0.003		0.0

Patterns of Energy Use: Industry:	Coal:	Petroleum	Electricity	Natural Gas
1. Forest:	0.070	0.517	0.0	
2. Coal:	0.031	0.517	0.001	
3. Petroleum:	0.239	0.304	0.169	
4. Electricity:	0.065	0.471	0.134	0.024
5. Natural Gas:		0.517	0.0	0.0
6. Agriculture and Food:	0.031	0.471	0.0	0.024
7. Intermediates:	0.114	0.684	0.077	0.024
8. Durable and Capital Goods:	0.031	0.472	0.0	
9. Other Consumption Goods:	0.158	0.517	0.002	
10. Services and Transport	0.031	0.471	0.0	0.024
Consumption of Energy:				
1. Private:	0.105	0.354	0.048	
2. Public:	0.235	0.519	0.209	

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*: The experiment consists of increasing the postulated initial level of negotiated net national emissions quota by 1 per cent of the gross emissions of all industries in 1989. A figure of ECU 3 per tonne of carbon is assumed as the exogenous international trading price on an *ad-hoc* basis

**: The percentage changes are with respect to gross emissions of GHGs in terms of their carbon equivalent from all sources in 1989.

There is a slight increase in GDP but a fall in the Welfare Index, which is too small to be categorically interpreted as a reduction in consumer welfare. Gross GHGs emissions decrease and there is no change in GHGs offsets thus, the net GHGs emissions decrease. The changes in the class conflict ratios are negligible.

There is an appreciable rise in the domestic prices of forest products, intermediates, and of other consumption goods, while the price of petroleum registers a significant decline. All other prices register slight or perceptible increases. The value added is unchanged in the forest sector and decreases perceptibly in the case of the petroleum sector, while there is a very small decline in each of the other sectors overall there is a decreases in the value added from industries. The slight increase in GDP is accounted for by proceed from trade in GHGs offsets (quotas) which very nearly equal the increase in net national emissions quota[4].

This inflow is not a transfer payment because it results from exports of a national endowment which may be alternatively employed as an input in domestic production, and accrues to government income. An interesting aspect of these results is a divergence between change in GDP and the Welfare Index an increase in the net national endowment of GHGs does not categorically result in a consumer welfare increase in this simulation even while GDP increases.

There are marked increases in imports of forest and agriculture and food products, and a similar decrease in coal imports. There is a significant decrease in imports of durable and capital goods. Exports of all commodities are unchanged.

The use of coal by industries generally shows perceptible to significant declines, except in the case of the agriculture and food, durable and capital goods, and services and transport sectors, where there are slight increases. The use of petroleum increases significantly in all sectors, while changes in electricity use are variable, with a perceptible decreases in the major user sector of intermediates. Natural gas use declines slightly by the same percentage in all user sectors, except the natural gas sector itself. Private consumption of coals and electricity decline and that of petroleum increases, while in the case of public consumption of energy, there are significant increases for all three energy sources.

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[4] Trade in offsets is the sale (positive) or purchase (negative) of offsets/quotas in the world market for this 'good'. The postulated international regulatory scheme for GHGs requires the formation of a market where such international trades may be transacted. Because we have adopted the 'small country assumption' in all international trade for the economy, the world trading price for quota/offsets is exogenous, as it is for all commodities. See Gottinger (1993).

The effect of increasing the national endowment of the internationally tradeable GHGs quota displays clear evidence of "Dutch Disease". This term refers to the effects of appreciation of the real exchange rate resulting from a windfall inflow of foreign exchange (as for example, due to oil well-head revenues). The appreciation of the exchange rate makes domestic exports less competitive internationally, and import substituting industries less competitive domestically, and there is increase in domestic prices. The result is contraction of both types of industries and increase in imports. In addition, there may be an expansion of non-traded sectors, since factors are displaced due to the contraction of traded sectors. These effects are displayed to a large extent in the base case simulation of this experiment. The only non-traded sectors are natural gas and electricity, which are very largely employed as inputs in traded sectors, which contract. Thus, these non-traded sectors too, are unable to expand.Welfare loss (or at least the absence of welfare gain) is attributable to the factor that contraction of domestic industries reduces factor and household incomes, even as government income increases through revenues from trade in offsets. This result, while counterintuitive, conforms to well-established theoretical and empirical results, including those developed by other CGE models.

One may expect that because there is inflow of revenue from external trade in GHGS offsets, and there is no indication of welfare increase, that there would be a rise in total investment. This does not happen, and total investment actually falls slightly (by $0.139 \cdot 10^{-2}$ per cent, not tabulated above). One may explain this by the fact that both household and government income fall because of shrinkage of domestic industries, to an extent that there is reduced aggregate savings.

Table 8: **Comparison of Results of Sensitivity Analysis Simulations: Effect of Employing an International Regulatory Instrument: Net National Emissions Quotas on Endogenous Variables of Interest**

	Percentage Change 100 or Elasticity of Response 100				
Endogenous Variables:	**Base Case**		**Sensitivity Analysis:**		
		(1)	**(2)**	**(3)**	**(4)**
Economy Level Variables:					
1. Gross Domestic Products:	0.049	0.049	0.049	0.049	0.0
2. Welfare Index:	-0.039	-0.040	-0.039	-0.039	-0.045
3. Gross GHGs Emissions:	0.070	0.065	0.070	0.091	-0.002
4. GHGs Offsets:	0.0	0.0	0.0	0.0	-0.002
5. Class Conflict Ratios:					
Interest/Wages:	-0.004	-0.005	-0.004	-0.004	-0.659
Interest/Rental:	-0.006	-0.006	-0.006	-0.006	-0.658
6. Exchange Rate:	1.580	-1.584	-1.580	-1.578	-0.437
7. Public Savings Rate:					-0.368
8. Trade in GHGs Offsets**:	99.92	99.93	99.92	99.90	100.00
Industry Level Variables: Intermediates					
1. Energy Use:					
Coal:	0.114	-0.107	0.115	-0.104	0.0
Petroleum:	0.684	0.642	-0.693	-0.629	0.0
Electricity:	-0.077	-0.075	-0.081	-0.043	0.005
Natural Gas:	-0.024	-0.024	-0.024	-0.025	0.0
2. Value Added:	-0.003	-0.003	-0.003	-0.003	-0.342
3. Factor Use:					
Capital:	0.0	0.0	0.0	0.0	0.0
Labour:	0.002	0.001	0.001	0.002	-0.001
Consumption of Energy:					
1. Private:					
Coal:	0.105	-0.101	0.104	-0.079	-0.028
Petroleum:	0.354	0.326	0.354	0.352	-0.019
Electricity:	0.048	0.049	-0.048	-0.048	-0.026
2. Public:					
Coal:	0.235	0.237	0.235	0.234	0.0
Petroleum:	0.519	0.494	0.519	0.524	0.006
Electricity:	0.209	0.211	0.209	0.209	0.0

*: The sensitivity analyses conducted are as follows:
(1) Trade substitution elasticities are reduced by 10 per cent from the base case level for all commodities.
(2) Cost function (Allen-Uzawa) substitution elasticities are reduced by 10 per cent from the base case for all sectors for all inputs pairs.
(3) Energy sources substitution elasticities (Allen-Uzawa) are reduced by 10 per cent from the base case for all energy paris for all sectors
(4) Variant Closure rule is adopted in place of the base case assumption of the Normal Closure rule.
**: The per cent changes are with respect to gross emissions of GHGs in terms of carbon equivalent in 1989.

The sensitivity analyses results closely replicate the base case results, except for the case of Variant Closure, where there are several divergences. These include a negligible decrease in gross GHGs emissions and offsets generated in Variant Closure, while the Normal Closure simulations predict perceptible increase in gross GHGs emissions, and unchanged level of offsets. Also, while the direction of change in the case of class conflict ratios is unchanged between the Normal and Variant Closure simulations, the changes are significant in the latter and virtually negligible in the former set. The exchange rate falls less steeply in the case of Variant Closure than under Normal Closure.

The pattern of change in energy use in the intermediates sector also differs from that under Normal Closure. Coal use declines significantly under Normal Closure, but is unchanged in Variant Closure. While petroleum use increases significantly in Normal Closure simulations there is a perceptible decline under Variant Closure. Electricity use always decreases slightly under Normal Closure, but there is a very small increase in the case of Variant Closure. Natural gas use declines slightly in each Normal Closure simulation, and is unchanged in the case of Variant Closure.

The value added in the intermediates sector declines negligibly in each of the Normal Closure simulations, but significantly in Variant Closure. Factor use hardly changes in each of the simulations, and the decrease in value added under Variant Closure may be attributed to the significant decrease in factor reward for capital relative to labour, the intermediates sector being capital intensive, and an overall decrease in conventional factor incomes, which may be inferred from the fact that GDP is unchanged but that there are exports of GHGs quotas.

Private consumption of coal and electricity show perceptible to significant declines in all cases, while that of petroleum increases significantly under Normal Closure, but falls slightly under Variant Closure. Public consumption of energy increases significantly for all three energy sources in the Normal Closure simulations, and are virtually unchanged under Variant Closure.

The overall result, which is maintained in each of the simulations, is that of little change in GDP, but a slight decline in the Welfare Index, with an increase in the net national emissions quota, at the assumed world trading price. The level of net emissions of GHGs does not decrease, and the level of trade in GHGs offsets (quotas) is very nearly the same as the increase in GHGs quotas. The public savings rate is reduced under Variant Closure, signifying a fall in government income. This is because although there is increase inflow of revenue to the government from trade in international offsets and from tariffs from generally higher imports, there is countervailing contraction of domestic revenue due to reduced other indirect tax collections from reduced domestic industrial activity.

7 CONCLUSION

The above experiments are intended to be illustrative of the way in which the use of several different policy instruments may be simulated using the CGE model. They are not actual analyses of proposed policies, in fact there are no specific proposals presently under policy consideration. The present CGE model has not be subjected to formal validation tests, but in principle, such tests to validate key elements of the model, may be completed well within the time frame during which it may be necessary to evolve policies relating to the greenhouse effect. Policy analytical models which are not empirically validated may have a limited utility, to focus attention on policy instruments which appear promising or to reveal causal relationships which are not transparent to the intuition. In such cases, the credibility of the models will largely rest on their perceived theoretical rigor and structure, as well as the reliability of the date employed.

It is our contention that the CGE model employed meets the requirements for such restricted employment. Specifically;

1 The model is empirically demonstrated to be robust in the sense that significant changes in the values of key parameters or model assumption do not qualitatively alter the conclusions of experiments involving the use of different policy instruments.

2 The model is firmly founded on received microeconomic theory and the specific assumptions of the model are routine in the empirical modelling literature, including the CGE literature. If the parameter values employed are without significant error, then the results of the experiments should be given serious consideration by policy makers.

3 Most of the specific numerical parameter values employed are estimated and compiled by a permanent, highly trained profession cadre, and available in published sources. This data is regularly employed in policy analysis by respected research agencies and international public organizations. No serious questions have been raised regarding their reliability from any quarters in several decades of the use of these data sources. A large body of empirical research based on this data has been reported to date in the international, professional literature. It is true, of course, that there is a range of

plausible values for the parameter values utilized, and accordingly, sensitivity analyses have been carried out over key parameter values.

On this basis, we now proceed to locate some implications of the above results for further analysis.

The use of each of the policy instruments for direct GHGs regulation is promising. The results of the above experiments seem to show that first, emissions standards accomplish significant decreases in net GHGs emissions, with negligible relative GDP and Welfare Index changes, and without major distributional impacts in the sense of relative changes in factor rewards. They seem to work through major reduction in coal and natural gas use, and slight overall reduction in the use of petroleum.

Second, auctioned tradeable permits also accomplish large decreases in net GHGs emissions, with, however, a perceptible increase in the Welfare Index, and significant distributional impacts in higher rewards to land owners and labour relative to capital owners. They appear to work primarily by expansion of the forest sector, and associated increased offsets generation.

Third, the use of a GHGs tax on positive net emissions of GHGs by industries, accomplishes large reductions in net GHGs emissions, with significant increase in GDP and the Welfare Index. The relative changes in factor rewards are also important, and favour land owners over labour and capital owners. This instrument too, appears to work primarily through considerable expansion of the forest sector, and consequent increased offsets generation.

Each of these instruments show sufficient promise as effective policy tools for GHGs reductions, that it would be advisable to conduct further research in each case. The choice between standards on the one hand, and market based domestic regulatory instruments on the other, is not straightforward, if these results are verified through further analysis

Finally, the experiment involving a postulated increase in the internationally negotiated level of net national emissions quotas, at the assumed world trading price for GHGs quotas, shows that there is little impact on net GHGs emissions. The impacts include clear signs of Dutch Disease, which may occasionally concern. Further research would be advisable to determine the conditions under which Dutch Disease is likely, and to identify policies to mitigate its undesirable effects which include the shrinkage of traded sectors.

APPENDIX 1: MAIN FEATURES OF THE CGE MODEL

Table A.1: Summary of CGE Model Structure

Economy:	Open national market economy, price taker in the world market for imports.
Trade:	Imports and domestic goods are imperfect substitutes aggregated by a constant elasticity of substitution (CES) function. Users: industries, private consumers and government choose the mix of imports and domestic products by cost minimization ("Armington assumption").
Commodities:	N-10 commodities, including 4 "energy types": coal, petroleum, natural gas, and electricity. "Materials" are all commodities which are not energy types.
Industries:	N-10 industries, each named after its "characteristic commodity". Each industry produces the characteristic commodity and by products.
Supply:	Industries are cost minimizing, price takers, constant returns to scale and average cost pricing, multiple products (in fixed proportions) for each industry, transformation possibilities between exports and domestically used goods (constant elasticity of transformation, CET function). Inputs, capital, labour, land (for agriculture and forests), aggregate commodities (an aggregation of aggregate materials and aggregate energy). Trans log (TL) cost functions for industries. Aggregation of commodity inputs is by cost minimization on a CES aggregation function, materials are aggregated by fixed coefficients, and energy types by a Trans log cost function.
Demand:	Demands for commodities arise from private consumption, intermediate inputs, fixed capital, change in stocks, public consumption, and exports. Private demand is by an LES system, intermediate inputs as above, fixed capital goods demand is fixed value shares for each industry's share of gross investment and change in stocks are fixed value shares of gross investment, public consumption is fixed value share of government expenditure. Export demand function for each good has constant own price elasticity.
GHGs Pollution:	CO_2 and N_20: fungible in their damage potential in constant ratio. Result from energy use by industries, private and public consumption. Each energy type results in a unique emissions "signature" (fixed coefficients) of CO_2 and N_20.
GHGS abatement:	Offsets to GHGs are produced by the forest sector in proportion to the areas of land employed.

Domestic GHGs Regulation:	Instruments are a pollution ("GHGs") tax, standards, and tradeable emissions permits: assigned and auctioned.
Other domestic instruments:	Import and export tariffs, indirect taxes on commodities, direct taxes and subsidies, public consumption, quantity restrictions on imports and exports.
World GHGs Regulation:	Negotiated National Net Emissions Quotas, trade in quotas and offsets (world trading price is exogenous to the model), negotiated international financial flows related to past emissions.
Incomes:	Private incomes are factor payments, windfall profits from imports and exports, and subsidies. Government income results from direct and indirect taxes, GHGs taxes and quotas sale proceeds, and international trade proceeds of GHGs quotas.
Savings:	Private and public savings rates are exogenous, public savings rate may be negative.
Macroeconomic balances:	Gross investment equals sum of public and private savings and exogenous international financial flows. Exchange rate is endogenized by a foreign exchange balance of import, exports, GHGs trades, and international financial flows.
Markets:	All domestic commodity and factor markets balance, leading to endogenous commodity and factor prices for each. Overall price level is normalized. Wage rates vary across industries by constant ratios reflecting institutional rigidities, capital costs vary across industries due to different "replacement fractions". Domestic GHG markets balance so that net national emissions quota is not exceeded, yielding GHGs quota price.
Policy Interest Variables:	GDP, "class conflict ratios": factor prices ratios, Welfare Index: an average of Laspeyres and Paasche real consumption expenditure indexes, and net national GHGs emissions.
Consistency:	Empirical consistency checks on the model are: Homogeneity in degree zero in all prices for real variables, and that the model should yield a balanced "Social Accounting Matrix" (SAM).

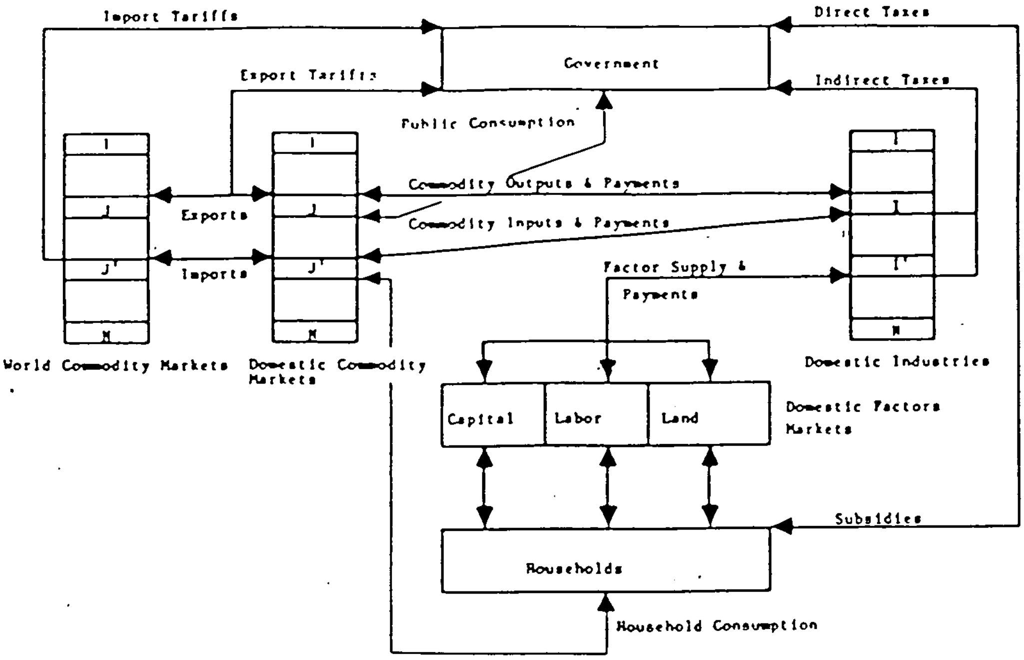

Figure A.1: Flow of Conventional Commodities. Factors. Payments and Transfers in the Economy

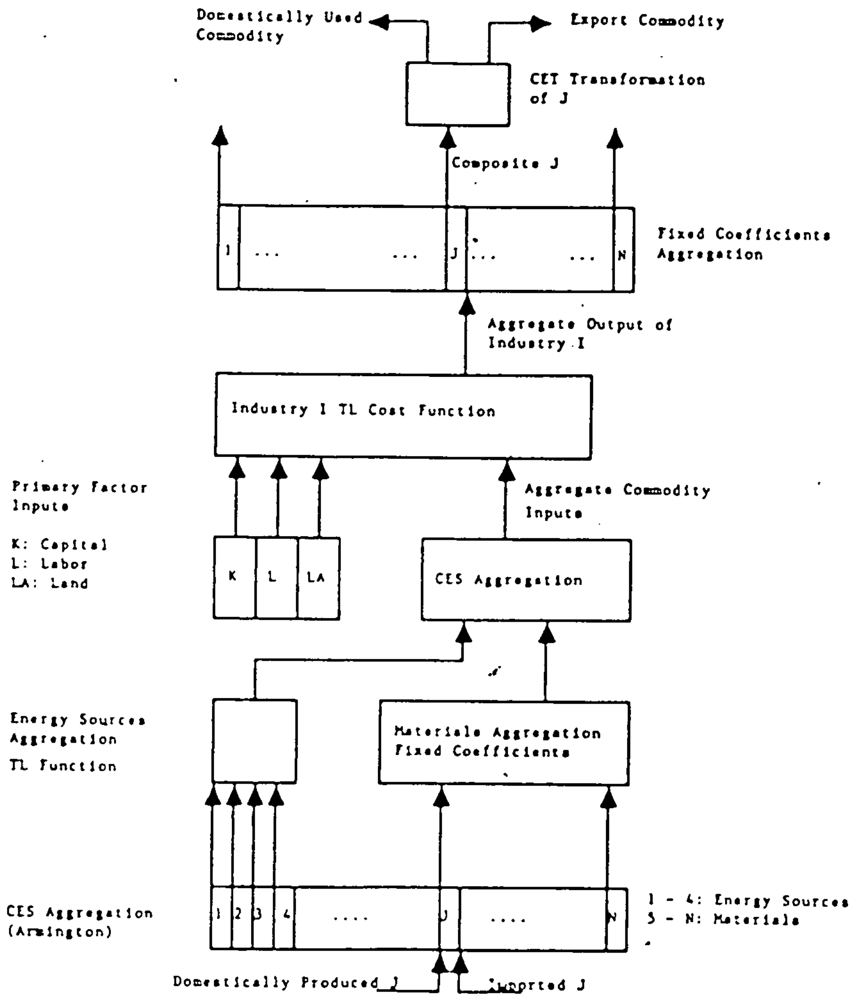

Figure A.2: Substitution and Transformation Possibilities at the Industry Level in the CGE Model

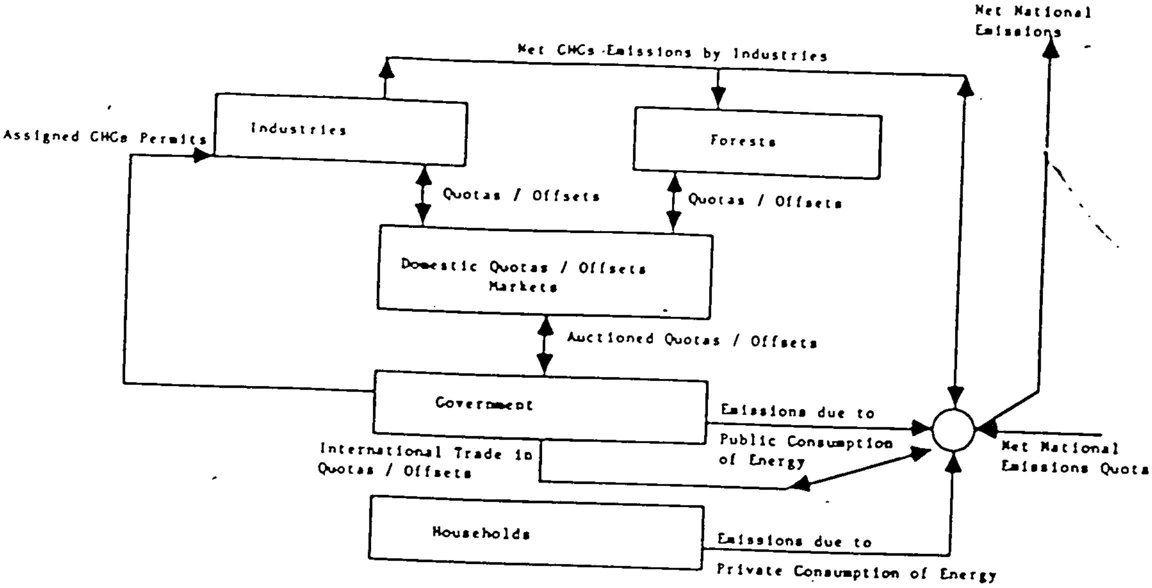

Figure A.3: Flow of GHGs Emissions. Quotas and Offsets in the Economy

APPENDIX 2: RECENT RESULTS OF CGE MODELLING

We discuss two recent econometric approaches to evaluating the impacts of environmental quality standards on a national (USA) economy. Each of these approaches is concerned exclusively with the use of emissions standards, and the models do not include any market based instruments. They represent at this point in time, the most detailed economy wide empirical approaches to evaluating the social impacts of environmental regulation, albeit of a restricted set of policies.

Hazilla and Kopp, (1990): This is an econometric general equilibrium model of the USA economy intended to estimate the social cost of environmental quality regulations mandated by the Clean Air and Water Acts. The research is motivated by the fact that current practices in cost-benefit analyses of environmental programs by federal agencies employ private expenditures rather than social cost as "cost" measures. Further, general equilibrium impacts and intertemporal effects of regulations are as a rule ignored.

The authors assert that the "correct" cost measure is the monetized change in social welfare due to the reallocation of resources from the production of goods and services to pollution abatement, rather than private expenditures. The correctness of this cost measure is attributed to welfare theory. From this assertion the authors proceed to assume that social welfare can be measured by using a function additive in individual utilities, and thus to a measure of social cost as the sum of individual compensating variations. The rest of the research is devoted to demonstrating that this assumed measure of social cost indeed diverges from costs measured by private expenditures, when general equilibrium and intertemporal effects are taken into account.

Other assumptions employed in the model are typical of empirical GE approaches to economy wide modelling, including the CGE approach. Theyinclude, perfect competition in all markets, a single form of malleable capital and mobility of all inputs. The capital stock is fixed in a given period, and augmented at the end of the period by current net investment. Households have myopic expectations, an initial wealth endowment, and transactions costs are assumed to be zero. The wage rate is the numeraire. Labour supply is endogenous, while population growth is exogenous. Household labour supply determines household incomes and savings and the latter determines net investment. Because of the intertemporal nature of the household labour supply, perturbations in the current labour market carry over to the next periods capital market. The only policy instrument included in the model is technology based command and control standards on industries subject to environmental regulation.

Simulations of the model conducted for the period 1975-1990, include a no-regulation base case based on historical values (1970-1985) and Data Resources Inc. forecasts (1986-1990) for exogenous variables and a regulatory scenario. The chief result of claimed policy significance is a divergence between the estimates of social cost produced by the model and EPA estimate of compliance cost using private expenditures. The compliance cost (in current dollars) for the period 1981-1990 determined by the EPA is $648 billion, while the model simulations yield an estimate of social cost of $977 billion.

The authors claim that their findings demonstrate that private expenditures are poor measures of social cost. Further, because of their findings regarding intertemporal effects, the authors assert that currently practised methods are unacceptable. Finally, based on the model simulations, the authors emphasize the importance of adopting a general equilibrium approach to social cost estimation.

The strengths of the model include a high level of disaggregation of commodities and industries, and a detailed treatment of consumer behaviour, including inter-temporal aspects. It is restrictive in that the use of but a single policy instrument (technology based emissions standards) may be simulated by means of the model. This model cannot be empirically validated even in principle, because it seeks to compare two mutually exclusive states of the world, only one of which may be actually observed. Given this inherent limitation, the claim made on behalf of the model, that the measure of social cost yielded by it should be employed in cost-benefit analyses of environmental regulations in preference to observed private expenditures, is unsustainable in terms of scientific norms.

Jorgenson and Wilcoxen, (1989): This paper describes research which was motivated by the fact that there was a sharp fall in USA growth rates during the 1970s and that growth rates remained low during 1980s. This has been at least partly attributed to increase in environmental regulation. The paper describes a detailed long-term model of the USA economy intended to simulate the USA growth path during the next century, under the impact of technology based pollution standards.

The model structure incorporates some standard characteristics of empirical general equilibrium models, and also presents some novel features. The assumptions shared with empirical GE models, include a division of the economy into business, household, and government sectors, besides a rest of the world sector. On the supply side, producers employ substitutable inputs: capital labour energy and materials, with each industry producing an array of commodity outputs. However, in contrast to GE approaches in which technological change is exogenous in dynamic simulations, productivity growth rates for each industry are endogenous, and are logistic in form so that the model ensures a steady states solution. Imports and domestic commodities are treated as imperfect substitutes, and the supply of each commodity is a function of the import and domestic prices, with a logistic time trend. There is a single, malleable capital stock that is allocated among all sectors, including the household sector. The price of investment goods is, unlike GE models, determined not by market balance, but by expectations about all future prices of capital services and all future discount rates. The price of capital services determined by the model enters into the price of investment goods for earlier periods through an assumption of rational expectations or perfect foresight.

Consumer behaviour is modeled by a tier structure of substitution among five commodity groups at the highest level, and within each commodity group at a lower level. Exact aggregation of individual demand functions is assumed in order to yield aggregate demand functions. A single time endowment is exogenously given to consumers, which is divided between labour and leisure. This is done by the concept of full consumption, composed of goods services and leisure. The opportunity cost of foregone labour income is the market wage rate and the price of personal consumption expenditures is a cost of living index. The price of full consumption is a function of the price of leisure time, the cost of living index, and a logistic time trend. Finally intertemporal preferences are represented by a utility function that depends on levels of full consumption in current and future time periods. The (Euler) equation for full consumption is forward looking, so that the current level of full consumption incorporates expectations about future prices and future discount rates.

The model differs from the typical GE approach by its heavy reliance on rational expectations and its strong assumption of an eventual steady state for the economy. Simulations of the model include scenarios with and without environmental regulations. Over the period 1974-1985, the overall impact on growth rate of all types of pollution control, is computed as a decline of 0.191 per cent. This result cannot be verified by any reference to observation, because the comparison is with respect to an unregulated state which did not exist in that time period. The only possible point of comparison is with other models results. For example, Denison (1985) finds that the decline in USA growth rates attributable to environmental regulations during 1973-82 is 0.07 per cent, which is significantly lower. The authors trace the differences in the results to differences in model structures.

Simulations of the model project long term effect of pollution control to the year 2050. The predictions include capital stock rises sharply to 1990, and levels off thereafter. The price of capital services declines rapidly to a minimum at about the same year, and increases very slowly after that. The rental rate nearly duplicates the movement of the price of capital, and real GNP closely replicates the movement of the capital stock.

The strengths of the model include a high level of disaggregation of sectors, and a detailed, inter-temporal modelling of consumer behaviour. The treatment of the internationally traded sector, is however, sketchy. The strong assumption of an eventual steady state of the economy, which renders productivity growth rates endogenous, is questionable. The fact of the model not being susceptible to a-priori empirical validation renders it of limited utility for actual policy formulation exercises.

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