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Mapping Energy Technology and Environmental Regulation: A Multisectoral Climate and Energy Policy Assessment Model (CEPAM)

Literature Review

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1. Introduction.

With the development of *Computable General Equilibrium* (CGE) models general equilibrium theory became an operational tool in applied economic analysis. CGE models are widely used in order to assess the socioeconomic impacts of energy, environmental and economic policies. These models, being able to capture the multiple interactions between all markets of an economy, provide fundamental insights into the factors determining the allocation of resources and the distribution of incomes.

The purpose of this report is to clarify the type of questions that CGE models are best suited in answering and to provide insights on the advantages and weaknesses of this type of models as compared to other modeling methodologies.

The first part of the report consists of a brief introduction to general equilibrium theory while a small CGE model is presented, facilitating a more transparent exposure of the key concepts underlying CGE modeling and theory. The second part of the report discusses the main features of CGE models and presents the specific advantages and disadvantages of the CGE approach over other modeling approaches. The topics covered in this part relate to parameter estimation techniques adopted in CGE models, and the selection of functional forms and closure rules. In the last part of the report, some of the most recent and widely used multi-sector, multi-region CGE models are presented. These models are reviewed, firstly in order to give a benchmark for the current status of CGE modeling, and secondly to be used as a point of departure for a discussion on specific potential extensions to be made on the GEM-E3-World model.

2. A brief introduction on general equilibrium theory.

2.1. History of general equilibrium theory.

The general equilibrium model is the product of nearly two centuries of research. Since the Wealth of Nations of Adam Smith in 1776, one main topic in economic analysis is the identification of the mechanisms that coordinate the actions of the economic agents so as to achieve a balance between supply and demand. Economists like Ricardo, Mill, Marx, and Jevons roughly approached the notion of general equilibrium by recognizing both the existence of equilibrium tendencies in the economy and the importance of the interaction between markets. However the notion of general equilibrium was not formalized mathematically until Leon Walras’ s

Elements d' Economie Politique Pure in 1874. Jevons, Menger and above all Walras suggested that the actions of the agents were coordinated by the price system, in particular all agents faced the same set of prices that provided the common flow of information needed to coordinate the system. This set of prices would adjust until demand and supply were equal while there would be no price movement once such a state was achieved. Because of this characteristic, the balancing of supply and demand was referred to as equilibrium in accordance with the standard use of that term in physics.

The adjective general refers to the argument that one cannot legitimately speak of equilibrium with respect to any one commodity since supply and demand on each market depends on the prices of other commodities, the overall equilibrium of the economy cannot be decomposed into separate equilibria for individual commodities, Arrow (1974).

Walras approach to proving that there is, at least, one solution to the equations characterizing market clearing was inadequate. In particular his proof of existence was limited to the equation-variable counting (if the number of equations equals the number of variables then a solution1 exists).

The modern period in general equilibrium theory starts in Vienna in the 1930' s. There Karl Menger chaired the mathematics seminar where amongst others Wald, a mathematician, and Schlesinger, a banker participated. Schlesinger introduced Wald to the problem of existence of general economic equilibrium. Wald presented mathematical proofs of existence in a variety of models, each representing a special case of a general equilibrium system Wald (1934, 1936,1951).

The question posed in Vienna, the general existence of equilibrium, was not answered until 1954. In this year the papers of K. Arrow, G. Debreu and L. McKenzie presented to the meeting of the econometric society shared the same modeling insight: A fixed point theorem would lead to general proofs of existence of equilibrium. Later proofs were provided by D. Gale (1955) and H. Nikaido (1956). In later years, H. Scarf (1967, 1973) would use fixed point-theorems as the basis of his methods for computing equilibrium via simplicial subdivisions, thus initiating the field of applied general equilibrium.

The theory of general economic equilibrium remains an active, productive demanding specialty of economic theory today. Current research is directed on incorporating inter-temporal considerations, endogenous technical change, imperfect competition, allocation under uncertainty etc.

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[1] This is true when the equations are linear, independent and unrestricted.

2.2. The General Equilibrium Model, an introduction.

In order to correctly use and interpret the results of a model its user needs to have a thorough knowledge of the theory and assumptions applied for its construction. Thus before beginning the discussion on the advantages, weaknesses and particular fields of competence of CGE models, it is reasonable to make a brief introduction to Walrasian general equilibrium theory. This introduction will take the form of a brief presentation of the general equilibrium model of Arrow and Debreu as elaborated in Arrow and Hahn (1971).

Assume an economy where a finite number *l* of commodities 1, ... ,l are exchanged, produced or consumed. The prices of these commodities are given by the l – dimensional vector $p = (p_1, p_2, ... p_l)$. Assume also that there is no money illusion in the economy and the price of each good is expressed relative to the price of the other. Thus a convenient confinement of the price vector is the set known as the unit simplex[2]. By definition the unit simplex implies $p_i \geq 0$ (strict equality holds for the so called *free goods*[3]).

In this economy each economic agent *c* = Firm, Household is endowed with W_i^c assets ($W_i^c \geq 0$ and strictly positive for at least one *i*). The household' s demand for consumption is derived through optimizing its behavior (i.e. maximize utility $U_i^H = f(M_i^H, i)$ s.t. budget constraint $M_i = f(W_i^H, p_i)$) and is denoted by $D^h(p)$. Similarly the firm' s supply denoted $D^f(p)$ is derived through profit maximization. These functions are nonnegative, continuous and homogeneous of degree zero in *p* (the latter assumption implies that doubling all prices doubles incomes and hence the physical quantities demanded are unchanged). The market excess demand function is defined as

$$Z(p) = \sum_{h \in H} D^h(p) - \sum_{f \in F} D^f(p) - \sum_i W_i^c \, .$$

Assume the following properties on Z(p)

For all $p \in P, p \cdot Z(p) = \sum_{i=1}^{l} p_i \cdot Z_i(p) = 0$ (Walras' Law)

and Z(p) is a continuous function (that is small changes in p result in small changes in Z(p)). Continuity of Z(p) reflects continuous behavior of household and firm demand and supply as prices changes. It includes the economic assumptions of diminishing marginal rate of substitution for households and diminishing marginal product of inputs for firms.

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[2] The unit simplex comprises a set of l-dimensional vectors fulfilling a simple restriction: Each coordinate of the vectors is nonnegative and together the l coordinates sum up to1.

[3] Equilibria in which there are free goods are referred to as corner equilibria.

The economy is said to be in equilibrium if prices in all markets adjust so that for each good supply equals demand. When supply equals demand the excess demand is zero. The exception to this is that some goods may be free and in excess supply in equilibrium. Hence we characterize equilibrium by the property that for each good i the excess demand for that good is zero. More formally $p^0 \in P$ is said to be an equilibrium price vector if $Z(p^0) \leq 0$ with $p_i^0 = 0$ for I such that $Z_i(p^0) < 0$. That is p^0 is an equilibrium price vector if supply equals demand in all markets (with possible excess supply of free goods).

Thus a typical general equilibrium is a state of the economy in which the following conditions hold:

- Every consumer chooses his preferred market basket subject to his budget line, which is determined by the prices of inputs and the prices of products.
- Every consumer supplies whatever amount of inputs he chooses given the input and product prices that prevail.
- Every firm maximizes its profits subject to the constraints imposed by the available technology, the demand for its product, and the supply of inputs, but in the long run profits are zero.
- The quantity demanded equals the quantity supplied at the prevailing prices in all product and input markets.

It is evident from the definition of general equilibrium that a great many conditions must be satisfied simultaneously if a state of general equilibrium is to be achieved. In general all CGE models attempt to simulate a market economy where prices and quantities for goods and factors adjust to equate supply and demand. Since equilibrium is achieved by the adjustment of prices, it is important to specify how each of the components of supply and demand depends on prices.

2.3. What is applied general equilibrium analysis.

CGE models are natural extensions of older Input-Output (IO) models, which have been widely used for decades to measure the effects of public policies. CGE models extend these older models to take into account substitution possibilities in terms of, for example, labor or capital-intensive technology choices as well as the circular flow of income across consuming households and producing firms. Although it is possible to make "ad hoc" extensions of IO models to incorporate some of these concerns, one is effectively trying to construct a CGE model through the back door. Thus a CGE model provides a straightforward generalization of earlier models used for impact analysis.

Moreover the CGE modeling approach achieved significant progress during the last 20 years, mainly motivated by the World Bank projects for less developed countries. The central idea of applied general equilibrium models is to “ *convert the Walrasian general equilibrium structure (in a Kenneth Arrow, Gerard Debreu framework) from an abstract representation of an economy into realistic models of actual economies”* Shoven and Whalley (1992).

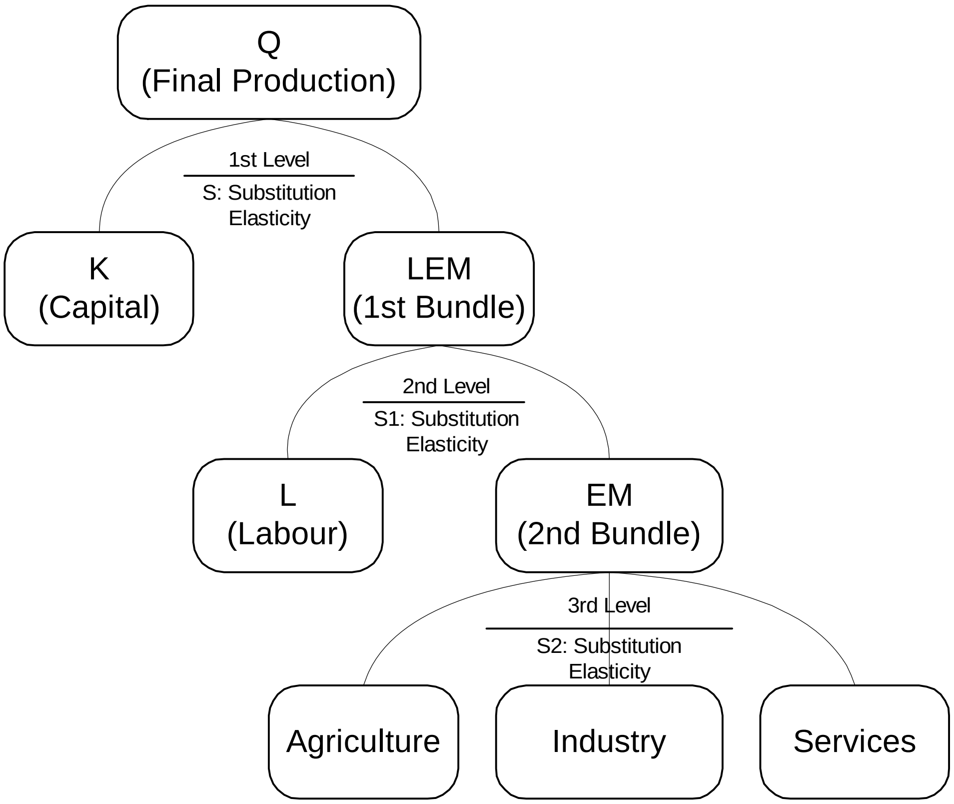
In the following a simple static CGE model is presented outlining key aspects of such models. This simple model describes a closed economy with three commodities (Agriculture, Industry and Services), two factors of production (Capital and Labour) and one economic agent (Household) that owns both production factors. In this model each commodity in the economy is associated with a production sector. These sectors are defined by the following input-output table.

Table 1: Benchmark Input Output Table.

	AGR	*IND*	*SER*	CON	**TOTAL**
AGR	50	5	1	104	160
IND	20	30	20	40	110
SER	30	25	60	26	141
CAP	10	40	10	0	60
LAB	50	10	50	0	110
TOTAL	160	110	141	170	

In linear models a fixed coefficient technology is specified for intermediate inputs, capital composition and non produced primary factors. CGE models sometimes retain this assumption for intermediate technology and the composition of goods. In this model both intermediate demand and the production technology for primary factors are described by a neoclassical production function that allows substitution among several inputs. The functional form adopted here is a nested (Figure 1) Constant Elasticity of Substitution (CES), the choice of which is justified in the “ Critical Appraisal of CGE models” section of this report. Although this nesting scheme has been chosen arbitrarily the choice of the number and structure of the nesting levels usually is based on the available econometric estimates of substitution elasticities.

Figure 1: CES Nesting Scheme (Quantities).



The CGE model has the following form:

Production

[1] $$P_i = \frac{1}{TFP} \cdot \left[D_i \cdot PLEM_i^{(1-s_i)} + (1 - D_i) \cdot PK^{(1-s_i)} \right]^{\left(\frac{1}{1-s_i}\right)}$$

[2] $$PLEM_i = \left[D1_i \cdot PL^{(1-s1_i)} + (1 - D1_i) \cdot PEM_i^{(1-s1_i)} \right]^{\left(\frac{1}{1-s1_i}\right)}$$

[3] $$PEM_i = \left[\sum_j D2_{ij}^{(1-s2_i)} \right]^{\left(\frac{1}{1-s2_i}\right)}$$

[4] $$K_i = Q_i \cdot (1 - D_i) \cdot \left(\frac{P_i}{PK} \right)^{s_i}$$

[5] $$LEM_i = Q_i \cdot D_i \cdot \left(\frac{P_i}{PLEM_i} \right)^{s_i}$$

[6] $$L_i = LEM_i \cdot D1_i \cdot \left(\frac{PLEM_i}{PL} \right)^{s1_i}$$

[7] $$EM_i = LEM_i \cdot (1 - D1_i) \cdot \left(\frac{PLEM_i}{PEM_i} \right)^{s1_i}$$

[8] $$IO_{ij} = EM_j \cdot D2_{ij} \cdot \left(\frac{PEM_j}{P_i} \right)^{s2_j}$$

Household Consumption

[9] $$HC_i = THETA_i \cdot \frac{M}{P_i^{SC_i} \cdot \sum_j \left[THETA_j \cdot P_j^{(1-SC_i)} \right]}$$

Equilibrium Conditions

[10] $$\sum_j \left(ENDOWMENT_{CAP,j} \right) = \sum_j \left(K_j \right)$$

[11] $$\sum_j \left(ENDOWMENT_{LAB,j} \right) = \sum_j \left(L_j \right)$$

[12] $$Q_i = HC_i + \sum_j IO_{ij}$$

In this model it is assumed that firms minimize costs under perfect competition, that is:

$$\text{Min } Cost = Pk*K + PLEM*LEM$$

$$\text{s.t } Q = CES(K, LEM)$$

where,

Pk : Cost of Capital.

K: Volume of Capital.

PLEM: Aggregate Cost of 1st bundle.

LEM: Volume of 1st bundle.

Q: Production Output.

Equations [1], [2] and [3] are the dual functions of this problem denoting the price of each factor at each level of the nesting scheme. Dynamic effects such as changes in the productivity are captured through the TFP parameter (Total Factor Productivity). D, D_1 and D_2 are the value share parameters and i is the index denoting the various economic activities of the real economy (agriculture, industry and services sector). Equations [4],[5],[6],[7] and [8] are the so called derived demands of the cost minimization problem, representing demand for factors and intermediate goods.

Households' demand for consumption [9] is derived from maximizing its utility subject to its budget constraint. Household demand is a function of household income (emanating from its ownership of the production factors) and the vector of consumer prices. The functional form representing households' utility is also a CES.

Factor markets are treated differently since the allocation of labor and capital across the sectors of the economy must be determined. There are two diametrically opposed specifications for allocating factors. One case is to assume that factors are perfectly mobile across sectors, i.e. factors will be allocated such that a uniform price will hold across the economy or that the factors are sector specific, i.e. perfectly immobile. The first assumption of fully flexible factor markets is relatively realistic in the long run. The second assumption, perfect immobility, is more realistic for the short run, since long run equilibrium would normally imply that rates of return across sectors of the economy would equalize. In this model the first approach was adopted.

Equations [10] and [11] determines the equilibrium condition on the factor market: the sum of labor and the sum of capital demand from each sector must equal the total initial endowment of labor and capital (which is assumed to be fixed). In essence these equations can be selected in order to determine the equilibrium cost either of capital or labour. Finally equation (12) equates demand for good i, with its supply X_i i.e. this equation defines equilibrium in the goods market.

Counting variables and equations one can verify that the model as presented above is underdetermined, that is the number of independent variables exceeds the number of equations; in particular there is one excess variable. The variable selected as a numeraire in order to close the model is the wage rate.

3. Selection of the Model for Policy Analysis.

3.1. Why General Equilibrium?

As described in Devarajan (2002) the desired characteristics of a model to be used for policy analysis are: (i) Policy relevance, (ii) Transparency, (iii) Incorporation of recent data so as to use the model in ongoing policy debates, (iv) Validity (Determination and estimation of the parameters of the model should be close to the domain of interest). These are mainly characteristics (but not only) of structural models. For example transparency, that is the explicit link between a policy variable and economic outcome, argues in favor of a structural model where the actions of the agents are fully consistent with economic theory and thus easily interpretable. On the other hand reduced form models are unable to identify the underlying structural relations and hence difficult to trace out the links between policy variables and outcomes.

The issue of validation of a policy model also argues for a structural model. The domain of applicability of a reduced-form econometric model must be contained within the historical range of the data used to estimate the model. The domain of applicability of a structural model depends on the applicability of the structural relations and on the stability of its parameters in the period of analysis.

The 1970s oil crises provide a good example in making the discussion more concrete. The macro-econometric models used at the time failed to capture the impacts of large changes in oil prices because they were estimated on past periods where oil prices were relatively stable. Thus while these models included oil prices, their domain of applicability was too limited to capture the impact of large changes in world oil prices. To capture these links, new structural models were developed which explicitly incorporated links between oil prices and the rest of the economy. A number of CGE models were developed for this purpose.

Computable general equilibrium models are now widely used in supporting policy decisions. The range of issues on which CGE models are utilized is broad including resource economics (Devarajan, Luis and Robinson (1986)), international trade (De Melo (1988)), fiscal policy (Pereira and Shoven (1988)), energy (Bhattacharaya (1996)), employment (Francois and Nelson (1998)), agriculture, and environmental policy (Capros et al (1997), Conrad (1999,2001), Bohringer et al (2002)).

The particular feature that made CGE models such a valuable tool for the study of income distribution, and the analysis of the restructuring effects of alternative policy measures is their ability to trace the consequences of a " shock" induced in a particular sector throughout the entire economy[4]. This comprises the fundamental difference between general and partial equilibrium analysis. In partial equilibrium analysis the study focuses on an isolated market taking the prices and quantities of the commodities produced in other markets as given (following A. Marshall). This approach ignores the effects of changes in the price of a commodity on all other related market prices including the prices of factors of production. These changes may have feedback effects on the original market, which can only be analyzed, in a system of general equilibrium. Another advantage of general equilibrium models is the fact that they incorporate micro-economic

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[4] A common feature with Input Output analysis. However the CGE approach permits a more flexible treatment of the consumer side of the economy and is less rigid in the requirements placed on the productive side.

mechanisms and institutional features within a consistent macro-economic framework, and avoid the representation of behavior in reduced form. Thus using a general equilibrium model in policy analysis, allows taking into account interactions throughout the economy in a consistent manner.

3.2. Critical Appraisal of CGE models.

Beyond any doubt the CGE approach is not flawless. The major criticism of CGE models is briefly presented below and analytically discussed in the subsequent subsections[5].

- Weak econometric validation. In most models there are virtually hundreds of substitution and other type of elasticities. While the ability to estimate them is rather limited due to scarcity of observations. Many of the parameters in the models are calibrated using base year data and elasticity estimates while these parameters are likely to change over time (potential solution: sensitivity analysis).
- The critical role of functional forms.
- Simplification of exogenous elements of the model (closure rules). CGE models by definition are economy wide and all economic flows have to be accounted for. Despite their significant structural detail most CGE models simplify the specification of one or more markets.
- Data intensity (the construction of consistent data sets requires significant human and computer resources, a thorough knowledge of data sources and limitations and an understanding of economic theory and numerical techniques).

3.2.1. Calibrated v.s. Econometrically estimated CGE models.

The problem of numerical specification of a model is not unique to CGE models, it applies to all types of models. The standard form of the problem is stated as follows: Given a system of n equations $F(y, X, b, e) = 0$ where y is a vector of the n endogenous variables, X is a vector of exogenous variables, b is a vector of unknown parameters and e is a vector of non stochastic disturbances of a known or unknown distribution how the vector b should be determined numerically. CGE literature provides three different answers to this question: (i) Econometrical estimation (ii) Calibration (so named by Mansur and Whalley) and (iii) Application of Cross Entropy methods[6].

The most commonly used method among the three is the calibration method. This method amounts to setting all components of *e* identically equal to zero and solving for the vector *b* on the basis of a single realization of *y* and *X*. However, to the extent that *b* has more than *n* components (i.e. *m*), extraneous information is needed in order to

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[5] Apart for the comments on data which are discussed in the last section of the report.

[6]

determine *m - n* of the unknown parameters. Thus, the " calibration method" implies the strong assumption that the observed values of the endogenous variables are determined only by the factors explicitly included in the model. A common practice in the calibration method is to determine some parameters on the basis of a survey of empirical literature, some are chosen arbitrarily (according to the economic intuition of the modeler), and the remainder are set at values, which force the model to replicate the data of a chosen benchmark year.

This approach has been criticized by, among others, Jorgensen 1984 , Lau 1984 , Jorgensen et al. 1992, Diewert and Lawrence 1994 and McKitrick (1998) on several grounds. First, researchers often use elasticities estimated for commodity classifications, which are not fully consistent with those maintained in the model, or for countries other than the ones represented by the model. Second, the calibration procedure causes the quality of the model to be at least partly dependent on the quality of the data for an arbitrarily chosen benchmark year. Jorgenson (1984) argues: *the selection of a single base year means that whatever stochastic anomalies are present in observations for that period will be unduly influential on the model structure. The parameters drawn from eclectic sources may be outdated, or refer to different industry, commodity, or regional aggregates than those defined in the model.* Third, in order to keep the number of parameters to be calibrated sufficiently low, the representation of preferences and technology to a large extent has to be based on CES or Cobb-Douglas functions, i.e. functional forms with a small number of parameters. But this also implies that very restrictive assumptions about the underlying preferences and technological constraints have to be accepted

Despite these disadvantages the calibration method is still the most commonly used. The reason for this has to do with a very important feature of this technique: The parsimony of the data requirement. Indeed there are very few countries in the world that can provide SAM related time series data. Thus in building a multi-regional CGE model one is almost obliged to adopt the calibration technique.

Regarding the restrictive assumptions imposed on the preferences by the selection of relatively simple functional forms one could argue that if one were to do sensitivity analysis of the model with respect to the values of the independent unknown parameters the results would be much easier to interpret and to understand because of both the smaller number of parameters and the simpler functional forms used.

The obvious way to overcome these limitations, and thus increase the empirical relevance and usefulness of CGE models, is to use a stochastic specification model and to estimate the parameters of the model using econometric methods. However, there are significant difficulties associated with such an approach. In particular the dimensionality of any reasonably disaggregated model causes serious degrees-of-freedom problems, especially if restrictive assumptions about the structure of preferences and technologies are to be avoided. In addition the simultaneous estimation of a general equilibrium model requires quite sophisticated econometric techniques (see for instance Lau, 1984, and Whalley and Mansur, 1984).

Recent advances in methods of econometric parameter estimation should reduce the intensity of this particular debate (calibration-econometric estimation). In particular new methods of maximum entropy econometrics are providing a framework for econometric estimation that supports use of information in many forms, and from many sources, in estimating structural parameters. The theory of this estimation technique, comparing it to other methods, is described in S. Robinson, A. Cattaneo, and M. El Said " Updating and Estimating a Social Accounting Matrix Using Cross Entropy Methods" in *Economic Systems Research*, June, 2001.

3.2.2. Selection of functional forms in the CGE model.

The selection of the functional form to be used in a model is constrained upon the objectives of the analysis and the theoretical assumptions of the model. Although this limits the available options of the modeler there is still a wide variety of compatible functional forms to choose from. Then three criteria are usually applied: (i) Parsimony in parameters (the functional form should contain no more parameters than necessary), (ii) Ease of interpretation (parameters in complex functional forms usually do not have an intuitive economic interpretation) and (iii) Computational ease.

In the case of CGE models the most commonly adopted functional forms are those of the CES family. CES encompasses two widely used production functions:

(1) The Cobb-Douglas function (a special case of CES where the substitution elasticity is 1)

(2) The Leontief (fixed coefficients) functional form (this is a special case of CES when the substitution elasticity is 0).

The properties of CES are in accordance with the general equilibrium model requirements. In particular this function is defined for positive levels of inputs, is continuous, differentiable, monotonic (an increase in inputs cannot decrease production), strictly quasi-concave and homogeneous of degree 1 (constant returns to scale). Moreover it qualifies for the application of Euler's theorem[7] and possesses average and marginal products that are homogeneous of degree 0. Most of the variants of the CES function can be seen as the result of attempting to eliminate the assumption contained in

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[7] Marginal productivity theory of distribution in terms of Euler: (i) Each input is paid the value of its marginal product (ii) output is just exhausted.

the multifactor CES formulation, namely, equality of all partial AES Uzawa(1962), Mc Fadden(1963). One extension that relaxes this restriction is the nested[8] CES function Sato (1967). The main disadvantage of these non-flexible functions is that they are very rough representations of actual technical production processes imposing this way very restrictive assumptions regarding preferences and technological possibilities.

3.2.3. Selection of Closure Rule.

Walras stated that if n-1 markets are in equilibrium then the nth market is in equilibrium as well. This means that during the development of a CGE model one need not explicitly specify all markets. Thus the closure rule problem consists of deciding which market to leave out and therefore which variable to consider exogenous. In other words the modeler should select the " mechanism" through which the savings-investment identity will be satisfied. This selection is not straight forward given that selection of the exogenous variable depends not only on the main focus of the analysis but also on data availability. In applied policy analysis the " closure rule" issue has been often taken as a drawback of general equilibrium models, as the results depend on its choice.

4. CGE models.

4.1. Classification of CGE models.

Although the label "computable general equilibrium" conveys an intuitive message, there is no precise definition of a CGE model. Yet the class of economic models usually referred to as "CGE models" has a set of common and distinct features.

- One of these is that both quantities and relative prices are endogenously determined within the models. In this respect CGE models differ sharply from input-output and programming models used for development planning purposes.
- Another feature is that CGE models in general can be numerically solved for market clearing prices on all product and factor markets. Moreover, CGE models are generally focused on the real side of the economy, although financial instruments and financial markets are included in some modeling approaches (see for instance Feltenstein, 1984, Bourguignon et. al. 1988, Capros et. al. 1992).
- With few exceptions CGE models are aimed at elucidating equilibrium resource allocation patterns rather than business cycle phenomena, and the mechanisms by which policy measures affect the economy rather than the exact outcome of a certain government intervention. In other words it seems that the aim of Adelman

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[8] See M. Prywes (1986) for an estimation of a nested CES with four factors of production capital, labor, energy, material (KLEM).

> and Robinson to build “ a realistic structural model, not a reduced form forecasting model” is shared by most CGE modelers. As a consequence most CGE models are intended for quantitative comparative static or dynamic analyses of the impact of non-marginal changes in conditions, which are exogenous to the modeled economy.

In traditional CGE models all product and factor markets are taken to be fully competitive and excess demand functions are homogeneous of degree zero in prices and satisfy Walras’ s law. Moreover, household product demand and factor supply functions are specified to be consistent with utility maximization subject to a budget constraint, while, in the same spirit, product supply and factor demand functions of the producers are specified to be consistent with profit maximization (or cost minimisation) subject to technology constraints, usually represented through production functions.

Within this general modeling framework, however, there is a lot of variety. For instance, there are both one-country and multi-country CGE models. Models in the former class are generally intended for analysis of resource allocation and income distribution issues within a national economy faced with given world market conditions, while those in the latter category are typically aimed at elucidating the corresponding issues in a regional or global perspective.

Moreover CGE models differ significantly with respect to the level of aggregation as well as to the emphasis in the representation of the modeled economy. Thus, in some models the representation of production and technical change is rather elaborate, while a disaggregated household sector and a detailed treatment of the tax and transfer system are the main features of other CGE models. It should also be mentioned that some CGE models can be characterized as large or even very large, multipurpose models, while another category comprises CGE models that are especially designed and used for analysis of a particular problem in a particular context (such as for example those intended to address environmental policy issues).

These dissimilarities between existing CGE models of course reflect the simple fact that different models are intended for a number of different specific purposes. As already indicated, however, most CGE models are intended for some kind of numerical comparative static analysis of changes in exogenous conditions.

Occasionally it is pointed out that the results obtained in simulations with numerical models all refer to special cases and thus are less general than results obtained from analytical models. However, although this is certainly true, it is the validation and not the limitation of CGE models: Applied CGE models are particularly useful just because they reflect the actual structure of the economy, and that the results obtained from CGE models do reflect the existing distortions and structure of the economy.

4.2. The development and current status of CGE models.

Many authors have surveyed the literature on CGE models. Shoven and Whalley (1984) focused their review on taxation and trade while Pereira and Shoven (1988) specifically surveyed studies related to dynamic CGE modeling of national tax issues. De Melo (1988) surveyed the contribution of CGE models to quantification of trade policy scenarios in developing countries. Decaluwe and Martens (1988) presented a comprehensive survey of CGE models. They discussed country specific economic structure of production, private consumption, external trade blocks, and type of closure rules. Devarajan (1988) surveyed energy CGE models and their applications. Bandara (1991) surveyed CGE studies of development policies in LDCs. Robinson (1991) surveyed "micro-macro" CGE models that incorporate assets market and product and factor markets. Kraybill (1993) compared the regional CGE approach to input-output analysis and regional issues. Bhattacharyya (1996) reviewed CGE studies of energy and environmental issues. Recently, Partridge and Rickman (1998) review regional CGE modeling to examine regional economies and regional policy issues. Other recent reviews on CGE literature are by Dixon and Parmenter (1996), Ginsburg and Keyzer (1997), Weyant (1999) and Conrad (1999).

This part of the report begins by reviewing some of the basic and most influential applied general equilibrium models and continuous with recent developments in CGE modelling.

4.3. The Basic Approaches.

Four basic approaches can be identified in CGE modeling and each one of these is dealt with in a separate subsection.

- The first, also chronologically of the four approaches to be discussed, originates from the late Leif Johansen's so-called multisectoral growth (MSG) model. Two paths have evolved from the Johansen' s tradition: the D. Jorgenson " generalised Leontief" model and the ORANI model. Because of its importance, the former will be discussed in a separate paragraph.
- The second is largely due to Arnold C. Harberger, Herbert E. Scarf, John B. Shoven and John Whalley. It is represented by a number of CGE models aimed at elucidating efficiency and income distribution effects of trade or tax and transfer policies.
- The third is the World Bank class of models. These were mainly developed within the auspices of the world bank and were usually used in comparative static analysis for developing countries,

- The fourth approach is due to Victor Ginsburgh and Jean Waelbroeck and can be characterized as an extension of activity analysis and linear programming modeling.

4.3.1. Johansen's multisectoral growth model

CGE modeling began with Leif Johansens' doctoral dissertation "A multi-sectoral study of economic growth" (Johansen, 1960). As the title suggests, Johansen's study was intended to be a contribution to the analysis of economic growth in Norway. In particular his aim was to study phenomena such as the sectoral reallocation of labor and capital changes in sectoral terms of trade in the process of economic growth. The basic tool in this analysis was a disaggregated numerical model, which later has become known as the "MSG model".

Since Johansen's model is the natural point of departure in a discussion about the development of CGE modeling, it is worthwhile to briefly consider the structure of that model. The following paragraphs give a short description of the main building blocks in the MSG model and particularly point out how it differs from CGE models of more recent vintage.

The MSG model was essentially a model of a closed economy; the only endogenous foreign trade was imports of certain goods, which could not be produced domestically (non-competitive imports). The rest of Norway's foreign trade was treated as exogenously determined (positive or negative) final demand and added to the exogenously determined demand for public consumption and net investment purposes. On the resource side, the aggregate supply of capital and labor, as well as the rate of technical change, was also exogenous to the model. As a consequence of these features relative product and factor prices were determined largely by domestic factors.

In the original version of the MSG model, there were 20 " real" production sectors, each one using the other sectors' outputs as inputs in its own production process. In addition there were two " bookkeeping" sectors, i.e. artificial sectors with the role of defining certain aggregated commodity groups.

The assumptions about the technological constraints on the sectoral level can be summarized by the following three equations, where X_i is gross output in sector *i*, $X_{i,j}$ the use of sectors' *i* output by sector *j*, N_i the use of labor in sector *i*, K_i the use of capital in sector *i* and M_i denotes imports in sector *i*.

The parameters $a_{i,j}$ and m_i are Leontief-type fixed input coefficients for domestically produced and imported inputs respectively, while the parameters u_i and v_i are the output elasticities for labor and capital respectively, in the value-added process. As t is a time index, the parameter g_i represents the rate of annual (neutral) technical change.

$$X_i = A_i \cdot N_i^{u_i} \cdot K_i^{v_i} \exp(g_i \cdot t) \qquad i = 1,\ldots,22$$

$$X_{i.j} = a_{i,j} \cdot X_j \quad i = 1,..\ 22 \quad j = 1,\ldots,22$$

$$M_i = m_i \cdot X_i \qquad i = 1,..\ 22$$

Inter-industry deliveries were determined as in the input-output model, whereas value-added deliveries were determined in accordance with Cobb-Douglas production functions. In other words the possibilities for input substitution on the sectoral level were confined to the value-added process. Johansen's approach was to depict a complex economic system by means of a simple model in which *ad hoc* constraints were added in order to account for important aspects of the real world. Similar approaches have been adopted by several other CGE modelers, while others to a larger extent have emphasized consistency between the model and general equilibrium theory. In fact, "consistency with standard (Walrasian) general equilibrium theory" seems to be a dimension along which CGE models could reasonably be classified.

In the demand side, commodity demand for public consumption, investment and export purposes were exogenously given. Thus, household consumption was the only truly endogenous final demand component in the MSG model. However household demand functions are derived on the assumption of utility maximization under a budget constraint on the part of the representative household.

A distinctive feature of the MSG model is related to the procedure for obtaining numerical solutions. The method adopted by Johansen essentially amounts to specifying log-linear approximations to the general equilibrium solution and then solving the resulting linear equations for changes in the endogenous variables as functions of changes in the exogenous variables. This means that the solution describes the relative rates of change of endogenous variables from an initial, and known, allocation of resources. Of course this approach limits the model specification excluding the possibilities for non-linearities.

From a technical point of view Johansen's method has advantages as well as disadvantages. One advantage of the method is that it is simple and relatively cheap to apply. This is of course important in the case of large-scale models. A disadvantage is that the results are affected by approximation errors, and these errors tend to increase with the magnitude of changes in exogenous variables. Considerable efforts have been spent on the development of more efficient and precise methods for finding solutions to CGE models. That work involves elaborations of Johansen's method as well as the development of algorithms capable of directly solving the model in its nonlinear form.

4.3.2. Extensions of Johansen's approach.

Although Johansen's MSG model can be regarded as the first CGE model, not all CGE modelers have taken the MSG model as their point of departure. In particular, the Harberger-Scarf-Shoven-Whalley approach to CGE modeling (discussed later) seems to have been initiated and developed quite independently of, although somewhat later than, Johansen's work in this field. However, there is a significant branch of CGE modeling within which the individual models should be regarded as extensions and elaborations of the MSG models.

4.3.2.1. The ORANI model.

The close relation to practical economic planning and policy evaluation is a feature that the "MSG project" shares with the Australian IMPACT project. Within the IMPACT project an MSG-type model called ORANI has been developed. Of all the widely known models in the CGE catagory, ORANI is the one that most resembles the MSG model. This is true with respect to both the general specification of the model and, as mentioned above, its heavy orientation towards practical application. By the late 1990s, its successor, ORANI/MONASH and derivative models have played an important role in public debates on motor vehicle tariffs, textile tariffs, overall protection and sales taxes (Dixon (2001)).

4.3.2.2. Models of the world bank tradition for developing countries

Another branch of CGE modeling originating from Johansen's MSG model is focused on developing countries. The work along these lines was initiated in the early 1970s and was for a long time almost entirely carried out at, or at least for, the World Bank. The first major study was presented in the book by Irma Adelman and Sherman Robinson *Income Distribution Policy in Developing Countries: A Case Study of Korea* (Adelman and Robinson 1978). As the title suggests, income distribution issues were of major concern in this study. The emphasis on this aspect of economic development remains a typical feature of most models in this branch of CGE modeling, although a number of studies have dealt with trade policy and other aspects of economic policy in a developing country.

However, it is worth pointing out that while both the MSG model and the ORANI model were linearized and solved for the relative rates of change of the endogenous variables at a certain point in time, the Adelman-Robinson model was solved directly in terms of the levels of the endogenous variables. Apart from the possible computational advantages, this made it possible to incorporate an explicit time dimension in the model. Thus the model was specified as a static within-period model linked to a dynamic intertemporal-adjustment model. The underlying feature of reality, which could then be captured, was that the adjustment possibilities of firms and households were considered to be a lot more limited within periods than between periods.

4.3.3. The Harberger-Scarf-Shoven-Whalley approach

This approach to CGE modeling began with three distinct scientific contributions. The first is Arnold Harberger's studies in the early 1960s on the incidence of taxation within the frame of a numerical two-sector model (Harberger, 1962). The second is Herbert Scarf's computer algorithm for numerical determination of the equilibrium of a Walrasian system (Scarf, 1967). The third is the work of John Shoven and John Whalley on the proof of existence of, and computational procedure for finding, a general equilibrium with taxes (Shoven and Whalley, 1973).

The models in the Harberger-Scarf-Shoven-Whalley tradition differ from the MSG models in basically three respects: First there is a difference in terms of the level of aggregation of the household sector. Thus a typical model in the Harberger-Scarf-Shoven-Whalley tradition explicitly incorporates two or more types of households and for that reason a specification of the initial endowments and the determination of the budget constraint of each type of household. The second basic difference is related to the type of applications the models are intended for. Thus, the MSG models essentially are aimed at elucidating the impact of changes in exogenous conditions on the allocation of resources in the economy, while income distribution aspects are neglected or treated in a superficial way. The Harberger-Scarf-Shoven-Whalley models, however, are to a large extent aimed at evaluating policy changes in terms of both efficiency and income distribution effects. Moreover, these effects are usually expressed in terms of one-dimensional welfare measures such as Hicksian compensating or equivalent variations. Although the practical importance of this difference may seem insignificant, it clearly indicates that the Harberger-Scarf-Shoven-Whalley models have their roots in applied welfare economics, while the models dealt with in the previous section to a large extent originate from the literature on economic planning and input-output analysis.

The third basic difference is related to the way in which Walrasian general equilibrium theory is incorporated in the models. The Harberger-Scarf-Shoven-Whalley models can be regarded as numerical counterparts of Walrasian general equilibrium models. However this does not necessarily reflect a basically different view on the functioning of real world economies. Instead it reflects the view that CGE modeling is an extension of theoretical general equilibrium analysis;

In contrast with the MSG model, Harberger-Scarf-ShovenWhalley models are solved directly in the levels of the endogenous variables. Initially numerical solutions were determined by means of Scarfs algorithm (Scarf, 1967; Scarf and Hansen, 1973), but later faster variants of Scarfs algorithm, especially due to Merrill (1972), or Newton-type local linearization techniques have become more commonly used. Making use of Scarfs algorithm, Shoven and Whalley were able to design a computational procedure for finding an equilibrium in a general equilibrium model with taxes (Shoven and Whalley, 1972). Initially the applicability of their method was limited in the sense that the analysis had to be confined to one tax at a time. But in Shoven and Whalley (1973) a refined method capable of dealing simultaneously with several taxes was developed.

The Shoven-Whalley method has been applied in a number of studies of the efficiency and income distribution effects of taxation. An example of a large-scale application is that of Piggott and Whalley (1977) in which the tax and subsidy system of the UK was analyzed by means of a 33 product and 100 households CGE model. Due to the disaggregated representation of the household sector, with households classified by income, occupation and family size, the model enabled the authors to elucidate the income distribution consequences of a series of hypothetical tax changes.

A survey of this field of CGE modeling can be found in Shoven and Whalley (1984), while Fullerton, Henderson and Shoven (1984) and Mieszkowski (1984) provide quite positive evaluations of what has been accomplished. Contrary to the MSG model, the work along the lines discussed in this section has led to the development of several different models, more or less focused on a distinct set of policy issues. The models have to a large extent been applied in empirical studies aimed at evaluating actual or proposed changes in national tax or international trade policies.

4.3.4. Models in the D. Jorgenson tradition (Econometrics).

The difficulties associated with full stochastic specification of a CGE model call for a somewhat less ambitious approach. One alternative is to implement stochastically specified sub-models of production and/or consumption and to use these models as building blocks in a general equilibrium model. That approach has for instance been adopted in the development of later versions of the MSG model. The first example of this type of econometric approach to CGE modeling is due to Hudson and Jorgenson (1975) and the subsequent work along these lines to large extent is due to Dale W. Jorgenson.

The Hudson-Jorgenson model was basically aimed at highlighting the long-run economic impact of a set of energy policy strategies for the USA. The core of the model was a nine-sector (five energy and four non-energy sectors) two-stage production model. In the first stage of the so-called KLEM model sectoral output was taken as a function of the inputs of capital and labor services, an aggregate of the five energy inputs and an aggregate of the four non-energy inputs. At the second stage the compositions of the two aggregates in terms of the individual energy and non-energy inputs respectively were determined within two separate sub-models.

At each stage of the production model the substitutability of the different factors of production was represented by econometrically estimated constant returns to scale price possibility frontiers. As these were specified as so-called translog price possibility frontiers, no a priori constraints on the pattern of partial elasticities of substitution were imposed. Thus, unlike most CGE models where the technological constraints are represented by CES or Cobb-Douglas production functions, neither complementarity between two types of inputs nor different partial elasticities of substitution between different pairs of inputs were ruled out by the specifications of the model.

The main function of the production model was to generate sectoral output prices as well as a complete set of input-output coefficients. However, in order to solve the production model for equilibrium output prices, the prices of capital and labor services, as well as the prices of imported inputs, had to be determined. The latter set of prices were simply taken to be exogenously determined, while the prices of capital and labor services were determined within a Klein-Goldberger type of macroeconometric model with explicit factor market equilibrium conditions. By the so-called nonsubstitution theorem the sectoral output prices, and therefore the input-output coefficients, thus determined by the production model were independent of the sectoral output levels as long as the capital and labor services prices were kept constant. As a result sectoral output levels were linear functions of the final demand levels in the usual input/output fashion. However, while there is only one set of input-output coefficients in a standard Leontief model, there was one set of input-output coefficients for each set of capital, labor and import prices in the Hudson-Jorgenson model.

In order to build a complete model the nine-sector production model was linked to the macroeconometric model. Thus the aggregate consumption and investment expenditures determined within the macroeconometric model were taken as constraints on the solution of the nine-sector production model. Technically this was done by means of a fairly simple household demand model and a set of assumptions about the sectoral composition of investment and government demand. In this way the allocation of resources as well as the determination of product and factor prices could be modeled. Moreover the model could be used for year-by-year projections of the development of the US economy on the nine-sector level under alternative assumptions about the national energy policies.

However, the Hudson-Jorgenson model was not a complete general equilibrium model. For instance, there was no endogenous mechanism ensuring that the aggregated demand for capital services by the nine production sectors at the given prices did not exceed the supply of capital services determined within the macoeconometric model, and the same applies to the demand for labour services. Moreover, imports were used as inputs in sectoral production processes but not in the aggregated production function. This means that, for instance, an increase in international oil prices affected capital and labor service prices only indirectly through the rate of saving and capital accumulation. It should also be emphasized that the level of net exports was essentially exogenously determined in the Hudson-Jorgenson model.

Subsequent work in this field by Jorgenson and his associates does not seem to have led to any major revision of the basic structure of the original Hudson-Jorgenson model. However, both the production and the household consumption sub-models have been significantly elaborated. Thus, the production sub-model has been disaggregated to the 35-sector level as well as elaborated to incorporate endogenous technical change (see for instance Jorgenson, 1984a, b). As is demonstrated by Jorgenson (1982) the production model has also been elaborated to incorporate detailed engineering data describing the technological constraints of the energy sector.

Another example of the econometric approach to CGE modeling is provided by Jorgenson and Yun (1986). This is a highly aggregated intertemporal general equilibrium model, aimed at elucidating and measuring welfare losses due to tax-induced inefficiencies in the allocation of capital in the US economy. Most CGE models are static or, in some cases, designed as a series of partially linked static models. Consequently the work of Jorgenson and Yun represents an important extension of CGE modeling. It is also interesting to note that Johansen's original aim was to shed light on the process of economic growth, and how different economic policies could affect that process, rather than on the intertemporal allocation of resources. However, the multisectoral perspective was emphasized in the MSG model as well as in the mainstream of CGE modeling, and from this point of view the Jorgenson-Yun model is somewhat limited.

A more recent and very interesting addition to the CGE literature comes from a former PhD student of D. Jorgenson, G. Wilcoxen, who together with J. McGibbin developed the G-Cubed model.

4.4. Recent extensions to the CGE literature.

4.4.1. The financial/monetary closure

In standard CGE models there is always the arbitrary question of defining the model closure and the numeraire. Although each approach may be equally valid, the outcome of a policy simulation depends on the closure rule. A way to overcome this shortcoming is to incorporate a financial/monetary block into the CGE model. The resulting non-neutrality of money in this case, is sufficient to lift the need for a numeraire, so that all quantities and prices (including the level of inflation) can be endogenously computed. Theoretical papers have demonstrated the existence and uniqueness of equilibrium given a model of an economy with money.

4.4.2. Models with market imperfections

The assumption about perfect competition and constant returns to scale in all factor markets has several attractive features and has therefore been widely adopted. However, it also has several limitations that render them inadequate for a number of reasons. The main incentive for moving beyond the perfect competition paradigm was given in the late 80s, when economists were trying to investigate the impact of the European Single Market Programme. The main positive effect from this programme, it was argued, would come from the exploitation of the potential for economies of scale, from the intensification of competition and from specialisation. All these issues could obviously not even be addressed by model assuming perfect competition in the goods markets.

Given this incentive the question was to find an elegant micro-economic foundation of imperfect competition that could serve as the basis for building a CGE model with imperfect competition. This framework was provided by the seminal approach of Dixit and Stiglitz[9] that adopted the approach of product varieties. Virtually all subsequent work in the field has been dominated by this approach. CGE models with market imperfections were mostly developed within the European Union[10] while papers from the US have also followed[11].

4.4.3. Models with endogenous technical change.

Despite the undisputed relevance of CGE models in policy analysis they all share the same main shortcoming: Technological development and factor productivity is treated only partially (through the inclusion of autonomous trends that interact with the prices of intermediate inputs, in the case of the Jorgenson-Wilcoxen model, or through the concept of capital vintage in the GREEN model).

The theory of endogenous growth was revitalised by the work of Romer (1986), after being dormant for almost two decades. The growing body of recent literature draws from advances in the theory of imperfect competition and concepts from industrial organisation economics. The general consensus among theorists that technological evolution is primarily the result of conscious action taken by the economic agents is reflected in the most influential works on the subject such as Romer (1990), Grossman-Helpman (1991), Aghion and Howitt (1992) which provide the micro-economic foundations of RTD investment decisions and their links to economic performance. Finally the more elusive concept of the potential of each technology and its ultimate evolution, linked to advances in " general purpose technologies" that permeate the whole economy is less well covered and some theorists (Helpman, Bresnahan and Trajtenberg, 1994) find that even a simple stylised model can be exceedingly complex.

4.5. CGE models for Environmental and Trade issues.

There are more CGE models now available than at any time in the past. The development of solution algorithms along with software specially designed for CGE modeling (i.e. MPSGE) provides a user-friendly framework that facilitates the development of new models. This section will provide a short description of multi-sectoral and multi-regional CGE models designed to analyze environmental and trade policy issues. The models are: EPPA-MIT, G-CUBED, GEM-E3-World, GTAP-E, GTEM, ORANI, and WorldScan.

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[9] See Dixit and Stiglitz (1977).

[10] Smith, A., και A.J. Venables (1988), Burniaux, J.M. και Waelbroeck, J.(1992), Willenbockel D. (1994)

[11] Harrison G., T. Rutherford, D. Tarr (1994)

4.5.1. G-Cubed.

The G-Cubed model was originally developed by McKibbin and Wilcoxen (1992). It combines the dynamic macroeconomic modelling approach taken in the MSG2 model of McKibbin and Sachs (1991) with the disaggregated, econometrically estimated, intertemporal general equilibrium model of the U.S. economy by Jorgenson and Wilcoxen (1989). The Jorgenson-Wilcoxen model breaks the economy down into 35 separate industries, each of which is represented by an econometrically estimated cost function.

The G-Cubed model has only 12 sectors but each sector is based on econometrically estimated cost functions. The G-Cubed model has been constructed to contribute to policy debates related to environmental policy and international trade with a focus on global warming policies. It is a world model with substantial regional disaggregation. In addition, countries and regions are linked both temporally and intertemporally through trade and financial markets. G-Cubed contains a strong foundation for analysis of both short-run macroeconomic policy analysis as well as long run growth consideration of alternative macroeconomic policies. Intertemporal budget constraints on households, governments, and nations (the latter through accumulations of foreign debt) are imposed.

To accommodate these constraints, forward-looking behaviour is incorporated in consumption and investment decisions. G-Cubed also contains substantial sectoral detail. This permits analysis of environmental policies, which tend to have their largest effects on small segments of the economy. By integrating sectoral detail with the macroeconomic features of MSG2, G-Cubed can be used to consider the long run costs of alternative environmental regulations yet at the same time consider the macroeconomic implications of these policies over time. The response of monetary and fiscal authorities in different countries can have important effects in the short to medium run which, given the long lags in physical capital and other asset accumulation, can be a substantial period of time. Overall, the model is designed to provide a bridge between computable general equilibrium models and macroeconomic models by integrating the more desirable features of both approaches. Details on this integration and how G-cubed bridges the gap between CGE and traditional macro-econometric models can be found in McKibbin (1993b).

The main features of the G-Cubed model are:

- Specification of the demand and supply sides of industrial economies
- Integration of real and financial markets of these economies
- Intertemporal accounting of stocks and flows of real resources and financial assets

- Imposition of intertemporal budget constraints so that agents and countries cannot forever borrow or lend without undertaking the required resource transfers necessary to service outstanding liabilities
- Short run behaviour is a weighted average of neoclassical optimising behaviour and ad-hoc "liquidity constrained" behaviour
- The real side of the model is disaggregated to allow for production and trade of multiple goods and services within and across economies
- Full short run and long run macroeconomic closure with macro-dynamics at an annual frequency around a long run Solow/Swan neoclassical growth model.
- The model is solved for full rational expectations equilibrium at an annual frequency from 1993 to 2200.

4.5.2. GTEM

The Global Trade and Environment Model (GTEM) is derived from the MEGABARE model, whose static core was based on the GTAP model. GTEM is considered as an extended and thoroughly revised version of the MEGABARE model. The major addition relates to the extended coverage of greenhouse gas emissions and the provision for inter-fuel substitution and emission response function in non-combustion greenhouse gases in the model (Brown et al. 1999; Tulpulé *et al.* 1999).

Moreover, revisions made to GTEM model include a new and simple rule of allocation of household income between private and government consumption and regional savings de-linking of the saving rates to the population module and modified investment function. On an overall basis, GTEM retains the main conceptual framework of the MEGABARE model intact, except the so-called use of the life-cycle model of savings behavior.

Producers in GTEM are assumed to operate in perfectly competitive markets using constant returns to scale technologies. Under these assumptions prices will be set to cover costs and GTEM industries earn normal profits at all times, with all returns paid to primary factors of production. Thus, changes in output prices are determined by changes in input prices of materials and primary factors. In GTEM, a representative household in each region owns all factors of production and receives all payments made to the factors, all tax revenues and all net interregional income transfers. The representative household allocates its net income across private and public consumption and savings. National savings are assumed to move in line with national income.

The GTEM model uses the GTAP 4.0e database, altered in order to comply with the specific needs of the model. In particular changes were made to the energy sector while additional data were collected for emissions and population. The standard version of the model has 23 regions and 19 sectors.

GTEM is solved using the GEMPACK suite of programs and so it is written using GEMPACK syntax. GEMPACK allows the user to solve a complex non-linear model, which can be written in linear or level form. No matter how is it written, the model will be solved in a sequence of linear solutions (similar to the method of polynomial approximations to any curve) updating the database after each linear solution.

4.5.3. GEM-E3.

GEM-E3-World is an applied general equilibrium model, covering the world (separated in 21 regions) that provides details on the macro-economy and its interaction with the environment and the energy system. It is an empirical, large-scale model, written entirely in structural form. The model computes the equilibrium prices of goods, services, labor and capital that simultaneously clear all markets under the Walras law. In brief, the model can be characterized as follows:

- It is a multi-country model, treating separately each region and linking them through endogenous bilateral trade of goods and services.
- Includes multiple industrial sectors and economic agents, allowing the consistent evaluation of distributional effects of policies.
- It is a multi-period model, involving dynamics of capital accumulation and technology progress, stock and flow relationships and backward looking expectations.

In addition, the model covers:

- The major aspects of public finance including all substantial taxes, social policy subsidies, public expenditures and deficit financing.
- All energy and non-energy related greenhouse gasses covered by the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6)
- Policy instruments specific for the environment/energy system (i.e option for regional or at a club level abatement, different recycling mechanisms, implementation of JI, CDM mechanisms etc.).
- Imperfectly competitive market structures in the sectors that have a large potential for economies of scale.
- Existence of many varieties of a good, enabling different specialization of demand (“ Love of Variety” property).
- Resource depletion mechanism for oil and gas sectors.

The results of GEM-E3 include projections of full input-output tables by country, national accounts, employment, and capital flows, balance of payments, public finance and revenues, household consumption, energy use and supply, and atmospheric emissions.

The computation of equilibrium is simultaneous for all domestic markets of all 21 regions and foreign trade links. A major aim of GEM-E3 in supporting policy analysis is the consistent evaluation of distributional effects across countries, economic sectors, and agents. The burden sharing aspects of energy supply and environmental protection are fully analysed, while ensuring that the world economy remains at a general equilibrium condition.

4.5.4. EPPA

The Emissions Prediction and Policy Analysis (EPPA) model is a component of an Integrated Framework of natural and social science models being developed by the MIT Joint Program on the Science and Policy of Global Change. It is a detailed, global, computable general equilibrium (CGE) model with a long time horizon and regional as well as sectoral detail. The EPPA model can be used to simulate different GHG mitigation policy scenarios and to analyze the impacts and consequences of these policies. Within the Joint Program's Integrated Framework, the EPPA projections of anthropogenic GHG emissions are inputs to a coupled chemistry-climate model. It thereby forms the first link in an integrated analysis of global climate change.

The EPPA model is derived from the General Equilibrium Environmental model (GREEN), which was developed by the OECD (Burniaux et al., 1992). The EPPA model is a multi-region, multi-sector, recursive-dynamic computable general equilibrium model. It covers the period 1995 to 2100 in five year steps and divides the world into the 12 regions. . The economic structure in each region consists of eight production sectors. Each of the eight production sectors has a multi-layer constant elasticity of substitution (CES) nesting structure that combines the output of other sectors as material or energy inputs, and uses labor and capital as primary factors.

The EPPA model is calibrated in 1995 data. The data set consists of Input Output tables for each of the 12 regions, and a bilateral trade matrix. The dataset used is the GTAP/IEA v.4 database.

The EPPA model is programmed in GAMS language. Under the GAMS platform, the static structure of the EPPA model is written in MPSGE (Rutherford, 1994), which is an abstract, high-level language for formulating CGE models. The equilibrium prices and quantities of the EPPA model are solved by using the PATH solver, a generic algorithm for solving MCP (Mixed Complementary Programming) problems

4.5.5. WorldScan.

The first version of the model was built by Ben Geurts and Hans Timmer, and was used for the scenario study " Scanning the Future" (CPB, 1992). WorldScan fits into the tradition of applied general equilibrium models since it builds upon neoclassical theory, has strong micro-foundations and explicitly determines simultaneous equilibrium on all markets.

WorldScan divides the world into twelve regions and represents the economy in 8 sectors. Production functions in the model are represented by a nested structure of constant elasticity of substitution (CES) functions and Cobb-Douglas (CD) functions. The model assumes a similar production structure for each sector and region.

WorldScan identifies two types of labor: skilled and unskilled. Supply for both high and low skilled workers is exogenous. Projections on educational attainment are used to classify labor supply into the categories of high skilled and low skilled. The model assumes relatively abundant high-skilled labor in the OECD regions while low-skilled labor is assumed to be relatively abundant in developing regions. The distinction between high- and low-skilled workers thus facilitates the description of specialization patterns between OECD and non-OECD regions.

In WorldScan savings and investments are equal at a world level indicating the integration of regional capital markets. Moreover regional capital markets are modeled in such a way so as to allow capital supply to come from various regions.

The model assumes adaptive expectation for some central variables, like interest rates, macro growth rates and market shares. These adaptive expectations are modeled in such a way that they would be model consistent in a steady state. In overall the model uses a combination of backward-looking macro expectations and an accurate equilibrium mechanism at the sectoral level.

The model is calibrated in 1995 mainly on the GTAP database. The projections on total population size are taken from United Nations (1995), and those on participation rates are from ILO (1996).

The main characteristics of World Scan are:

- An Armington trade specification, allowing market power to determine trade patterns in the medium run, while allowing Heckscher - Ohlin mechanisms in the long run, and explaining two-way trade;
- Imperfect financial capital mobility; - consumption patterns depending upon per capita income, and developing towards a universal pattern;
- A Lewis-type low-productivity sector in developing regions, from which the high-productivity economy may draw labor, enabling high growth for a long period;
- Two types of labor: low skilled and high skilled.

4.5.6. GTAP.

The standard GTAP model is a multi-region, multi-sector, computable general equilibrium model, with perfect competition and constant returns to scale. Bilateral trade is handled via the Armington assumption. The standard model also gives users a wide range of closure options, including a selection of partial equilibrium closures, which facilitate comparison of results to studies based on partial equilibrium assumptions.

The manner, in which the firm in GTAP combines individual inputs to produce its output, depends largely on the assumptions on separability in production. It is assumed that firms choose their optimal mix of primary factors independently of the prices of intermediate inputs. Since the level of output is also irrelevant, (constant returns to scale), this leaves only the relative prices of land, labor, and capital as arguments in the firms' conditional demand equations for components of value-added. By assuming this type of separability, GTAP imposes the restriction that the elasticity of substitution between any individual primary factor, on the one hand, and intermediate inputs, on the other, is equal. The intermediate input side of the production tree in GTAP is also independent of the prices of primary factors.

Furthermore, imported intermediates are assumed to be separable from domestically produced intermediate inputs. That is, firms first decide on the sourcing of their imports; then, based on the resulting composite import price, they determine the optimal mix of imported and domestic goods (Armington assumption).

In GTAP regional household behavior is governed by an aggregate utility function, specified over composite private consumption, composite government purchases, and savings. The GTAP model employs a special case of the Stone Geary function where all subsistence shares are equal to zero.

Another feature of GTAP regional household utility function is the use of an index of current government expenditure to proxy the welfare derived from the government's provision of public goods and services to private households in the region. This draws from Keller (1980) (chap. 8), who demonstrates that if preferences for public goods are separable from preferences for private goods, and the utility function for public goods is identical across households within the regional economy, and then a public utility function can be derived.

4.5.7. An Overview of the models.

All models described above mainly focus on a medium/long term analysis of the effects of climate or trade policies. Most of them share common features (i.e. common functional forms, datasets, solvers, etc.) but in principle they have one or two major features that distinguishes them and determines their value added contribution to the literature. In particular:

- Endogenous technological progress (GEM-E3).
- Econometrically estimated parameters (G-Cubed)
- Incorporation of financial Markets and Intertemporal framework (G-Cubed).

- Imperfect competition (GEM-E3)
- International growth and trade (World Scan, EPPA-MIT,GEM-E3)
- Skilled Unskilled Labor representation (World Scan)
- Incorporation of depletable resources (EPPA, GEM-E3)
- Incorporation of all GHGs (EPPA, GEM-E3)
- Treatment of private household preferences using the non-homothetic CDE functional form (GTAP).

4.5.7.1. Firms - Production side.

The majority of the models presented above adopt the nested CES production function. In a nested production function approach the final output is defined as a function of inputs, which are in turn defined as a function of inputs at a lower level. As discussed in a previous section this formulation has the advantage of imposing different substitution elasticities at each level of the ' production tree' (it creates complementarity between certain input factors while excluding such between others). Some models (i.e. EPPA, WorldScan) combine CES, Leontief and Cobb Douglas functions in their nested structure. Usually the nesting scheme applied is the KLEM (Capital-Labor-Energy-Material).

4.5.7.2. Labor – Consumption.

The behavior of consumers is modeled in various ways. The most straightforward approach is that of the representative consumer that allocates his income among consumer goods and savings (EPPA). Additionally, in GEM-E3 model households' utility depends not only on consumption but also on leisure time, which implies that households make a labor market participation decision prior to consumption decisions (voluntary unemployment). WorldScan contains a detailed consumption block in which consumption is determined in three stages according to allocation over time, over categories of goods (corresponding to production sectors) and over varieties of goods (corresponding to regions).

In all models described above labor is a primary factor input included in the nested production function structure, either directly or as part of a composite input. The supply of labor is assumed to be provided by households or private consumers and is exogenously given.

4.5.7.3. Emissions-Environment.

GTEM covers three greenhouse gasses (CO_2, CH_4 and N_2O) while GEM-E3 and EPPA incorporate all energy and non-energy related greenhouse gasses allowing for a more consistent evaluation of climate change policies.

4.5.7.4. Trade.

All models incorporate endogenous bilateral trade of goods and services. Usually the models incorporate the Armington-specification: imports are imperfect substitutes for domestically produced goods, which implies product differentiation (GEM-E3, GTAP, EPPA). World Scan however allows Heckscher - Ohlin mechanisms in the long run.

4.5.7.5. Dynamics.

WorldScan, EPPA, GEM-E3, GTAP and GTEM are recursively dynamic models. That is, agents behave myopically expectations in the sense that they react to current prices only. As a consequence the economy evolves in a sequence of period related but inter-temporally uncoordinated temporary flow equilibria.

4.5.7.6. Parameter Estimation Techniques.

Given the copious amount of data required by a multi-regional, multi-sectoral model, the majority of the aforementioned models determine their parameters through the calibration technique. It is only the G-Cubed model that econometrically estimates its parameters (the main bulk of its estimates concerns the U.S.A.).

4.5.7.7. Data

The data used to calibrate the different models are mainly sourced from the GTAP database. This is the only option available since most models are based on social accounting matrices. However additional data needed (i.e. on employment, interest rates, energy balances, consumer price indices) are usually extracted from sources as the ILO, World Bank, OECD and IFS.

Table 2: Formulation of Economic Agents Behaviour.

Model	Demand		Production		
	Demand Functions	*Number of Households*	*Production Functions*	*Number of Sectors*	*Government Behaviour.*
GEM-E3-WORLD	LES (Stone Geary)	One	Nested CES	20	Exogenous
G-CUBED	CES	One	Nested CES	12	Exogenous.
EPPA-MIT	CES	One	Nested CES, Leontief	8	Exogenous.
WORLDSCAN		One	Nested CES, CD	7	
GTAP	Special Case Stone Geary	One	Nested CES		
GTEM	CES			19	Exogenous

Table 3: Summary of Characteristics of CGE models for Climate Change and Trade.

Model	Regional Coverage	Base Year Time Coverage	Data Sources	Parameter Estimation Technique	Solver.	Special Characteristics
GEM-E3-WORLD	21 regions.	1995-2030	GTAP v4.	Calibration	MCP/PATH	Incorporates all greenhouse gasses, Depletable Resources module,
G-CUBED	8 regions.	1993-2200	U.S. Bureau of Economics Analysis Department of Commerce	Econometric estimation on U.S data (applied to all regions)	Solver developed by MacKibin.	Incorporates real and financial markets, Intertemporal.
EPPA-MIT	12 regions.	1995-2100	GTAP/IEA v4.	Calibration	MCP/MPSGE	Nuclear separate sector, Backstop Technologies, Incorporates all greenhouse gasses.
WorldScan	12 regions.	1995	GTAP v4.	Calibration		Different consumption patterns, Imperfect financial capital mobility.
GTAP		1995 or 1997	GTAP	Calibration	GEMPACK	Treatment of private household preferences using the non-homothetic CDE functional form, global banking sector which intermediates between global savings and consumption
GTEM	23 regions.	1995	GTAP v4.	Calibration	GEMPACK	Representation of carbon sequestration,

5. Data.

The value of the information a model provides is correlated positively with the quality of its database. As many studies argue [Srinivasan (1994), Kaergard (2000)], no matter how sophisticated a model can be, its results are crucially affected by its data. A recent study confirming this relationship is the Mercenier *et al.* (1999). In this study, the authors use a CGE model with two different databases (the one refers to the 1990 Turkish input output table and the other to an " adjusted" version of this I/O table made by the authors) in order to evaluate certain trade policy options. Regardless of which one of the two databases depicted better the real economy of Turkey, the findings of their study were striking. The results of the model were not only different in magnitude but also in sign, indicating to a large extent the role of the data in the ability of the model to offer valid policy recommendations.

5.1. The Social Accounting Matrix framework.

Before proceeding with the presentation of readily available data resources for CGE models, it stands to reason to identify the data requirements of a typical multi-regional, multi-sectoral model. These mainly relate to:

1. Final demand.
2. Intermediate consumption.
3. Government revenues.
4. Bilateral trade matrices.
5. Investment matrices.
6. Consumption matrices.
7. Transfer payments among institutional agents.
8. Interest rates.
9. Inflation rates.
10. Employment.

Most of these are incorporated in the Social Accounting Framework (SAM). In particular a SAM is a square matrix of monetary flows that describes all transactions taking place between the economic agents of an economy for a determined year. The number of transactors constitutes the dimension of the square matrix. By convention, columns represent expenditures while rows represent receipts. A schematic representation of the GEM-E3 SAM is shown in Table 4. The construction of the SAM (Social Accounting Matrices) is the starting point of the model building work. In the base year, by definition the balance of flows in the SAM is satisfied in both constant and current money terms.

The balance is conceived as the equality between the sum by row and the sum by column. In addition, a SAM ensures the fulfillment of the Walras law in the base year, since by construction the algebraic sum of surplus or deficits of agents is equal to zero. The GEM-E3 SAM represents flows between production sectors, production factors and economic agents. The production sectors produce an equal number of distinct goods (or services), as in an Input-Output table[12].

Production factors include only primary factors, namely labor and capital. The economic agents, namely households, firms, government and the foreign sector, are owners of primary factors, so they receive income from labor and capital.

Table 4 The GEM-E3 SAM.

	Industries	**Labour**	**Capital**	**Consumption**		**Firms**	**Investment.**			**Ch. in Stocks**	**Exports (F.O.B)**	**Total**
	1………...20			**Household**	**Government.**		**H.**	**G.**	**F.**			
Products 1 . . 20	Intermediate consumption at producer's prices.	-	-	Demand of household and government. consumption. (incl. NPIHs)		-	Demand for investment goods				Demand for exports	Total demand for goods
Wages and Salaries	Primary factors' income.	-		-			-			-	Income transfers from foreign.	Total factor revenues
Social Security Contribution												
Operating Surplus												
Households	-	Factor payments to agents according ownership.		Domestic income transfers between agents.			-			-	Income transfers from/to abroad.	Total income of agents.
Firms	-											
Government	Gov. Firms											
	Gov. Foreign	-										
	Direct Tax											
	Subsidy											
	VAT											
	Duty											
	Social Security											
	Indirect Tax											
G. Transfers	-						-			-		
Imports												

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[12] It should be noted that the SAM is the product of two other matrices: i) The make matrix which is a product by industry matrix, ii) and the use matrix which is an industry by product matrix.

Savings	-						
Total	Total supply of goods	Total payments of factors	Total spending of agents				

In addition, there exist transactions between the agents, in the form of taxes, subsidies and transfers. The agents distribute their income between consumption and investment, and form final domestic demand. The foreign sector also makes transactions separately with each sector. These transactions represent imports (as a row) and exports (as a column) of goods and services. The difference between income and spending (on consumption and investment) by an economic agent determines his surplus or deficit.

Combining the Input-Output data, adapted to market prices and to the national product concept (instead of the domestic product concept), and the data of the National Accounts by sector allows building the Social Accounting Matrix for each country.

5.2. Data Sources.

One of the reasons for the increasing number of CGE models developed during the last decade is the significant advancement in the field of data collection and reconciliation. A notable example is the Global Trade Analysis Project (GTAP) database established in 1992. The most recent version of GTAP version 5 covers the whole world separated in 66 regions (EU-15 fully disaggregated) and all sectors of the economy classified in 57 categories. This database combines detailed bilateral trade, transport and protection data characterizing economic linkages among regions, together with individual country input-output tables, which account for inter-sectoral linkages within regions (for a more detailed description of the GTAP database see: Dimaranan (2002)).

For the European countries the benchmark data source is the NEW CRONOS [13]Database of EUROSTAT. The database covers a broad range of data including: national accounts, consumption by purpose and by product, investment by product and by branch, transfers between institutional agents, capital transfers, employment and interest rates. Data related to bilateral trade matrices are provided by the COMEXT database. Recent European input output tables (after 1995) are provided by the respective statistical office[14] of each country.

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[13] http://europa.eu.int/newcronos/

[14] http://unstats.un.org/unsd/methods/inter-natlinks/sd_natstat.htm

6. Conclusions.

- CGE models have proven to be a very useful economic tool in helping policy makers to asses the impacts of changes of a wide variety of economic policies and exogenous shocks. They have significant advantages over many other possible tools but also have drawbacks. In most cases they are used as complements to other forms of analysis.
- The particular advantage of CGE models lies on their ability to capture all effects induced by a policy shock since they monitor all interdependencies between the markets of the economy.
- Given the existing limitations on parameter estimation it is often not the objective to forecast the exact outcome of policy measures as with for instance a reduced form forecasting model but to give only an indication for the direction and size of the effects.

References

[1] Adelman, I., and S. Robinson (1988) Macroeconomic Adjustment and Income Distribution, *Journal of Development Economics*, Vol. 29.

[2] Arrow, K. J. (1974) General Economic Equilibrium: Purpose, Analytic Techniques, Collective Choice, *American Economic Review*, Vol. 64, pp. 253-272.

[3] Babiker, M.H., J.M. Reilly, M. Mayer, R.S. Eckaus, I.S. Wing, and R.C. Hyman (2001) The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results, MIT Joint Program on the Science and Policy of Global Change.

[4] Bandara, J. S. (1991) Computable General Equilibrium Models for Development Policy Analysis in LDCs, *Journal of Economic Surveys*, Vol. 7, pp. 3-69.

[5] Bhattacharyya, S. C. (1996) Applied General Equilibrium Models for Energy Studies: A Survey, *Energy Economics*, Vol. 18, pp. 145-164.

[6] Bourguignon, F., J. de Melo, and A. Suwa (1989) Distributional Effects of Adjustment Policies: Simulations for Two Archetype Economies. Background Paper for 1990 WDR, World Bank.

[7] Bourguignon, F., J. de Melo, and A. Suwa (1991) Modelling the Effects of Adjustment Programmes on Income Distribution, *World Development*, Vol. 19, pp. 1527-1544.

[8] Bohringer C. and T.F. Rutherford "Carbon Taxes with Exemptions in an Open Economy - A General Equilibrium Analysis of the German Tax Initiative", *Journal of Environmental Economics and Management 32*, 189-203, 1997

[9] Bohringer C., "Climate Politics From Kyoto to Bonn: From Little to Nothing?", *The Energy Journal* 23 (2), 51-71, 2002

[10] Bohringer C. and A. Löschel, "Assessing the Costs of Compliance: The Kyoto Protocol", *European Environment* 12(1), 1-16, 2002

[11] Capros P., P. Georgakopoulos et al. "Coordinated versus uncoordinated European carbon tax solutions analysed with GEM-E3 linking the EU-12 countries", in S. Proost (editor) "Economic Aspects of Environmental Policy", Kluwer Academic Publishers, 1996

[12] Capros P., P. Georgakopoulos et al. “Double Dividend Analysis: First results of a general equilibrium model linking the EU-12 countries”, in C. Carraro and D. Siniscalco (editors) “Environmental Fiscal Reform and Unemployment”, Kluwer Academic Publishers, book published in 1995.

[13] Capros, P., P. Karadeloglou, and P. Mentzas (1990) An Empirical Assessment of Macroeconometric and CGE Approaches in Policy Modeling, *Journal of Policy Modeling*, Vol. 12, pp. 557-585.

[14] de Melo J. and S. Robinson (1982) Trade Adjustment Policies and Income Distribution in Three Archetype Developing Economies, *Journal of Development Economics*, Vol. 10.

[15] de Melo, J. (1988) Computable General Equilibrium Models for Trade Policy Analysis in Developing Countries: A Survey, *Journal of Policy Modeling*, Vol. 10, pp. 469-503.

[16] Decaluwe, B., and A. Martens (1988) CGE Modeling and Developing Economies: A Concise Empirical Survey of 73 Application to 26 Countries, *Journal of Policy Modeling*, Vol. 10.

[17] Dervis, K., J. de Melo, and S. Robinson (1982) General Equilibrium Models for Development Policy. World Bank Research Publication.

[18] Devaragnan, J., J. Lewis, and S. Robinson (1986) A Bibliography of Computable General Equilibrium (CGE) Models Applied to Developing Countries. Division of Agriculture and Natural Resources, University of California. (Paper No. 400.)

[19] Dixon, P. B., and B. R. Paramenter (1996) Computable General Equilibrium Modelling. In H. M. Amman, D. A. Kendrick, and J. Rust (eds) *Handbook of Computational Economics*, Vol.1. North-Holland, New York. pp.385.

[20] Don, H. (1999) *WorldScan: the Core version*, Netherlands Bureau for Economic Policy Analysis.

[21] Ginsburgh, V., and M. Keyzer (1997) *The Structure of Applied General Equilibrium Models*. Cambridge: MIT Press.

[22] Hansen, L. P., and J. J. Heckman (1996) The Empirical Foundations of Calibration. *Journal of Economic Perspectives*, Vol. 10, pp. 87-104.

[23] Hertel, T.W., and M.E. Tsigas (1997) Structure of GTAP, in Hertel, T.W. (ed.) *Global Trade Analysis: Modeling and Applications*, Cambridge University Press.

[24] James de Melo (1988) CGE Models for the analysis of Trade Policy in Developing Countries. (Working Paper 3.)

[25] Jorgensen, D. W. (1984) Econometric Methods for Applied General Equilibrium Analysis. In H Scarf and J. B. Shoven (eds) pp. 139-203.

[26] Jorgensen, D. W., D. T Slesnick, and P. J. Wilcoxen (1992) Carbon Taxes and Economic Welfare. Harvard Institute of Economic. (Research Discussion Paper 1589.)

[27] Kaegård, N. (2000) The balance between theory and data in applied economic models: A historical survey, International Network for Economic Methods, Vancouver, Canada.

[28] Lau, L. (1984) Comments on Mansur and Whalley's Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration and Data. In H. Scarf, J. B. Shoven (eds) pp. 127-137.

[29] Mansur, A., and J. Whalley (1984) Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration and Data. In H Scarf. and J. B Shoven (eds.) pp. 69-126.

[30] McKibbin, W.J., and P.J. Wilcoxen (1995) The theoretical and empirical structure of the G-Cubed model, Brookings Discussion Paper in International Economics No. 118.

[31] McKitrick, R. R. (1998) The Econometric Critique of Computable General Equilibrium Modelling: The Role of Functional Forms, *Economic Modelling*, Vol. 15, pp. 543-573.

[32] Pant, H. (2002) *Global Trade and Environment Model (GTEM): A Computable General Equilibrium Model of the Global Economy and Environment*, Australian Bureau of Agricultural and Resource Economics.

[33] Partridge, M. D. and D. S. Rickman (1998) Regional Computable General Equilibrium Modelling: A Survey and Critical Appraisal, *International Regional Science Review*, Vol. 21, pp. 205-248.

[34] Pereira, A. M., and J. B. Shoven (1988) Survey of Dynamic Computational General Equilibrium Models for Tax Policy Evaluation, *Journal of Policy Modelling,* Vol. 10, pp. 401-436.

[35] Perroni, C. and T. F Rutherford (1995) A Comparison of the Performance of Flexible Functional Forms for Use in Applied General Equilibrium Analysis. University of Colorado. Working Paper.

[36] Shoven, J. B. and J. Whalley (1984) Applied General Equilibrium models of Taxation and International: An Introduction and Survey, *Journal of Economic Literature*, Vol. 23, pp. 1007-1051.

[37] Shoven, J. B. and J. Whalley (1992) *Applying General Equilibrium*, Cambridge: The University Press.

[38] Starr, R.M. (1997) *General Equilibrium Theory*, Cambridge University Press.

[39] Thissen, M. (1998) A Classification of Empirical CGE Modelling, SOM Research Report 99C01, University of Groningen.