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Review of Analytical Tools for Assessing Trade and Climate Change Linkages

By

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Executive Summary

Trade and climate change are clearly among the most important economic and political issues facing the global community. Although it is generally agreed that the two areas are closely related, the nature and outcome of these linkages are still debatable. On the one hand, there is a view that trade can contribute negatively to the problem of climate change because of its impacts on the level of economic activities and the impact on international transport. On the other hand, there is also the contrary view that trade is not only helpful, but may even be necessary, for the development, diffusion and transfer of technologies which can help in the combat against climate change. To assist in the understanding of the nature of these complex interrelationships and to assess their overall impacts on the economy and the environment, especially with respect to the problem of climate change, it is important that we understand the theories behind these interrelationships and use the practical models which are built to represent these linkages in the analysis of climate change and trade policies. In this paper, we briefly refer to the essential elements underlying the theoretical linkages between trade, economic development, and climate change and review the analytical tools which are used to describe these linkages. We look specifically at a particular type of analytical tool called computable general equilibrium (CGE) models; consider their strengths and limitations when used as a tool for the analysis of these trade and climate change linkages. The paper finds that the tool have been more useful than 'misused', and this explains for the popularity of its use in the past. Looking to the future, to increase the usefulness of the tool in the area of policy analysis, there will need to be continuing training for the policy analysts in the modern and expanding techniques of CGE modelling. Such training will include not only the surveying and reading of the literature and understanding the basic theories but also 'hands on' experience on its practical applications. This survey paper therefore is only an important first step towards that ultimate direction.

> *Insofar as trade leads to growth, and growth leads to an increased willingness and ability to pay for a cleaner environment, freer trade and investment flows will enable countries to adapt better to any adverse effects of climate change and to mitigate emissions.* Sallie James (2009). p.14.

> *Globalization...has been a major driver behind global warming. This trade model has promoted the production and consumption of goods regardless of their impact on our environment, excessive and wasteful shipping of goods globally, depletion of natural resources at a break-neck pace...Free trade has most significantly contributed to global warming ...*Sierra Club (2008) p. 2

> *Trade...can - at best - offer no more than part of the answer to climate change. It is not in the WTO that a deal on climate change can be struck, but rather in an environmental forum, such as the United Nations Framework Convention on Climate Change*. Pascal Lamy, WTO Director- General, Bali, December 2007

1. Introduction

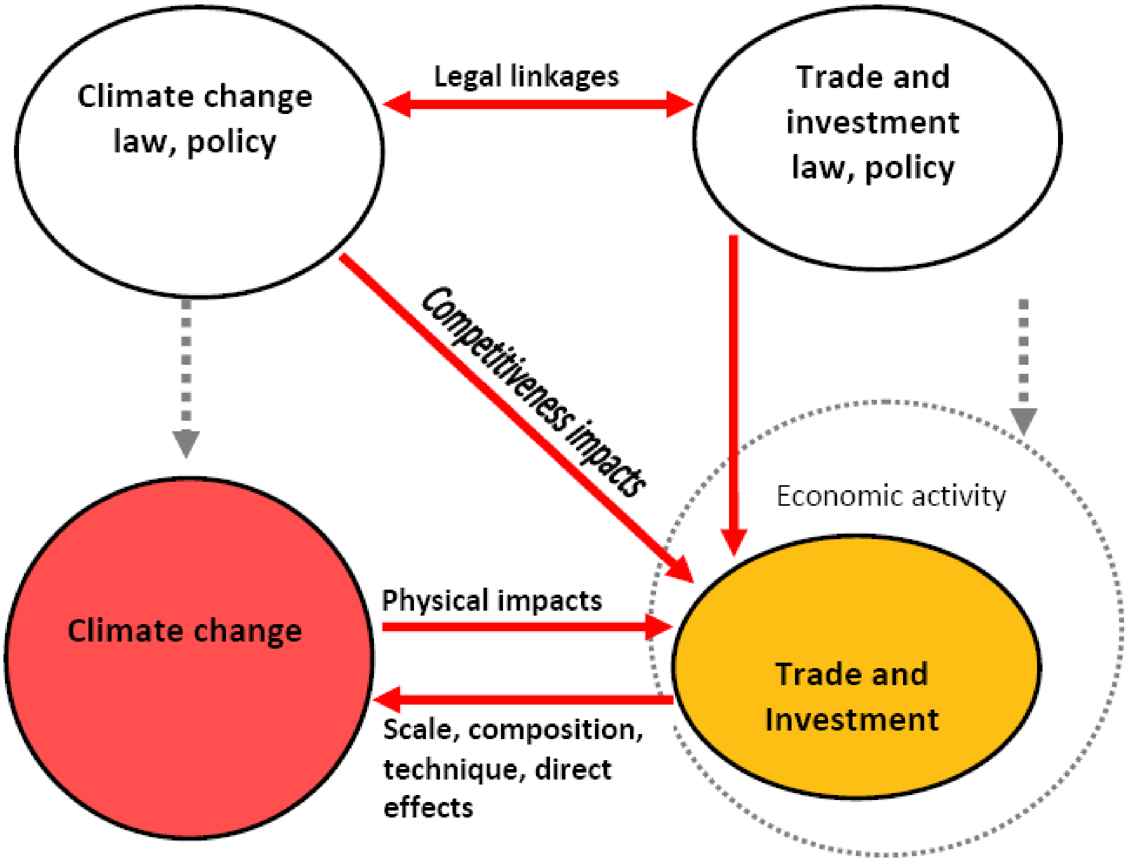
Trade and climate change are clearly among the most important economic and political issues facing the global community. Although it is generally agreed that the two areas are closely related, the nature and outcome of these linkages are still debatable. On the one hand, there is a view that trade can contribute negatively to the problem of climate change because of its impacts on the level of economic activities and the impact on international transport (Sierra Club, 2008). On the other hand, there is also the contrary view that trade is not only helpful, but may even be necessary, for the development, diffusion and transfer of technologies which can help in the combat against climate change (see, for example, James (2009)). To assist in the understanding of the nature of these complex interrelationships and to assess their overall impacts on the economy and the environment, especially with respect to the problem of climate change, it is important that we understand the theories behind these interrelationships and use the practical models which are built to represent these linkages in the analysis of climate change and trade policies. In this paper, we briefly refer to the essential elements underlying the theoretical linkages between trade, economic development, and climate change and review the analytical tools which are used to describe these linkages. We look specifically at a particular type of analytical tool called computable general equilibrium (CGE) models; consider their strengths and limitations when used as a tool for the analysis of these trade and climate change linkages.

The plan of the paper is as follows. Section 2 explains the theoretical linkages between trade and climate change issues. Section 3 looks at the analytical tools used in the analysis of these linkages. Section 4 looks more closely at a particular type of analytical tool: CGE models, and assesses the strengths and limitations of this tool. Section 5 gives some examples of the use of CGE models in the analysis of trade and climate change linkages. Section 6 concludes.

2. Trade and Climate Change Linkages – Theoretical Hypothesis

Trade and climate change can be assumed to be linked in several ways. Figure 1 shows a schematic diagram of these linkages.

Figure 1: Trade, investment and climate change linkages



Source: Cosbey (2007)

2.1 Impacts of Trade on Climate Change: Scale, Composition, Technique and Direct effects

The impacts of trade and investment policy on climate change can be summarised in terms of four different components[1]: scale effects, composition effects, technique effects, and direct effects. In practice, these different components are closely intertwined and it's hard to separate them out, but from a theoretical viewpoint, it is useful to distinguish between these components so that we can have a better understanding of the nature of the interrelationships.

- *Scale effect*: this is the effect that trade (and investment) policy can have on climate change via a change in the scale of production and consumption activities. For example, if trade results in an increase in the level of economic activities in certain sectors of an economy, and/or certain parts of the world, and if these increased activities result in higher levels of GHGs emissions, then trade can be said to have a negative impact on climate change. The scale effect is almost always negative; therefore, criticisms of the current trading system often resort to this scale effect to point to the negative impact of globalisation on the environment and especially on climate change.

- *Composition effect*: trade and climate change policies can also have impacts on the patterns of production and consumption activities in different countries. For example, through trade opening,

[1] "Scale, composition, and technique effects" were first used by Grossman and Kruger (1991) and others to describe the impacts of the North American Free Trade Agreement (NAFTA) on pollution levels in North America. The precise definitions of these terms in the context of a general equilibrium model were subsequently given in Copeland and Taylor (1994).

the income level of trading countries can increase and if we assume that the environment is a normal good, then an increase in income level will lead to an increase in demand for this good. The pressure of demand for more environmental good means the patterns of production and consumption activities will have to change and shift gradually from a reliance on environmentally 'dirty' goods (such as steel, cement, and chemicals) towards 'cleaner' goods (such as electronics, telecommunications, and other services)[2]. These composition effects can have a beneficial impact on climate change. However, this depends also on other factors. For example, if climate change regulations in rich countries are not matched by similar regulations in other poorer countries, then the 'leakage effects' implies the beneficial composition effects in the former countries will be offset by the negative composition effects in the latter countries.

- *Technique effects*. Trade liberalization (and investment agreements which may go with it) can bring about changes in production techniques which are often more energy efficient, and hence emit less GHGs per unit of output. The changes in production techniques can come about from the autonomous pressure of competition but can also be induced by policies. For example, the European Union climate policy of targeting the share of renewable energy in production and consumption activities of the European Union in the year 2020 to a level of 20% may have the effect of inducing climate friendly technological change in the European Union. Currently within the Doha Round, there are discussions about how to use trade liberalisation in the area of so-called environmental goods and services (EGS) to help in the diffusion and transfer of climate friendly technologies between countries.[3] The analysis of these climate and trade policies linkages may require further research using tools which can capture the essential elements of these linkages.

- *Direct effects*: free trade increases the demand for international transport of goods. Transport currently uses fossil fuels and hence this will increase the overall emissions of GHGs. The direct (negative) effects of trade and transport on the environment and climate change, however, must be considered in the context of trade and transport are only a means to an end ('margin' commodities) rather than an end in itself (i.e. final commodities). Therefore, although the direct effects of trade and transport on the environment are always negative, this does not mean these activities are not necessary or useful for other activities. Negative direct effects are only part of the overall scale, composition and technique effects considered previously.

2.2 Impacts of Climate Change on Trade: Productivity changes, Changes in Comparative Advantages

The impacts of climate change on trade can be summarised under two headings:(i) physical impacts of climate change on the natural resource endowments of a particular country which then affects the comparative advantage of the country in international trade, and (ii) policy impacts of climate change policies on comparative advantage or competitiveness of firms in these countries.

- *Physical impacts*: with rising temperature, changing level of precipitation, increased level of CO_2 concentration in the atmosphere, productivity of the agricultural sector may be affected. It has been estimated (see Cline (2007) for example) that agricultural productivity in some regions such as India, South East and South West Plains of the United States, Mexico, South Africa, Ethiopia can be reduced by these aspects of climate change by as much as -20% to -30%. Some other regions, however, may gain: For example, China, the United States (other than South East and

[2] This is also the main hypothesis underlying the so-called 'Environmental Kuznets Curve' (EKC) (see World Bank (1992), Grossman and Kruger (1995)). It has been suggested (see WTO (2009, p.52)) that although the hypothesis may work well for the case of a local environmental good attached to a specific country, it may not apply well to the case of a global environment issue such as GHGs emissions because in this case the bulk of the costs of GHGs emissions are borne by other countries and hence there is always very little incentive left for the polluting country to reduces its own emissions even if its income are rising.

[3] See WTO (2009).

South West Plains), Canada, Germany, Spain, Russian Federation can gain in agricultural productivity, and these gains can range from about 5% to 12%. The increase in temperature as well as other aspects of climate change such as the bleaching of coral reefs, forest die-off, and fundamental ecological changes can also affect other sectors of the economy such as tourism and infrastructure (harbour, shipping docks, etc.).

- *Policy impacts*: climate change policies can affect the comparative advantage of a country and the competitiveness of firms in various sectors of an economy. One of the principal concerns when countries try to implement unilateral climate change policies is the fact that such policies may not be effective from the global environmental viewpoint. This is because of the problem of so-called 'leakage': environmental goods in one country are offset by environmental bads in other countries due to a lack of international policy co-ordination. Another important concern is the impacts of such unilateral policies on the relative comparative advantages of a country in international trade, and also the relative competitiveness of different firms in different sectors of the economy in domestic trade. To deal with these concerns, there have been suggestions that some border tax adjustment (BTA) measures such as environmental tariffs could be applied. However, the effectiveness of such policy measures can be doubtful and the impacts of such measures on the world economic and trading systems can also be unpredictable. Therefore, there is a need for further research into these trade-climate change policy linkages before such policies measures could be adopted.

3. Trade and Climate Change Linkages – Empirical Analytical Tools

The most common tools which are used in applied analysis of trade-climate change linkages are (i) econometric techniques, and (ii) applied (or computable) general equilibrium models[4].

3.1 Econometric techniques

Generally, these are used to establish partial statistical relationships between certain environmental or climate change variables (temperature, humidity, precipitation, wind velocity, etc.) and some specific socio-economic variables. For example, in the study of the (partial or direct) impacts of climate change on health issues, regression analysis can be used firstly to establish a statistical relationship between morbidity or mortality rates (dependent variable) and maximum daily or average weekly temperature, humidity ratio, wind velocity, etc. (independent variables). This statistical relationship is then fed into some other micro-simulation or computable general equilibrium models to estimate more generally the overall impact of a particular temperature (climate change) scenario on the health condition of a particular region.[5] Similarly, in the analysis of the impact of climate change on the tourism industry, regression analysis can first be used to establish a relationship

[4] Some authors (e.g. Mitra-Kahn (2008)) distinguish between 'applied general equilibrium' (AGE) and 'computable general equilibrium' (CGE) models, citing mainly their differences in historical origins and computational methods as the reasons. However, as Hertel *et al.* (1991) pointed out, these differences are not really the main issue because the two 'schools' have much in common in theory. Dixon (2006) also pointed out that computational technique of the 'AGE School' (Scarf algorithm) was mainly inspirational rather than practical or 'applied' and in fact, by the 1980s, it was completely abandoned by the 'AGE School' in favour of more traditional techniques used by the 'CGE school' such as Newton-Ralphson and Euler algorithms. Computational technique is also becoming less of an issue for economists using CGE models because now with the advent of powerful modern computer and computational softwares (such as GEMPACK (Pearson (1988), Harrison and Pearson (1996)) or GAMS (Kendrick *et al.* (1988)), economists can concentrate on the more productive task of *interpreting* and *explaining* the results rather than the methods of computation behind these results.

[5] See, for example, Kalkstein *et al.* (1987).

between the total number of tourist arrivals or departures from a particular region and the environmental or climate change variables relating to this region. The relationship can then be used in a more general micro or macro simulation model to estimate the overall impacts of some climate change scenarios on tourism.[6] Econometric techniques therefore, can be part of the set of analytical tools which are used in the analysis of the impacts of climate change on economic activities or the linkages between climate change and trade policies.

3.2 General equilibrium models

Linkages between climate change and the economy and international trade are much more complex than a simple (and partial) econometric relationship can capture and hence these relationships must be used in conjunction with a more general or comprehensive simulation model (such as CGE model) to analyse the overall linkages between trade and climate change. In theory the 'general equilibrium' in a CGE model refers to the complete balance between supply and demand in all markets described by the model. In practice, however, disequilibrium is also routinely allowed into these models to capture the real situations in some specific markets. For example, if the labour market is in a Keynesian-type disequilibrium situation because of the 'stickiness' of labour price, then one can assume that this price is to be determined exogenously of the model (e.g. by union bargaining) and then a 'slack' variable is introduced into the model which represents the excess demand or supply which now characterise this market. The slack variable is now endogenously determined by the model instead of the labour price variable. 'General equilibrium' is thus not a very accurate term to be used to describe these models. A more accurate term would be 'general inter-connectedness' or 'general linkages' model.[7]

4. The Use of Computable General Equilibrium (CGE) Models for Policy Analysis in the Area of Climate Change and Trade Linkages

In this section we look more closely at the CGE tools which are commonly used in the analysis of trade-environment-climate change issues. We explain why these tools are used, what their strong characteristics are and what are their limitations or inappropriate uses.

4.1 Why 'general equilibrium'?

An alternative to 'general equilibrium' is 'partial equilibrium' analysis using methods such as regression analysis which is used to estimate parts of the linkages between trade and climate change (see previous section 3.1). Partial equilibrium analysis is not comprehensive enough to account for all the complex interrelationships between trade, economic activities and climate change issues. These complex interrelationships involve the linkages between different *sectors* of an economy (upstream/downstream; domestic/foreign, infrastructure/final production); different *agents* (consumers, producers, governments, investors, savers, importers, exporters), different *economies* (developing/developed), and also different *generations* (current/future).

- Different sectors of an economy may face with different choices or opportunities for reducing GHGs emissions and the imposition of different climate change policies focusing on these different sectors may also have different overall impacts on the economy and on the costs of these

[6] See, for example, Lise and Tol (2002), Hamilton *et al.* (2005).

[7] Apart from the word 'general' which is used only in a relative' sense, the word 'equilibrium' is abstract and can be artificial. For example, in the analysis of trade-economic-environmental linkages, the idea of 'equilibrium' between the trade-economic system and the natural environment is not something which is easy to define. Therefore a more appropriate term to use is 'interconnectedness', or simply 'linkages'.

climate change policies. For example, if a carbon tax is imposed on producers of fossil fuels (i.e. on upstream coal mining or petroleum refining sectors) instead of on the final consumers (down stream electricity generation, or transport services sectors). this may save on transaction and monitoring costs (because there are less number of establishments to monitors) but this can result an opportunity for end-of-pipe emissions reduction method such as carbon capture and sequestration to be utilized because there is now no incentive for the downstream polluters to install them (see for example, Mansur, 2010).

- Different types of agents may face with different decisions in responding to climate change and trade policies. For example, consumers may want to maximize their utilities or welfare, firms may want to minimize their costs or maximize profits, government may have to optimize with respect to their fiscal budget constraints and/or trade balances. Decisions by private individuals or firms or different countries may also create 'externalities' which regulatory bodies or public organisations (such as the UNFCCC or WTO may also want to take into account (for example, when dealing with the issue of carbon leakage)

- Different types of economies (developing/developed) may follow different types of policies because they face with different economic/environmental challenges (e.g. growth or poverty reduction versus environmental protection).

- Finally, different generations (current/future) can also have different and sometimes conflicting interests in the preservation of the environment or exploitation of natural resources.

Because of all these interconnecting differences, there is a need for an analytical framework which can comprehensively describe and also measure up all the differences and consistently 'adding up' all the results. For example, all income and expenditure flows of all economic activities from all sectors of an economy (two sides of the same coin) must be balanced; total imports and total exports of all countries must be checked to be equal; total world savings must balance total world investments, etc. These requirements that the world economic and environmental systems to be in some state of 'general balance' or 'equilibrium - if not for theoretical reasons then at least for numerical consistency - is the main reason why (computable) general equilibrium' model is the adopted tool for most trade-climate change linkage studies.

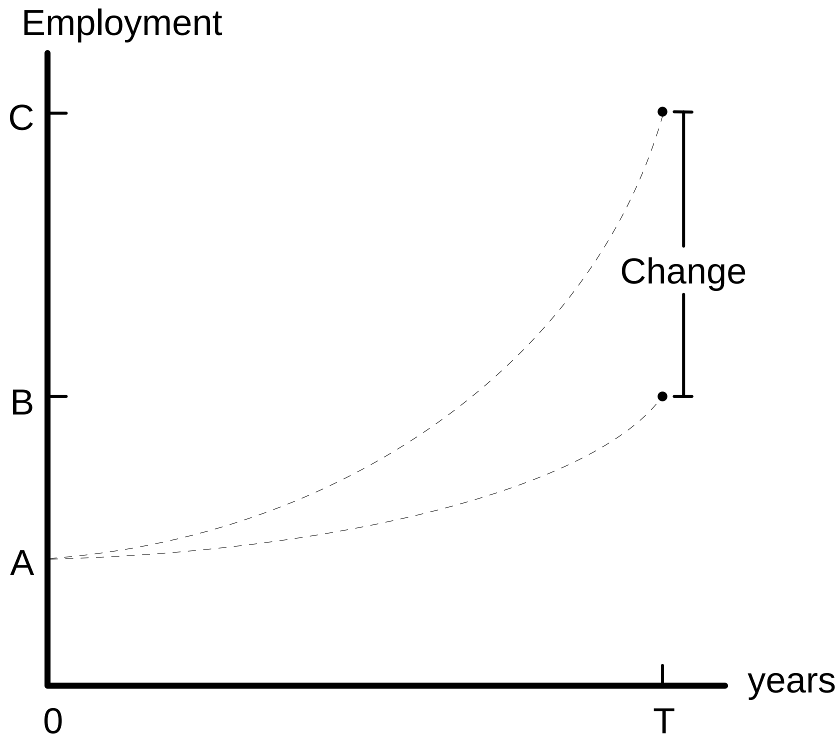
4.2 What 'computable'?

Computable general equilibrium (CGE) models can be used in different 'modes'. In the traditional 'comparative statics' analysis, it is used to analyse the impacts of a particular policy on an economy ('what if' or impact analysis). In a more dynamic approach, CGE models can be run in four different modes: *historical*, *decomposition*, *forecasting*, and *policy* (or *deviation*) modes (see Dixon and Rimmer (1998)).

- *Comparative static analysis*: in this approach, first, an economy is assumed to be in a state of equilibrium at position *A* at time *t*=0 (see Figure 2). Assume there are 'business as usual' shocks to some exogenous variables but *no policy* is applied to the economy at this point, the economy will move away from position *A* but after a period of time *T* it will settle back again to a new equilibrium position at point *B*. Now, assume that a *policy* shock had also been applied to the economy at time *t*=0 (in addition to all the BaU shocks). The new equilibrium position at time *t*=T may be at point *C* rather than point *B*. The 'distance' *BC* can be said as resulting from the *impacts of the policy.*

In comparative static analysis, the implicit assumption is that the distance *BC* due to the impact of the policy can be measured independently of the time path of the economy from *t*=0 to *t*=T.[8] However, as Dixon and Rimmer (1998) discovered, this is not to be the case. The policy impact *BC* can depend on assumptions made regarding the time path of the economy from *t*=0 to *t*=T in the 'base case' (i.e. when no policy was applied).[9] This means even for policy impact analysis, comparative static analysis is not sufficient and a more dynamic analysis may be necessary.

Figure 2: Comparative-static interpretation of results



Source: Horridge (2003).

- *Dynamic analyses*: in dynamic analysis, a CGE model can be run in four different 'modes': *historical*, *decomposition, forecast,* and *policy* (or deviation) modes.

    - *Historical* mode: in this mode a CGE model is run to retrace the history of the economy over a specific period of time in the past to derive information about certain key variables which are normally assumed to be exogenous in a comparative static analysis: changes in technology, consumer preferences, positions of foreign demand curves for domestic products and numerous other naturally exogenous trade variables. To set up the CGE for this type of run, first, certain variables which are often assumed to be endogenous in a CGE model for a comparative static run are now assumed to be exogenous: investment, domestic output, export, imports, etc. Next, using published information about these variables (also called 'observables') for the historical period involved, the variables can then be shocked by their actual past values. Now the variables which are normally

[8] This assumption is necessary because in fact, for comparative analysis, the model contains no time variable and the analysis is actually 'timeless', i.e. there is no time path involved but the only information available are about the positions *A*, *B*, and *C*.
[9] Critics of the CGE model have always pointed out this fact, but this criticism only refers to the fact that without a time path, the costs of adjustment to the new equilibrium cannot be estimated. Here, however, Dixon and Rimmer (1998) refers to, not just the adjustment costs (which depends on the 'path' from *A* to *B*), but also the distance *BC* itself.

assumed to be exogenous in a comparative static run (technology, tastes, etc.) can now be set as endogenous, in exchange for the above 'observable' variables which are now defined as exogenous. Hence, the results of the historical run can be used to estimate the historical values of these technological and taste change variables for the historical period involved. In addition to these technological and taste change variables (often referred to as 'shift' variables in a traditional CGE model because they refer to the changes in demand which involve only a 'shift' in the curve - i.e. keeping the relative ratios of the various component demands unchanged), other new and important variables can also be defined and estimated using the historical run. For example, in an analogous manner to the 'shift' variables, some 'twist' variables can also be defined which refer not to the shift in the absolute levels of demand, but to the *relative* changes in demand *ratios* (imports to domestic, capital to labour, motor vehicle relative to all other goods, etc.).[10]

- *Decomposition* mode: given the important results obtained from the historical run, the model can now be rerun in a 'decomposition' mode. Here, for example, the 'endogenous' (historically estimated) variables representing technology and taste changes (both 'shift' and 'twist' variables) can be reset as 'exogenous'. However, with their values having been estimated from the historical run, these values can be used as shocks in a decomposition run. This enables us to estimate the results for other variables in the case 'with' and the case 'without' technological change, and hence isolate or decompose the results into pure technological change effects, and the effect due to other variables. Similar exercises can be repeated for other variables which are assumed to be exogenous in a decomposition run, but allowed to be endogenously estimated in a historical run. In this way, the combined historical and decomposition runs will enable a complete decomposition of many historical changes into various components (technological change component, export shift component, employment change component, etc.).

- *Forecasting* mode: Forecasting mode is similar to historical mode, except that instead of 'exogenizing everything that we know about the past', here in a forecasting mode, we 'exogenize everything that we think we know about the future' (Dixon and Rimmer, 1998, p. 7). Opinions from experts about future technological developments, tastes changes, growth of the economies, changes in the natural environment and resources, etc., can be incorporated as 'exogenous shocks' in a forecasting run. It is quite naturally expected, however, that what we think we know about the future is much less than what we know about the past, hence in most cases, past information is used in combination with expert opinions about the future to provide some 'guesswork' about the future (e.g. on technological developments) for the exogenous variables.

- *Policy* mode: As forecasting mode is similar to historical mode, policy mode is similar to the decomposition mode. If historical simulation provides information on certain exogenous variables for the decomposition mode (such as changes in technologies and tastes), then similarly, forecasting mode provides information on certain exogenous variables for the policy mode - except of course for those exogenous variables which are now controlled or determined by the policy itself. While historical and decomposition simulations should provide the same results for all variables (except for the switch in exogenous/endogenous definitions) - this is because they are both defined by the known past - results for a forecast (of a base case scenario) are quite naturally not the same as the results for a policy scenario, due to differences in the values of the policy variables in the two scenarios.

[10] See Dixon and Rimmer (1998). Traditional neoclassical analysis assumes that changes in the *ratio of* demands can only come from changes in the relative (i.e. *ratio of*) prices. Here, the twist variables allow for this relative demand change *even if* the relative prices remain unchanged.

4.3 Uses and pitfalls of CGE models

As Dixon (2006) pointed out, the 1960s witnessed "the development of large-scale, economy-wide econometric models (e.g. the Wharton, DRI, MPS, St Louis, Michigan and Brookings models)" and interests in CGE models were given a boost only after the 1973 oil price shock. This event was an important turning point for CGE modelling because up to that point, applied economists were attracted mostly to the underlying philosophy of econometric modelling of "letting the data speak" and hence CGE models, being based on optimisation theories and input-output data rather than time-series, were not a contender in this respect. With the oil price shock, however, the situation changed, since time-series data do not have much to "speak" about significant oil price changes of such magnitude as the oil price shock. Therefore, economists turned their attention to CGE models because at least with a reliance on optimisation theories rather than merely historical data, the models can provide some foundation on which the future can plausibly be assessed. During the 1990s, the problem of climate change and trade added yet another challenge for econometric modelling because historical experience with respect to these problems were limited or non-existent, hence, to predict the future, reliance on theories must take an equally important role as data. CGE modelling became a popular tool because of its reliance on theories and of its flexible ability to incorporate many different kinds of theories into the model (for example, theories about induced technical change and technology diffusion).

In summary, as Mattoo (2009, p. 3) pointed out: "An econometric approach seems handicapped by the absence of past events and our inability to construct experiments that are comparable with the policy changes of greatest interest". A CGE model can help to bridge these gaps with its reliance on theoretical insights and 'expert' opinions to look into the future rather than just reliance on historical data to look at the past. A CGE model also has the flexibility of design to allow various theories and types of policy experiments to be simulated. These are the strengths of the CGE modelling approach and which explains for its popularity.

On the weaknesses side, because of its complexity, a CGE model is often considered to be a 'black box' and this can lead to some misuses. McDougall (1993) considered the following examples where CGE models can be misused:

- *Misinterpretation of results:* The structure of a CGE model is often rich in inter-connections between different markets and different effects; therefore, these effects can be mixed up or confused. A CGE model which is used to study the effects of trade liberalisation on the economy can contain rich details on both domestic labour market and international trade. A close connection between these two areas means that if trade liberalisation impacts on the levels of real wages and employment, the main welfare gains from such a policy may actually come from labour market deregulation rather than from the theories of comparative advantage and the 'gains from trade'.

- '*Confabulation*'*:* Related to the case of misinterpretation of the results is the case of so-called 'confabulation', meaning confused interpretation of the results of a CGE model to such an extent that the interpretation may give some explanations which makes sense from a theoretical viewpoint but which has nothing to do with the actual structure of the model. An example is the case of a study looking at the effect of growth in East Asian countries on the Australian economy. The study claimed adverse welfare effects on the Australian economy due to the outflow of foreign capital from Australia, but the actual structure of the model contained no government taxes on foreign-owned capital and therefore the welfare effects could not have come from the effects of foreign capital outflow.

Other weaknesses of a CGE modelling approach includes:

- *Absence of money or financial assets in most CGE models*: it is not easy to incorporate money and financial assets into a CGE model, therefore, most CGE are used only for study of the 'real' economy where, only relative prices matter. Most CGE models therefore, cannot be used for the analysis of monetary or financial policies.

- *Consistent and up-to-date data for CGE modeling is not easily constructed or readily available*: All CGE models require a data set which must be constructed consistently from input-output tables, social accounting matrices (SAMs), trade tables, and, in the case of a global economy-energy-environment CGE models, also data on energy and environmental variables such as GHG emissions which must be linked to the economic data. The availability of such a consistent data set requires considerable efforts which go beyond the resources of any single individual CGE modeler, and therefore, the existence of a consortium to compile such a database as GTAP (Narayanan and Walmsley (2008)) is quite unprecedented and unique.

5. Examples of CGE Models Used for the Study of Trade and Climate Change Linkages

In this section we look at the structures of some publicly available CGE models which have been used for the analysis of trade and climate change linkages.[11] The objective is to give some insights into the workings of a CGE model, how it is constructed, what type of database it requires, and how the model can be used for the analysis of trade and climate change issues. Emphasis is on the hands-on techniques for the practical implementation of a CGE approach rather than discussing the theoretical issues - which have already been covered in sections 2-4, hence we concentrate on just one type of CGE models, namely those related to 'GTAP-family' of models. Even here, limited space allows us only a brief overview of the main points rather than all the necessary details which are required by a CGE specialist. For the latter, the readers are referred to practical training courses for these models,

5.1 *ORANI-G model*

ORANI (Dixon *et al.*, 1982) was a CGE model of Australia built during the late 1970s for the analysis of trade issues in Australia. The model has been extended in several ways and the current version, ORANI-G, has been used as a 'template' for the creation of many other CGE models: for South Africa, Vietnam, Indonesia, Republic of Korea, Thailand, the Philippines, Pakistan, Denmark, China, Fiji and Taiwan, Province of China. Apart from being among the very first CGE models built to look at trade issues (tariff reform) for a national economy (Australia), ORANI was pioneering in the development of techniques for data, theory, and software construction for use in the building of a CGE model. These techniques were later used in the construction of other (global) CGE models such as GTAP. This section briefly describes the techniques of the ORANI-type model.

5.1.1 *Data base*

The data base for ORANI-G is shown in Figure 3. The basic information used for the construction of this database are firstly, input-output data on flows of intermediate goods $c = \{1,...,C\}$ from sources $s = \{\text{dom, imp}\}$ to industries $i = \{1,...,I\}$ used in *current* production (i.e. production in current period) (matrix V1BAS); margins services (whole sale and retail trade, transport) associated with these flows (matrix V1MAR):; commodity taxes on these intermediate goods (matrix V1TAX) including import duty on imported goods (matrix V0TAX); primary factors (labour, capital, land) used in current production (V1LAB, V1CAP, V1LND); production tax or subsidy (matrix V1PTX);

[11] Although all CGE models have similar theoretical approaches, their practical implementation in terms of computer software and mathematical techniques used in solving the equations of the model can be different. To enable us to look more closely at the practical implementation of CGE models rather than just theoretical issues - which have already been covered in sections 2-4, we concentrate on just one type of CGE models, namely those related to 'GTAP-family' of models. Even here, the emphasis is on a brief overview rather than details which are necessary for a CGE specialist. For the latter, the readers are referred to practical training courses for these models.

'other costs ticket' which stands for miscellaneous items such as municipal taxes or charges (V1OCT). IF we sum up the columns of these matrices, we get the values of production in these industries. These values defined the 'basic price' of commodities produced in these industries. To allow for multiple-product industries (mainly in agricultural sector), we define a 'MAKE" matrix which shows which commodity is produced by which industry. Next, in addition to usage (as intermediate gods) in current production, each commodity can also have other uses: as investment goods for next period production (V2BAS), as final goods used for household and government consumption (V3BAS, V4BAS), as export goods (V5BAS) and as addition t inventory stock (V6BAS). There are margin services (V2MAR, V3MAR, V4MAR, V5MAR) and commodity taxes (V2TAX, V3TAX, V4TAX, V5TAX) associated with all these uses (except inventory), but there are no primary factor inputs in these final consumption activities.

Figure 3: ORANI Model – data base

		Domestic Industries (Current production)	Absorption or Final Demands				
			Investment	Household Consumption	Government Consumption	Exports	Change in Inventories
Basic flows of Domestic commodities Basic flows of Imported commodities		V1BAS $C \times S \times I$	V2BAS $C \times S \times I$	V3BAS $C \times S \times 1$	V4BAS $C \times S \times 1$	V5BAS $C \times S \times 1$	V6BAS $C \times S \times 1$
Margin type *m* on	domestic flows imports flows	V1MAR $M \times C \times S \times I$	V2MAR $M \times C \times S \times I$	V3MAR $M \times C \times S \times 1$	V4MAR $M \times C \times S \times 1$	V5MAR $M \times C \times S \times 1$	
Taxes on	domestic flows imports flows	V1TAX $C \times S \times I$	V2TAX $C \times S \times 1$	V3TAX $C \times S \times 1$	V4TAX $C \times S \times 1$	V5TAX $C \times S \times 1$	
Primary Factors	Labour	V1LAB $O \times I$					
	Capital	V1CAP $1 \times I$					
	Land	V1LND $1 \times I$					
Production tax		V1PTX $1 \times I$					
Other costs		V1OCT $1 \times I$					
Domestic commodities		MAKE $C \times I$	V0TAR $C \times 1$				

C commodities

S sources (domestic, imported)

I industries

M margins

O occupations

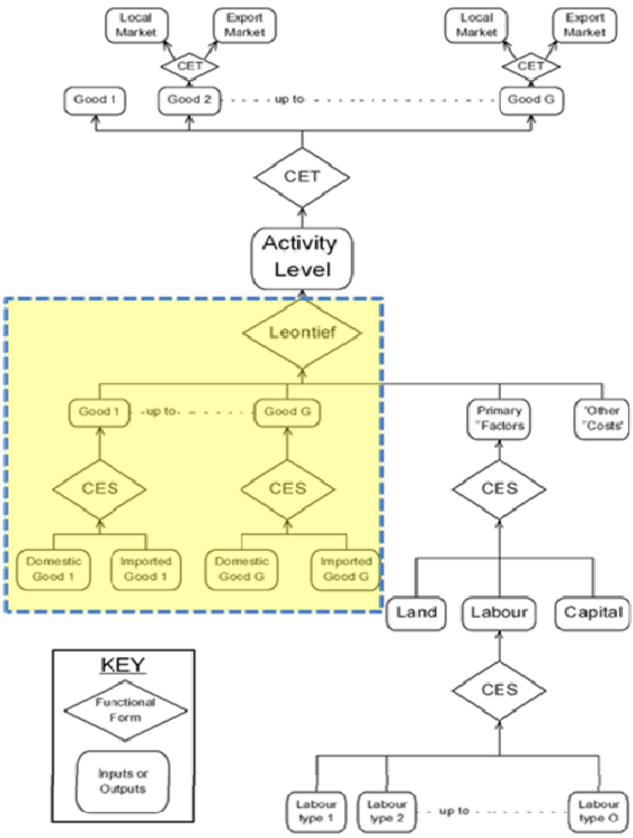
Source: Horridge (2003).

5.1.2 *Theoretical structure*

The theoretical structure for ORANI-G is shown in Figures 4-8. First, Figures 4-6 highlights the structure associated with *current* production. The structure of the demand for intermediate goods (V1BAS) is highlighted in Figure 4. Here, each intermediate good is seen to be a 'composite' of goods produced domestically and imported goods. The composition is represented by a CES (Constant Elasticity of Substitution) production function which allows for domestic and imported goods to be treated as though imperfectly substitutable goods (the Armington approach, see Armington (1969, 1970)). Figure 5 highlights the structure associated with the use of primary factors (V1LAB, V1CAP, V1LND). Here, aggregate "Labour" is assumed to be a composite of different types of labours in different occupations which are combined via a CES function. Aggregate labour is then combined with capital and land via a CES function to produce the aggregate 'primary factors' input. This is then combined with composite intermediate inputs and other costs via a Leontief production function (i.e. no substitution) to produce the final output for each industry. To allow for multiple-product industries, the 'output' of these industries are represented in terms of an 'activity level', which is then 'transformed' into outputs of different commodities via a constant elasticity of transformation (CET) production function. The theoretical structure associated with investment and household consumption activities are shown in Figures 7-8. Investment activity is seen to be simply a Leontief function of various commodity inputs, while household final consumption activity is assumed to follow a Klein-Rubin utility function (linear expenditure system of demand). Export demand is defined by a downward-sloping demand function with a constant elasticity of demand for each commodity, and the demand for inventory is assumed to be proportion to the level of output (with changes to be represented by exogenous shocks).

Figure 4: ORANI Model – Theoretical structure associated with the use of intermediate goods in current production

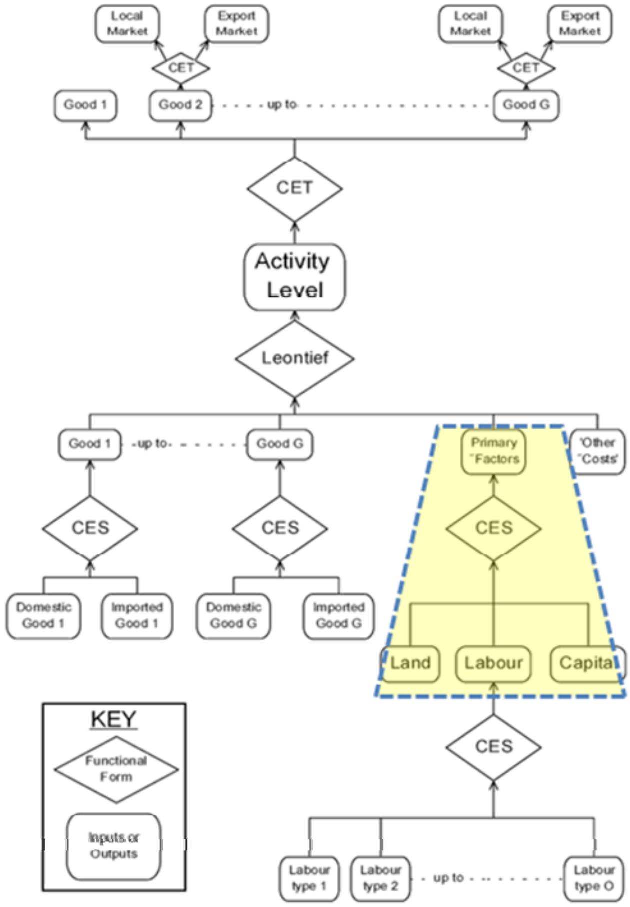
		Domestic Industries (Current production)
Basic flows of Domestic commodities		V1BAS $C \times S \times I$
Basic flows of Imported commodities		
Margin type *m* on	domestic flows	V1MAR $M \times C \times S \times I$
	imports flows	
Taxes on	domestic flows	V1TAX $C \times S \times I$
	imports flows	
Primary Factors	Labour	V1LAB $O \times I$
	Capital	V1CAP $1 \times I$
	Land	V1LND $1 \times I$
Production tax		V1PTX $1 \times I$
Other costs		V1OCT $1 \times I$
Domestic commodities		MAKE $C \times I$



Source: Horridge (2003).

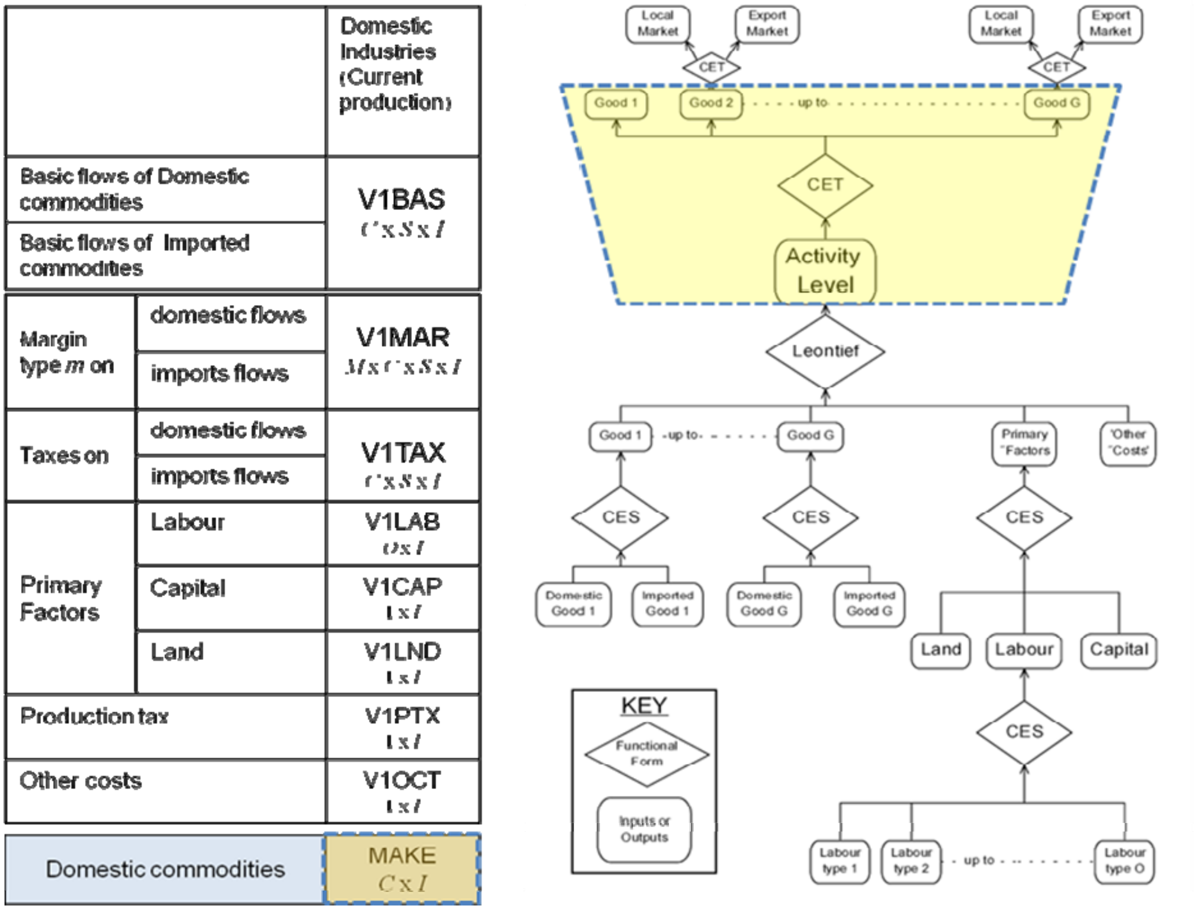
Figure 5: ORANI Model – Theoretical structure associated with the use of primary factors in current production

		Domestic Industries (Current production)
Basic flows of Domestic commodities		V1BAS $C \times S \times I$
Basic flows of Imported commodities		
Margin type m on	domestic flows	V1MAR $M \times C \times S \times I$
	imports flows	
Taxes on	domestic flows	V1TAX $C \times S \times I$
	imports flows	
Primary Factors	Labour	V1LAB $O \times I$
	Capital	V1CAP $1 \times I$
	Land	V1LND $1 \times I$
Production tax		V1PTX $1 \times I$
Other costs		V1OCT $1 \times I$
Domestic commodities		MAKE $C \times I$



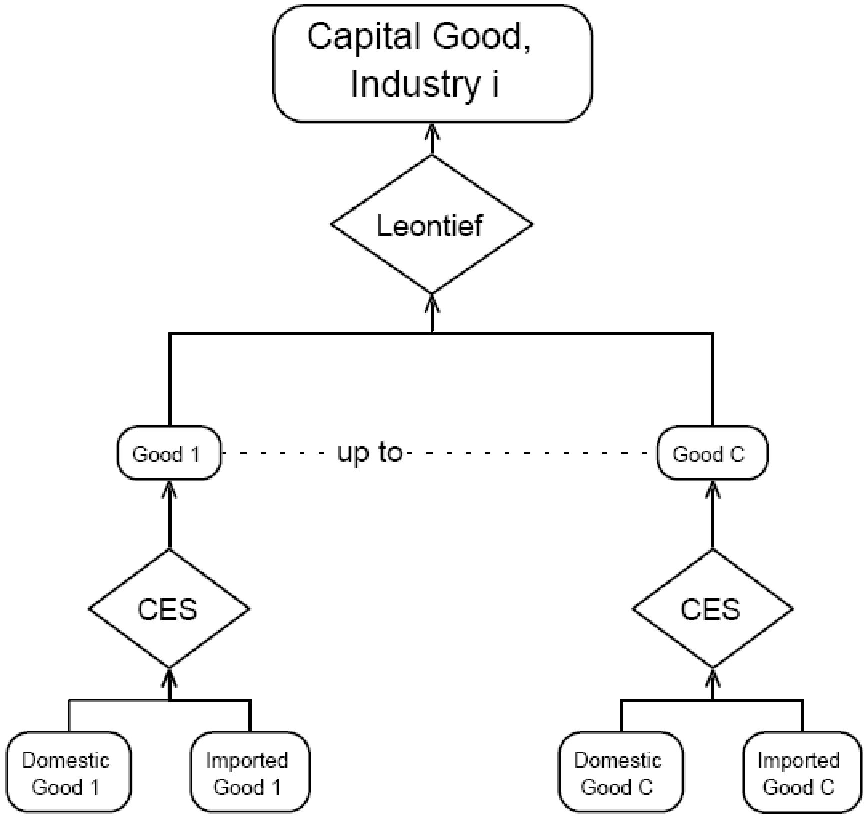
Source: Horridge (2003).

Figure 6: ORANI Model – Theoretical structure for the make matrix



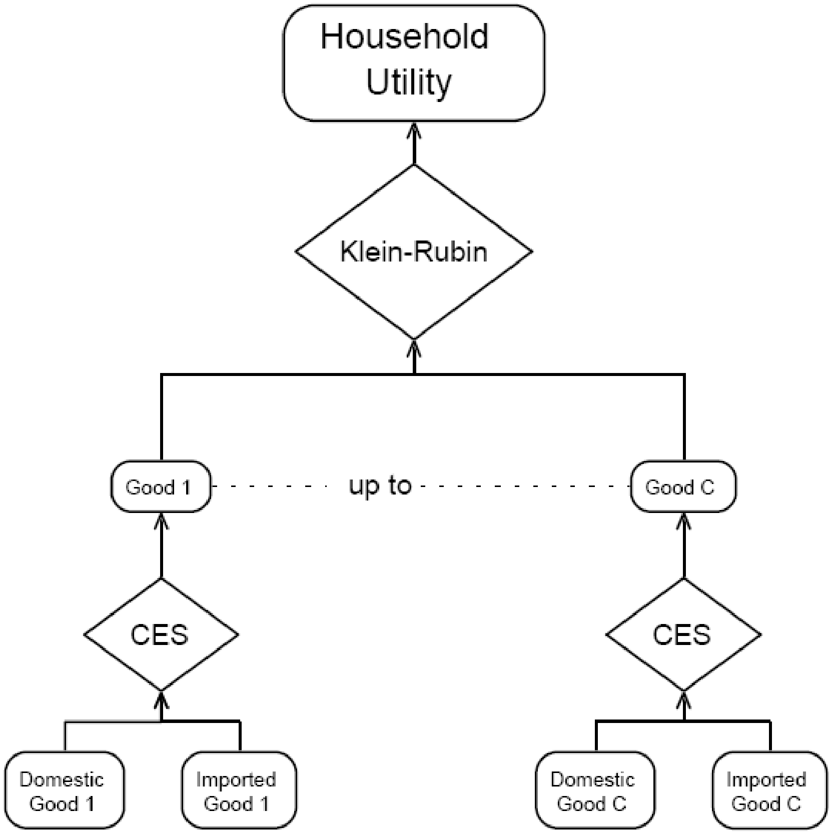
Source: Horridge (2003).

Figure 7: ORANI Model – Theoretical structure of investment activity



Source: Horridge (2003).

Figure 8: ORANI Model – Theoretical structure of household consumption activity



Source: Horridge (2003).

5.1.3 Details on the basic building block

As can be seen from Figures 4-8, the structure of a CGE model such as ORANI-G can be said to consist of many different 'branches' joined together to form a 'tree' structure which describes either production, consumption, or other activities. The basic 'building block' in this tree structure is either a CES function (or its variants such as Leontief function -when substitution elasticity is zero, or CET - when substitution elasticity is negative i.e. transformation elasticity is positive) or other functional forms such as Klein-Rubin, CDE (constant distance of elasticities).[12] The consumer or producer in a CGE model is assumed to optimize (maximize utility or profit, minimize cost) with respect to this function subject to a (budget, production, or cost) constraint to derive the demand functions (for final consumption goods), or producer's demand function (for inputs into production). To get familiar with the structure of most CGE models, therefore, it is important to get familiar with this basic 'building block'. Appendix 2 gives a brief description of how to derive demand functions from a CES (production, cost, or utility) function, in level form, or in percentage change form. Here it can be summarized that, if given a basic activity structure such as given in Figure 9, and assuming that the level of Y (production output, utility level) is related to the levels of X_1 and X_2 (production inputs, or consumption levels) according to a CES function with substitution elasticity δ, i.e.:

$$Y = \alpha\{\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}\}^{-1/\rho} \qquad (1)$$

where $\rho = (1-\sigma)/\sigma$; α is the scale parameter; δ_1, δ_2 are distribution parameters; then, maximize Y with respect to δ_1, δ_2 and subject to a (cost, budget) constraint:

$$M \geq P_1 X_1 + P_2 X_2 \qquad (2)$$

where P_1, P_2 are the prices of X_1, X_2 respectively, and M is the production cost or consumer budget level, then the optimal levels of demand for X_1, X_2 are given by:

$$X_i = Y\delta_i^{\sigma}\{P_i / P_{ave}\}^{-\sigma} \quad ; \quad i = 1, 2. \qquad (3)$$

where

$$P_{ave} = \{\delta_1^{\sigma} P_1^{\sigma\rho} + \delta_2^{\sigma} P_2^{\sigma\rho}\}^{1/\sigma\rho} \qquad (4)$$

Equations (1) - (3) are all in level form. If we now convert all variables into percentage change form, and using lower case to denote percentage change, we have:

$$x_i = y - \sigma\{p_i - p_{ave}\} \quad ; \quad i = 1, 2. \qquad (5)$$

$$p_{ave} = \{S_1 p_1 + S_2 p_2\} \qquad (6)$$

$$y = S_1 x_1 + S_2 x_2 \qquad (7)$$

5.1.4 *Calibration*

A CES function such as given in equation (1) has 4 parameters: □ □1, □□ and □ (or □). The scale parameter can be eliminated by defining the variables relative to the initial (base year) values, i.e.:

$$Y / Y^0 = \{\delta_1 (X_1 / X_1^0)^{-\rho} + \delta_2 (X_2 / X_2^0)^{-\rho}\}^{-1/\rho} \qquad (8)$$

[12] Hanoch (1975). CDE function is used in other models, such as GTAP (see section 5.2 below).

where the superscript '0' denotes initial value. The distribution parameters can be shown to be related to the value share of the inputs (see Appendix 2), i.e.:

$$\delta_i = P_i X_i / \{P_1 X_1 + P_2 X_2\} \quad ; \quad i = 1, 2. \tag{9}$$

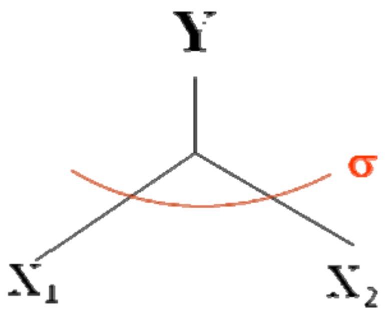
There remains only one parameter, □ (or □) to be determined, and this parameter is normally assumed to be given exogenously (i.e. determined independently of the CGE model).

5.1.5 *Closure*

Typically a CGE model has more variables than independent equations. Equations are derived from theories of consumer and producer behaviour, accounting identities, and various other constraints such as zero profit conditions, market clearing, etc. Each equation can be used to estimate the value of one (endogenous) variable. The total number of endogenous variables thus equal the number of equations, and the rest of the variables must be regarded as exogenous, i.e. determined outside of the model. The split between endogenous and exogenous variables for a particular simulation is referred to as a 'closure'. The choice of closure depends on the specific objective of a simulation. For example, in simulations which seek to estimate the impact of trade or climate change policies on the economy in the short run, capital stock and real wages are often assumed to be exogenous while the rates of return on capital and employment level are endogenous. In contrast, in long run simulations, capital stock and real wages are to be determined endogenously while rates of return to capital and employment levels are given exogenously. In some simulations, the trade balance is allowed to change and hence specified as endogenous, while in others, it is constrained to some exogenous value and hence will be specified as exogenous. If trade balance is exogenous, some other variable (such as government spending, or tax rate) must be 'swapped' with trade balance, i.e. specified as endogenous, and conversely. In Section 4.2, we have discussed the use of CGE model for comparative static analysis as well as for historical, decomposition, forecasting and (dynamic) policy analysis. To enable this flexibility in the use of a CGE model for various purposes, the choice of closure must also be flexible. This flexibility in the choice of a closure to fit in with different policy experiment is one of the advantages of a CGE modeling approach. On the other hand, because of this flexibility in the specification of a closure, it may require some skills and experience in CGE modeling before a user of a CGE model can independently design an appropriate closure to fit in with a particular experiment using a large CGE model. Without this skill, the user may run into difficulties such as non-convergence of a solution (due to numerical errors which arise from an inappropriate choice of closure), or - even when a solution is obtained - the solution may not make much sense from a theoretical viewpoint due to a poor choice of closure.

To illustrate the issue of closure, we can use the simple economic system of equations (5)-(7) even if this represents only the basic building block of a CGE model rather than any substantial part of an actual CGE model. Here, we notice that the system consists of six variables (x_1, x_2, p_1, p_2, y, p_{ave}) and four independent equations. This means to 'close' the system, two variables must be treated as exogenous. There are, however, 30 different combinations of endogenous/exogenous variables for this simple system that highlights the difficult task of choosing an appropriate closure to ensure the system has a solution and a meaningful one. As a first choice, we can select the input prices (p_1, p_2) to be exogenous and let the system to solve for (x_1, x_2, y, p_{ave}). This closure resembles the traditional assumptions in partial analysis of production or consumption activities where input prices are assumed to be given exogenously and input quantities are then determined by relative input prices. Output quantity then follows from input quantities via the production or utility function, and output price is determined by input prices (assuming zero profit condition). Next, we can also assume (x_1, x_2) to be exogenous (for example, when they are determined by a lower 'nest' where (x_1, x_2) are linked to other variables). In this case, (p_1, p_2, y, p_{ave}) can be endogenous. Finally, we can also assume (y, p_{ave}) as exogenous (e.g. determined by an upper nest), then (x_1, x_2, p_1, p_2) in this case will be endogenously. The choice between these closures depends on a particular policy experiment that we are conducting. For example, if x_1 is energy usage and x_2 is the aggregate primary factor input (such as labour) and y is output activity of a particular sector (such as electricity generation), then to simulate an experiment where carbon tax is to be imposed on x_1 to ensure some target GHG emissions (from the use of x_1) is met, and also to achieve the policy objective of keeping the level of employment unchanged in this sector, then we can set x_1 and x_2 to be exogenous (x_1 determines the level of GHG emissions and x_2 determines the level of employment) while letting (p_1, p_2, y, p_{ave}) to be determined endogenously. A solution for p_1 will determine the level of carbon tax, p_2 gives the nominal wage of labour, y is the level of electricity output, and p_{ave} is the price of electricity. The impact of this particular policy therefore may be a change in the level of nominal wage to keep employment constant, while letting the price of electricity to increase and perhaps also the output to be reduced.

Figure 9: Basic building block in a CGE model - CES function



5.2 GTAP model for the analysis of global trade issues

GTAP (Hertel, 1997) is a global trade CGE model developed at the Center for Global Trade Analysis in the Department of Agricultural Economics at Purdue university. The model has been widely used for the analysis of global trade issues and also for the study of the linkages between trade policies and climate change.

5.2.1 Data base of the GTAP model

The data base for the GTAP model is similar to that of ORANI-G except the it has an extra dimension to denote 'region' since this is a multi-regional rather than national data base (see Figure 10). In addition, GTAP data base also contains information on international trade and transport margins. In some other respects, GTAP has fewer details than ORANI-G. For example, in the standard GTAP data base and model, there is no information on domestic margin[13], all industries in GTAP are single-product industries, labour is split into skilled and unskilled rather than into occupations, and generally there are fewer tax details in GTAP than in ORANI-G.

5.2.2 Theoretical structure of the GTAP model

The production structure in GTAP (see Figure 11) is similar to that in ORANI-G, except that in GTAP, an imported good can be sourced from many different regions, reflecting the multi-regional character of the GTAP model. The consumption structure in GTAP, however, is different from that of ORANI-G: GTAP uses a CDE (constant difference of elasticity) consumption function whereas ORANI-G uses a Linear Expenditure System (LES) of demand based on the Klein-Rubin utility function. With respect to the investment decision, GTAP has a different structure due to the multi-regional characteristic of the model (see Hertel, 1999, Chapter 2). Firstly, total international investment is balanced by total international savings. The allocation of the total volume of global investment to different regions is decided according to two options: (i) regional and global net

[13] Although a special model called GTAP-M has been built to include domestic margins information into the standard GTAP data base and model (see Petersen (2006))

investments move in the same proportion so as to preserve the initial composition of capital stocks across regions, (ii) net investment to each region is decided on the basis of the regional rates of returns using a 'theory' which is similar to ORANI-G's theory of investment allocation across different *sectors*).

5.2.3 GTAP-E extension for the analysis of global trade-energy-environmental issues

The production structure in GTAP has one limitation which makes it unsuitable for the analysis of energy-environmental issues: it treats energy commodities (coal, oil, gas, refined petroleum products, electricity) on the same basis as other intermediate inputs into production, hence, given the standard GTAP production structure as shown in Figure 11, this implies there is no substitution between energy commodities, nor substitution between energy and other factors of production like capital and labour. This is a rigid assumption because it implies that in all production activities, energy and emission intensities are constant and cannot be changed in response to climate change policies. The only way to reduce total emissions, therefore, is by reducing total production level and/or by substitution between activities. This is clearly an unrealistic assumption which does not give technologies any significant role to play in responding to environmental and climate change policies. As a result of this limitation, to enable the GTAP model to be used for the analysis of energy-environmental and climate change policies, the assumptions on structure of production need to be changed. One of the possible modifications to this structure is suggested in the model GTAP-E (Burniaux and Truong, 2002). This modification is shown in Figure 12.

Figure 10: GTAP Model – data base

		Domestic Industries (Current production)	Final Demands			
			Investment	Household Consumption	Government Consumption	Exports
Domestic commodities		$g \times h \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$
Imported commodities		$g \times h \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$
Taxes on	Domestic commodities	$g \times h \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$
	Imported commodities	$g \times h \times r$	$g \times 1 \times r$	$g \times 1 \times r$	$g \times 1 \times r$	
Labour		$e \times h \times r$				
Capital						
Land						
Taxes on	Labour	$e \times h \times r$				
	Capital					
	Land					
Other costs e.g. production tax		$1 \times h \times r$				

r regions

e endowments; *g* commodities – *h* industries

SINGLE-PRODUCT INDUSTRIES

No domestic margin (but there are international margin on traded goods & services)

Figure 5: GTAP Model – Production structure

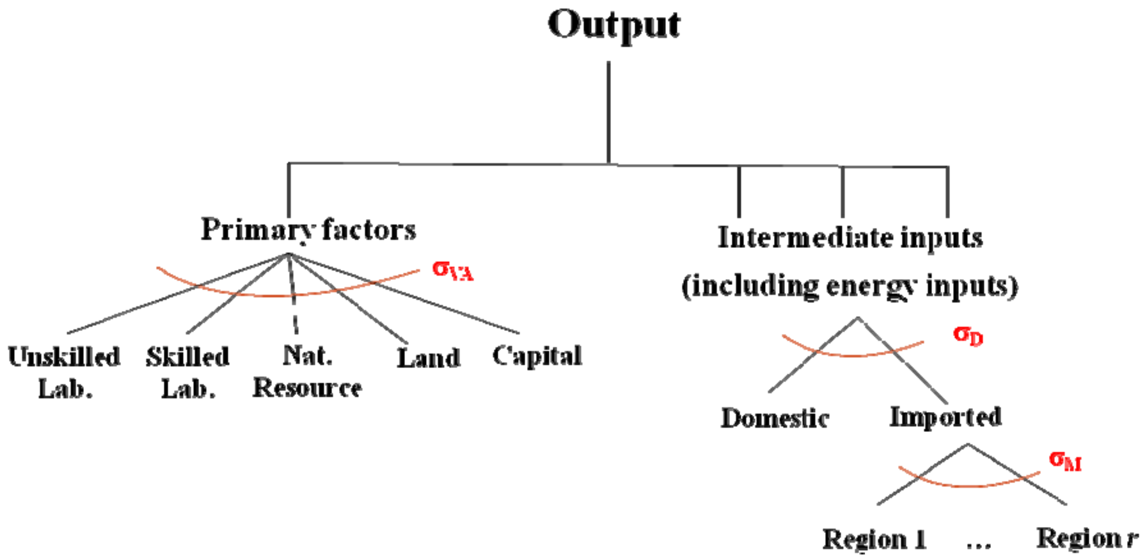
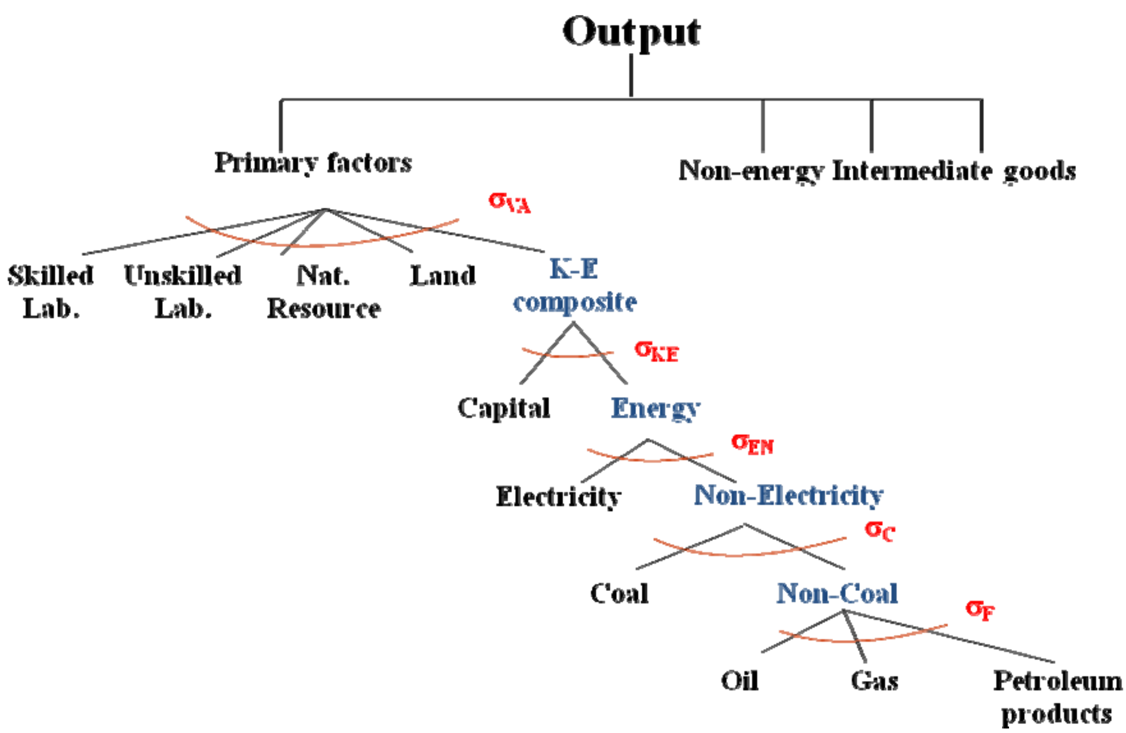


Figure 6: GTAP-E Model – Production structure



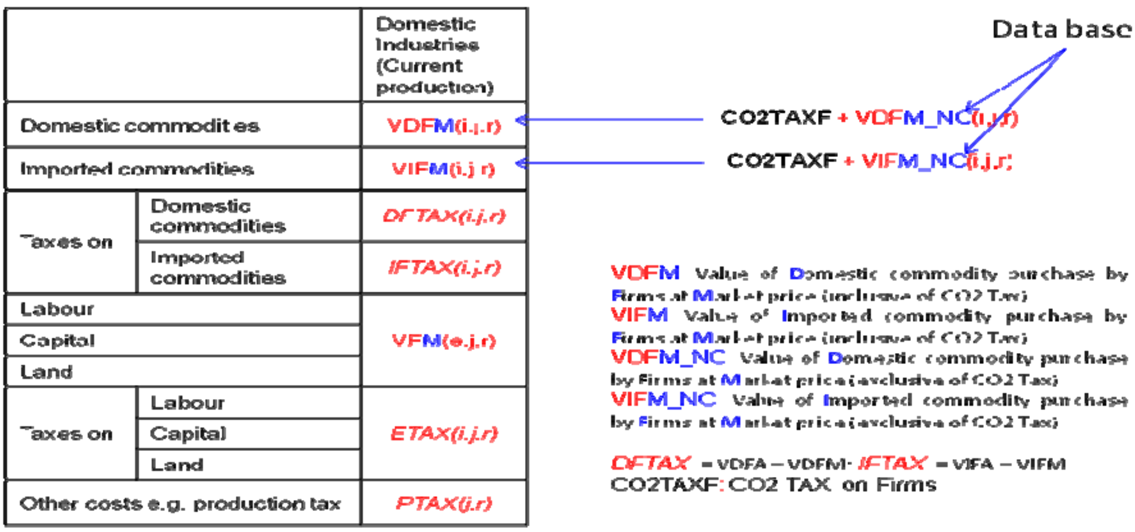
5.3.5 *An example of the use of GTAP-E for the analysis of trade-climate change linkages*

The multi-regional characteristic of the GTAP family of models (i.e. standard GTAP and GTAP-E extension as well as others using the standard GTAP as the starting point) makes these models especially appropriate as analytical tools for use in the analysis of global trade issues. Issues such as the economic and/or environmental impacts of trade liberalization policies on the world economies are easily handled and within these models. With an extension such as GTAP-E where the focus on energy commodities is given enhanced attention, the issues of energy usage, technologies, taxation, as well as issues of Greenhouse Gas (GHG) emissions and taxation from the use of these energy commodities are also given detailed attention. A model such as GTAP-E, therefore, is most suitable for use in the analysis of trade and climate change policy issues and their linkages. In this section, we look at an example where the GTAP-E model has been used to analyse such policy issues.

- *Introducing carbon-tax or Emissions Trading Scheme into the GTAP-E model.*

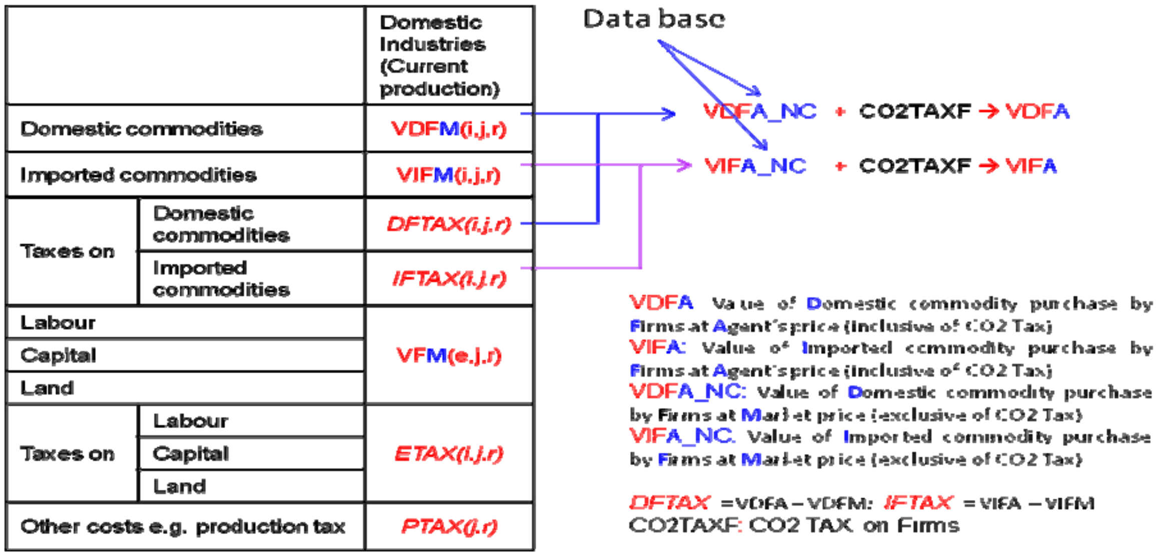
To facilitate the analysis of climate change policies, the concept of a carbon tax and/or emissions trading scheme need to be introduced into the model. If a tax is levied on the use of an energy commodity according to the carbon emissions associated with such use, this is called a carbon tax. A carbon tax imposed on an energy commodity usage will result in the cost of such commodity being increased to account for ('internalise') the environmental costs of such usage. This will result in the use of the commodity being reduced; hence GHG emissions will also be reduced. Conversely, if an emissions trading scheme put a constraint on the GHG emission level (and hence on the use of such energy commodities), this automatically imposes a 'shadow' price on GHG emissions, and this acts as though a carbon tax.[14] In a model such as GTAP-E, a carbon tax can be imposed either as a 'first best' or 'second best' option (see Figures 13a and 13b). In the first best case, the tax is imposed on the energy commodity *before* any other distortionary taxes are imposed, whereas in the second best case, it is imposed on top of pre-existing taxes. The difference between the two cases is that in the later case, a given absolute level of carbon tax will result in a lower tax rate than in the former case.

Figure 7a: GTAP-E Model – CO2 tax – first best



[14] In principle, therefore, emissions trading scheme is equivalent to a carbon tax system (except for differences with respect to the definition of endogenous and exogenous variables, i.e. closure in a CGE model experiment). In most cases and under the condition of perfect certainty, they yield the same results, and only give different results under condition of uncertainty (with respect to the parameters of the production and consumption functions), (see, for example, Low (2009)).

Figure 8b: GTAP-E Model – CO_2 tax – second best



- *A European climate policy study using the GTAP-E model*

In 2005, the EU introduced an emissions trading system (EU-ETS) in order to pursue its Kyoto obligations. Under this scheme, major emitters from the power and manufacturing sectors are first allocated with a given amount of CO_2 emission permits. The permit allows the emitters to emit a certain amount of CO_2 in any particular year, or it can be traded in an emissions trading market. The trading scheme allows firms to undertake the most efficient means to reduce their CO_2 emissions and therefore allows the EU meet its Kyoto obligation with a minimum amount of cost. Under this scheme, at equilibrium, the price of the emissions permit will indicate the minimum marginal cost of CO_2 emissions abatement by the most efficient means. To estimate this minimum marginal abatement cost (MAC) for Germany, Kemfert *et al.* (2006) used a version of the GTAP-E model.

First, an estimate of the likely percentage reduction of CO_2 emissions from a 'Business-as-Usual' or Reference scenario to meet with the quotas under the national allocation plan (NAPs) for various regions and sectors in the EU are made (see Table 1). These emissions reductions are then imposed on the model (emissions) variables as exogenous shocks. The model then gives an estimate of the equilibrium values of the MACs or CO_2 taxes to achieve these emissions reduction targets under various trading scenarios (see Tables 2-4). It can be seen from these tables that if there is no emissions trade (Table 2), the MACs for different sectors and regions will differ substantially, ranging from a low of 0.1 \$/t CO_2 in the 'paper' sector in Denmark (which has to cut down CO_2 emissions by -7.1% relative to the BaU case – see Table 1) to a high of 163.1 \$/t CO_2 in the refined oil sector in Sweden (which has to cut down CO_2 emissions by -13.9% relative to the BaU case). When there is domestic emissions trading between different sectors of a region but not across different regions, the MAC for each region will be uniform, but this will vary across different regions, and they can range from a low of 0.8 \$/t CO_2 for the UK (which has to cut down CO_2 emissions by -5% relative to the BaU case – see Table 1) to a high of 8.4 \$/t CO_2 for Sweden (which has to cut down CO_2 emissions by –6.3% relative to the BaU case). Finally, when there are emissions trading not only between sectors but also across regions (Table 4), the MAC for the EU as a whole is at 2 \$/t CO_2 (with a total emissions reduction of -2.2%).

Table 5 shows the macroeconomic effects of emissions trading such as changes in the GDP level (column 2), trade balance (column 3), and the welfare effects due to CO_2 tax (column 4) and due to terms of trade effects (column 6). As expected, emissions trading will result in improvements in GDP level, but not necessarily for trade balance for some regions (those regions which have higher MACs than other (see Table 3) and thus have to buy emissions permits from other regions, such as

Austria, Belgium, Denmark, Sweden). In general, however, most regions will gain in welfare from emissions trading with only a few exceptions such as Italy and the Netherlands (see the last column of Table 5) where the negative terms of trade effects is part of the reasons.

Table 1: Percentage deviation of emissions from projected Business-as-Usual level for period 2005-2007according to the NAP(*)

Region\ Sectors	Elec tricity	Refined Oils	Metals	Mineral Products	Paper	Motor Equip ment	Constr uction	Textile	Other Indus tries	Total
Austria	-8.9	-7.9	-3.5	-4.3	-3.6	-4.9	-4.6	-5.9		-4.3
Belgium	-27.4	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-8.5
Denmark	-26.2	-7.1	-7.1	-7.1	-7.1	-7.1	-7.1	-7.1	-7.1	-15.1
Finland	-12.5									-6.2
France	-0.4	-2.8	-10.3	-8.1						-1.5
Germany	-3.1	-2.6	-0.5	-0.4	-1	-2.2	-2.2	-2.2	-2.2	-1.8
Greece	-6.5	-16.8			-6.6					-3.4
UK	-8.7	-0.9	-18.4	-5.7	-3.3	-3.3	-2.9	-2.5		-5.0
Italy	-5.5		-4.2	-1.7	-3.4					-2.5
Netherlands	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-3.7
Portugal	-6.2			-1.2						-2.5
Spain	-6.5	-3.6	-2.9	-5.4	-4.5					-3.2
Sweden	-13.9	-13.9	-13.9	-13.9	-13.9	-13.9	-13.9	-13.9	-13.9	-6.3
Czech Rep.	-4.5	-4.3	-4.6	-4.5	-4.1					-3.5
Hungary	-3.1	-5.1	-5.1	-5.1	-5.1					-2.4
Poland	-9.3	-3.8	-10.3	-2	-7.5					-6.4

(*) (Allocated emissions – Projected Emissions)/(Projected Emissions) * 100

Table 2: Marginal Abatement Cost (1995US$/ton of CO2) when there is no emissions trade.

Region\ Sectors	Elec tricity	Refined Oils	Metals	Mineral Products	Paper	Motor Equip ment	Constr uction	Textile	Other Indus tries
Austria	3.8	42.2	1.6	3.0	1.0	2.0	3.2	2.0	
Belgium	11.5	32.3	1.6	4.4	3.2	5.7	6.4	3.5	7.7
Denmark	7.5	50.5	0.2	1.1	0.1	0.0	9.4	0.0	0.1
Finland	8.0								
France	0.5	17.3	4.1	11.6					
Germany	1.6	22.5	0.7	0.5	0.7	1.5	2.4	1.4	1.8
Greece	2.8	137.0			0.7				
UK	2.2	13.3	0.4	0.3	0.0	0.0	0.2	0.0	
Italy	2.8	0.0	2.1	2.6	1.7				
Netherlands	3.8	30.7	1.8	8.7	1.1	0.2	0.0	0.4	13.9
Portugal	2.0			1.6					
Spain	2.3	19.2	1.3	6.8	3.4				
Sweden	5.1	163.1	10.7	16.2	15.0	13.4	26.9	18.7	8.8
Czech Rep.	1.1	53.8	1.3	2.5	1.4				
Hungary	1.0	28.6	1.9	3.9	1.9				
Poland	2.3	45.8	2.9	1.3	2.6				

Table 3: Marginal Abatement Cost (1995US$//ton of CO2) when there is domestic emissions trading only.

Region\ Sectors	Elec tricity	Refined Oils	Metals	Mineral Products	Paper	Motor Equip ment	Constr uction	Textile	Other Indus tries
Austria	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	
Belgium	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Denmark	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Finland	8.0								
France	2.0	2.0	2.0	2.0					
Germany	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Greece	3.5	3.5			3.5				
UK	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	
Italy	2.6		2.6	2.6	2.6				
Netherlands	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Portugal	2.0			2.0					
Spain	2.8	2.8	2.8	2.8	2.8				
Sweden	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Czech Rep.	1.2	1.2	1.2	1.2	1.2				
Hungary	1.3	1.3	1.3	1.3	1.3				
Poland	2.2	2.2	2.2	2.2	2.2				

Table 4: Marginal Abatement Cost (1995US$//ton of CO2) when there are domestic emissions trading as well as regional emissions trading.

Region\ Sectors	Elec tricity	Refined Oils	Metals	Mineral Products	Paper	Motor Equip ment	Constr uction	Textile	Other Indus tries
Austria	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Belgium	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Denmark	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Finland	2.0								
France	2.0	2.0	2.0	2.0					
Germany	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Greece	2.0	2.0			2.0				
UK	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	
Italy	2.0	0.0	2.0	2.0	2.0				
Netherlands	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Portugal	2.0			2.0					
Spain	2.0	2.0	2.0	2.0	2.0				
Sweden	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Czech Rep.	2.0	2.0	2.0	2.0	2.0				
Hungary	2.0	2.0	2.0	2.0	2.0				
Poland	2.0	2.0	2.0	2.0	2.0				

Table 5: Macroeconomic effects of Regional Emission Trading (*)

Region	Real GDP change (%)	Trade Balance due to Emission Trading ($Millions)	Welfare Decomposition: Equivalent Variation (EV) due to various components ($Millions)			
			Allocative effects due to CO2 Tax	Other Allocative effects	Terms of Trade effects	Total(**)
Austria	0.10	-2.4	10.5	181.7	-20.4	171.9
Belgium	0.11	-13.4	43.2	209.5	-127.7	125.2
Denmark	0.12	-11.7	33.8	163.8	-10.0	187.1
Finland	0.04	-5.7	14.2	35.2	-7.7	37.9
France	0.05	0.0	31.9	660.2	-85.3	606.0
Germany	0.06	11.6	39.7	1155.7	118.0	1312.4
Greece	0.33	-2.4	30.6	357.2	-99.5	286.1
UK	0.02	34.6	-7.7	249.4	14.4	259.1
Italy	0.00	-4.1	3.5	-40.8	-13.1	-49.8
Netherlands	0.05	-5.9	21.8	183.5	-377.2	-171.8
Portugal	0.00	0.1	0.6	1.1	9.2	10.2
Spain	0.06	-3.7	9.1	334.6	-68.7	275.9
Sweden	0.13	-4.4	28.3	264.0	-122.2	174.1
Czech Rep.	0.05	8.5	-4.3	31.3	-6.9	19.4
Hungary	0.10	1.5	3.0	49.7	-5.6	47.0
Poland	0.02	-2.7	6.9	30.3	11.9	50.1

(*) The values shown in this Table are *changes* from the case of 'No Emissions Trading' (Table 2) to the case of 'Regional Emission Trading' (Table 4). All values are in 1995US$.
(**) Including a small effect due to changes in the price of capital goods.

6. Conclusions

Climate change is becoming increasingly important as a scientific and economic issue facing the world community in the same way that trade liberalisation and economic growth have always been and continuing to be the most important issues for the world economies. The new challenge is in understanding the close linkages between these two important areas of interests. To face with this new challenge, one needs to build up a body of analytical tools, not only in the scientific area to understand the physical and environmental aspects of climate change, but also in the economic and trade area for the analysis of the linkages between these physical and environmental aspects and their economic impacts. Econometric techniques and computable general equilibrium models are the two most important analytical tools that have often been used in these areas. In this paper, we attempted to explain briefly why this has been the case. One the one hand, there is a need for a *comprehensive* analytical tool to analyse the *complex* relationships between trade and climate change issues. The tool must also be able to produce *quantitative* assessments and predictions based on current knowledge. The theoretical underpinnings of the tool, even though deeply rooted in the economic theories of human behaviour and the economic system, cannot be confined just to these areas but must also be able to accommodate knowledge or assumptions about other physical and environmental systems. In other words, it is more like an analytical and computational 'platform' on which to build up and link the basic pieces of information and knowledge about economic, trade, and climate change issues rather than a single overarching 'theory' about the whole complex interrelationships. This has been the main characteristic of the use of computable general equilibrium (CGE) models (supplemented with the use of partial econometric techniques) to understand the linkages between trade and climate change issues. This has also been the main advantage of this approach. On the other hand, because of the complex and ambitious task, the analytical tool used has often been difficult for a beginning analyst to understand easily and/or the lay person to appreciate the usefulness of the results from such tools. Therefore, the tools have often been labelled as 'black boxes'. This is its main disadvantage, in addition to the fact that there are still many areas of interest that the tool will need to incorporate into its 'platform' in the future, such as realistic theories about the 'pure' financial aspects of the economic and trade systems, about future technological development, etc.

All in all, however, the tools have been more useful than 'misused', and this explains for the popularity of its use in the past. Looking to the future, to increase the usefulness of the tool in the area of policy analysis, there will need to be continuing training for the policy analysts in the modern and expanding techniques of CGE modelling. Such training will include not only the surveying and reading of the literature and understanding the basic theories but also 'hands on' experience on its practical applications. This survey paper therefore is only an important first step towards that ultimate direction.

Appendices

Appendix 1

Linearization – Some Useful Formulae

Let $Z = X.Y$	$W = X + Y$
$dZ = XdY + Y\,dX$	$dW = dX + dY$
$dZ/Z = dY/Y + dX/X$	$dW/W = [(X)/(X+Y)]dX/(X) + [(Y)/(X+Y)]dY/(Y)$
$d\ln Z = d\ln X + d\ln Y$	$d\ln W = S_x d\ln X + S_y\, d\ln Y$

Using lower case to denote ‚'dln' or percentage change:

$z = x + y$	$w = S_x x + S_y y$

Appendix 2

Basic Equations for the CES building block

Maximize the level of Y (production output, utility level) which is of the CES form:

$$Y = \alpha\{\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}\}^{-1/\rho} \tag{A1}$$

subject to a (cost, budget) constraint:

$$M \geq P_1 X_1 + P_2 X_2 \tag{A2}$$

where α is a scale parameter; δ_1, δ_2 are distribution parameters; X_1 and X_2 are production inputs, or consumption levels; P_1, P_2 are the prices of X_1, X_2 respectively, and M is the production cost or consumer budget level. Forming the Lagrangian:

$$L = \alpha\{\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}\}^{-1/\rho} + \lambda[M - P_1 X_1 - P_2 X_2] \tag{A3}$$

The first order conditions for optimality are:

$$\partial L / \partial X_i = \delta_i X_i^{-\rho-1}\alpha\{\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}\}^{-(1/\rho)-1} - \lambda P_i] = 0 \quad ; i = 1,\ 2. \tag{A4}$$

from which we can derive:

$$\lambda P_i = \delta_i X_i^{-(1+\rho)}\alpha\{\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}\}^{-(1+\rho)/\rho} \quad ; i = 1,\ 2. \tag{A5}$$

$$\lambda = Y / M \tag{A6}$$

$$S_i = P_i X_i / M = \delta_i X_i^{-\rho} / [\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}] \quad ; i = 1,\ 2. \tag{A7}$$

$$P_i = \lambda^{-1}\delta_i X_i^{-(1+\rho)}\alpha[Y/\alpha]^{(1+\rho)} \quad ; i = 1,\ 2. \tag{A8}$$

$$X_i = (Y / \alpha)[\alpha\delta_i /(\lambda P_i)]^{1/(1+\rho)} \quad ;i = 1,\ 2. \qquad \text{(A9)}$$

In percentage change terms (using lower case to denote percentage change, i.e. x = dX/X):

$$\begin{aligned} &Y = \alpha\{\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}\}^{-1/\rho} \\ &\Rightarrow d\ln y = -(1/\rho) d\ln[\delta_1 X_1^{-\rho} + \delta_2 X_2^{-\rho}] \\ &= -(1/\rho) S_1 d\ln(\delta_1 X_1^{-\rho}) + S_2 d\ln(\delta_2 X_2^{-\rho}) \\ &= S_1 d\ln(X_1) + S_2 d\ln(X_2) \end{aligned}$$

or:

$$y = S_1 x_i + S_2 x_2 = x_{ave} \qquad \text{(A9)}$$

$$M = \sum_i P_i X_i \Rightarrow m = \sum_i S_i p_i + \sum_i S_i x_i \quad = p_{ave} + x_{ave} \qquad \text{(A10)}$$

$$\lambda = y - m = p_{ave} \qquad \text{(A11)}$$

$$x_i = y - \sigma[p_i - \lambda] = y - \sigma[p_i - p_{ave}] \quad \text{where } \sigma = 1/(1+\rho) \quad ;i = 1,\ 2. \qquad \text{(A12)}$$

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