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Demystifying Modelling Methods for Trade Policy

by ROBERTA PIERMARTINI and ROBERT TEH

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World Trade Organization
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ABSTRACT

In recent years, quantitative analysis of the effects of policies on economic outcomes has grown sharply. These exercises in quantification have been made possible by advances in theory and analytical techniques, and no less importantly, by the dramatically increased computational and data processing power of computers. This paper focuses on two classes of quantitative tools – computable general equilibrium (CGE) models and gravity models. These are perhaps the most commonly encountered quantitative analytical techniques in the area of trade.

The primary purpose of this paper is to offer a non-technical explanation of CGE and gravity models to trade policymakers. We try to capture the essence of the analytical techniques, explaining the requirements of the models and computational procedures. We also seek to identify as clearly as possible the strengths and limitations of these analytical techniques. A second objective of the paper is to survey a range of studies based on CGE, particularly simulations of multilateral trade negotiations, and gravity models. The survey is useful in conveying a sense of how results can vary depending on what goes into the models by way of their structure and data, emphasizing the importance of judicious, critical interpretation.

The main benefit of CGE models is that they offer a rigorous and theoretically consistent framework for analysing trade policy questions. The numbers that come out of the simulations should only be used to give a sense of the order of magnitude that a change in policy can mean for economic welfare or trade. Much more can be done to create confidence in the results. The simulations should benefit from more systematic and informative employment of sensitivity analysis. *Ex-post* validation of CGE models is needed to increase confidence in the numerical results.

Correctly specified gravity models can illuminate questions that are important for trade policymakers. For example, what are the trade effects of WTO membership? How does entering a proposed preferential trade arrangement (PTA) affect a country's trade? How is non-members' trade affected? Does more trade lead to faster growth? Does trade improve the environment? Three important theoretical requirements that need to be taken into account in gravity models are highlighted in this study. First is the importance of relative distance and trade costs. Second is that liberalization, whether multilateral or regional, creates new trading relationships and not just increases the volume of existing trade. Third, trade is dynamic and this shows itself in new products and new firms that enter international commerce.

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I. INTRODUCTION

In recent years, quantitative analysis of the effects of policies on economic outcomes has grown sharply. These exercises in quantification have been made possible by advances in theory and analytical techniques, and no less importantly, by the dramatically increased computational and data processing power of computers. We shall focus on two classes of quantitative tools in this paper – computable general equilibrium (CGE) models and gravity models. These are perhaps the most commonly encountered quantitative analytical techniques in the area of trade. In essence, CGE models are computer-based simulations, like laboratory experiments. They compute how today's economy will look in the future as a consequence of a specified set of policy changes. In the trade field, CGE models are used to gauge the trade and income effects of different liberalization scenarios. They identify the sources of income gains or losses from further opening up to trade and show how these are distributed among countries or regions. The simulation results can then be taken into account by policy-makers as they consider their options. Multiple simulations can be undertaken, for example, to work out alternative policy changes that might turn a national income or welfare loss into a gain. In a multilateral negotiation scenario, the simulated outcome is the consequence of policy changes by multiple players. This means that from the point of view of an individual country, the size of a welfare gain or loss in a simulation will be affected by its own policy changes as well as those of others. Because of this multiplicity of linkages, an assessment of these reforms cannot be based solely on a model in the analyst's head or a simple diagram. Computer-based models allow us to track all of these interactions.

A perhaps neglected but very useful feature of CGE models is that they discipline thinking about how economies actually work, and that is a vital prerequisite for sound policy-making. The "general equilibrium" character of CGEs reflects the interdependency of economic variables – the notion that every change affects a range of other elements in an economy. It would be poor policy-making, for example, to assume that an export tax on a raw material is necessarily a good thing for the economy as a whole because it encourages industrialization by lowering the domestic price of the raw material that is an input into manufacturing. A CGE simulation will also show that, among other things, the reduced domestic price will lower the incomes of producers of the raw material (perhaps a low-income segment of society) and probably reduce supply as well. These ripple effects of policy changes need to be taken into account when governments consider their options. The utility of a CGE construct in understanding complex and sometimes unexpected interactions in an economy should not be underestimated.

Criticisms have been made of CGEs when they have been deployed to assert a degree of precision in simulations of the future that cannot be warranted by the quality of information that goes into the model nor the degree of sensitivity of the results to assumptions. Many factors are involved here. Computable general equilibrium models are typically aggregated to a degree that can obscure important underlying relationships. Data are not always of high quality. Data may be missing. Estimates of the responsiveness of supply and demand to price changes are not necessarily accurate. Choices among scenarios and model specifications can imply very different results. Static simulations are likely to miss crucial parts of the story and dynamic simulations are more complex and assumption-driven than static ones. Careful modellers can go some way in addressing these shortcomings. They can use "sensitivity analysis" to consider the impact of alternative assumptions. They can make their data and models available so that they can be scrutinized and validated or rejected by others. And they can also learn from *ex-post* validation of past simulations. As importantly, they can warn policy-makers about the degree of precision that can be accorded to the estimates.

Most modellers are, of course, well aware of the kinds of problems referred to above, but the same may not be true of their intended audience. Models are typically very complex and the details of technique are not readily accessible to non-specialists. It is incumbent upon the modellers to make clear the strengths and limitations of their work in order to avoid misunderstandings as to what the models are actually telling us. A failure to do this risks bringing a useful analytical tool into disrepute and may even induce unwarranted cynicism about the economic case for open trade.

Some of the richest uses of CGE modelling have been those where policy issues have been studied both qualitatively and quantitatively and where alternative quantitative techniques have been used alongside the CGE models. A growing trend in this direction is certainly to be welcomed.

Turning briefly to the other modelling approach discussed in this paper – gravity models – much the same can be said as for CGEs about the need for caution in presenting and interpreting results in light of the limitations on precision intrinsic to such exercises. The gravity model seeks to explain the pattern of bilateral trade among nations and its evolution over time in terms of certain fundamental variables. A major attraction of the gravity model is that estimates of the equations that depict the hypothesized relationships perform very well statistically. Gravity models explain and measure the effect on trade flows of a policy that has already been implemented. Unlike CGE models, they are not used to predict the impact of introducing a new policy. They can be used as a policy guide only to the extent that past policy impact may serve to understand the implications of a change in future policy.

The primary purpose of this paper is to offer a non-technical explanation of CGE and gravity models. We try to capture the essence of the analytical techniques, explaining the requirements of the models and computational procedures. We also seek to identify as clearly as possible the strengths and limitations of these analytical techniques. A second objective of the paper is to survey a range of studies based on CGE and gravity models. The survey is useful in conveying a sense of how results can vary depending on what goes into the models by way of their structure and data, emphasizing the importance of judicious, critical interpretation.

For the reader interested in knowing what CGE models are, Section II provides a short introduction. Section III is recommended for the reader who wishes to understand how a CGE model of trade is put together and what to make of simulation results. Those whose interest is in the results of simulations of multilateral trade negotiations will find Section IV quite useful. The reader interested in gravity models is requested to turn to Section V, for detailed discussions of how gravity models have been applied to study the impact of preferential trade arrangements and WTO membership on bilateral trade flows. We are aware that non-specialists may find some of the exposition dense and perhaps difficult to understand. For this, we apologize in advance, but urge the interested reader to persevere in following our effort at demystification.

II. MODELLING APPROACHES TO THE ANALYSIS OF TRADE POLICY

A. Why do policy-makers need models?

Why do policy-makers need to concern themselves with trade models? The basic answer is that the use of models should help improve policy-making. Hertel (1997) emphasized the value of a CGE framework to policy formulation and the flexibility that it provides policy-makers "to apply their own insights into particular problems within a consistent economy-wide framework." Writing about two decades earlier, Dervis, de Melo and Robinson (1982) also emphasized the support that modelling provides in the formulation and conduct of economic policy.

Economic models provide a theoretically consistent, rigorous and quantitative way of evaluating different trade policies. Models are a distillation of economic theory and so the use of models ensures that policy-making is guided by a correct understanding of how economies function. Models can confirm and strengthen existing insights. The policy-maker may have formed a judgement that trade reform will be good for the country. A simulation of the model can confirm that judgement and provide an estimate of the likely gains. Model simulations can surprise the policy-maker and alert him to some of the unintended consequences of his action that would not have been clear without the economy-wide framework and discipline of economic models. For example, a policy-maker may be particularly concerned by the effect of foreign competition on the domestic steel sector. The policy-maker may be inclined to adopt a tariff on imports to relieve the pressure of competition on the domestic industry. However, the model simulation may show that there are detrimental effects of the tariff on downstream industries and that if the interests of all sectors are taken into account, the economy would be worse off with the tariff than without it.

While models should complement or improve policy analysis, they are not a substitute for it. Simulation results are necessarily subject to error and the quality of the results will vary with the appropriateness of the model to the problem at hand, the quality and timeliness of the data and parameters chosen (We discuss this issue in greater detail in Section III.D below). Policy-makers will need to exercise judgement on how far model results should drive policy-making. The tail should not wag the dog.

B. *Ex-ante* and *ex-post* analyses

There are at least two ways to analyse the effect of a trade policy. The first is an *ex-ante* simulation of a change in trade policy, which involves projecting the future effects on a set of economic variables of interest. The *ex-ante* analysis approach answers "what if" type of questions.

The *ex-post* approach uses historical data to conduct an analysis of the effects of a past trade policy. Most econometric models of trade are of this form. These include gravity models. The challenge for any econometric study is to attribute a cause to a certain effect, that is, for example, to show that trade costs affect trade flows. Econometric analysis, in general, and gravity models, in particular, can only guide policy by explaining its effect where it has already been implemented. But the *ex-post* analysis can often be used to answer "what if" questions if after estimation, the model is used for simulations, relying on the assumption that the past impact of a policy may give guidance about what can be expected from a change in future policy.

In modelling, an important distinction is made between endogenous and exogenous variables. Endogenous variables are those variables of interest whose values are solved for or determined by the model. The model is able to explain the behaviour of these variables; no recourse is needed to information beyond that contained in the model. Exogenous variables are not solved for in the model but are determined outside it. The model cannot fully explain how the exogenous variable will behave so information from outside the model must be supplied in order to determine it. In most trade models, goods and factor prices, production, consumption, exports, imports and welfare are endogenous variables. On the other hand, tariffs, quotas and other trade policy measures are exogenous variables. This does not mean that the settings of these trade policy instruments do not change. In fact, the interest in trade modelling is to simulate the effects of these policy changes. Other variables that are usually exogenous in trade models are factor endowments – the size of the labour force, natural resources, capital stock and technological change.

C. Comparative static and dynamic analyses

Models differ in the type of analysis they conduct regarding how a change in trade policy affects the initial equilibrium of the economy, i.e., its initial state before the policy is introduced. In a comparative static approach, one examines how a change in policy changes the endogenous variables. The concern is with discerning the difference between the initial and final equilibrium of the economy and not with the transition required to move from the initial equilibrium to the final one. How much do prices, production, trade and welfare differ between the initial and final equilibrium of the economy?

One limitation of this approach is that it may fail to capture some of the costs and benefits associated with the transition and so overstate or understate the benefits from the change in trade policy. For example, for the benefits of trade liberalization to be realized, resources have to be moved from uncompetitive sectors to sectors where they can be more productively used. But this reallocation process may require workers to be retrained. Workers may also suffer temporary spells of unemployment during the transition. Capital that is specialized to the contracting sectors of the economy may not be transferable to the expanding sectors without expensive retooling. All the costs associated with this re-allocation of resources will not be included in a comparative static analysis.

Dynamic analysis on the other hand examines not only the nature of the final equilibrium but also the evolution of the economic system from the initial to the final state. So, in theory dynamic models will be able to capture some of the costs associated with adjustments to changes in trade policy. Not only that, they allow other "dynamic" effects to be included in the analysis, which can dramatically change the estimates of the effect of a trade policy. Two important examples of these dynamic factors are capital accumulation and technological change.

With a dynamic equilibrium analysis, it is possible to examine whether changes in trade policy affect the rate of investment or accelerate the pace of technological innovation. The process of capital accumulation and technological innovation are two of the most powerful sources of economic growth. Compared to comparative static models, dynamic models tend to estimate larger gains from trade liberalization because they take into account the subsequent increases in the rate of investment and the diffusion of technological knowledge.

But despite the shortcomings of comparative static models, most simulation models are of this sort. The reason is that dynamic models are more theoretically complex and computationally more difficult to solve. Existing numerical methods for calculating a solution (i.e. algorithms) may have difficulty in arriving at the equilibrium values of the model if the models are highly complex.

D. Partial equilibrium or general equilibrium analyses

Economic analysis may be partial equilibrium or general equilibrium in nature. A general equilibrium analysis explicitly accounts for all the links between sectors of an economy - households, firms, governments and countries. It imposes a set of constraints on these sectors so that expenditures do not exceed income and income, in turn, is determined by what factors of production earn. These constraints establish a direct link between what factors of production earn and what households can spend. A partial equilibrium model usually focuses only on one part or sector of the economy, assuming that the impact of that sector on the rest of the economy and vice versa are either non-existent or small. It does not take into account the link between factor incomes and expenditures. Therefore, partial equilibrium models cannot be used to determine income, while general equilibrium models can. However, there are circumstances when the benefits of a general equilibrium model are offset by the high level of aggregation required to be able to use comparable and consistent data and by the difficulties in the specification of parameters and functional forms in the model.

1. Partial equilibrium

A partial equilibrium analysis typically focuses only on a specific market or product and ignores interactions with other markets. All other factors that can affect this market are assumed constant (the *ceteris paribus* assumption). This appears in a number of ways. It is usually assumed that a policy change in a certain market only affects the price of that good, but that this does not lead to a spillover of the income effect on other markets (that is, the

fact that a lower price for a certain good increases the income available for purchasing other goods, thus *ceteris paribus* increasing demand for them is neglected). Thus prices in other markets remain constant. A partial equilibrium model also does not take into account the resource constraints of the economy, that to increase production in one sector resources need to be pulled away from other sectors.

A partial equilibrium model is most suited for policy analysis when the policy-maker is only interested in sectoral policies, or when the sector under study represents only a small share of total income, or policy changes are likely to change the price in only one market, while prices in other markets will remain constant.[1]

For example, a policy-maker may be interested only in estimating the likely change in imports of wheat from a cut in tariffs (see Box 1). Then, the use of a partial equilibrium model may provide a better analytical tool than a general equilibrium model. This is because many of the results will turn on a few key parameters, usually demand and supply elasticities, which measure the responsiveness of demand and supply to a change in price. Therefore, more of the modeller's resources can then be used to incorporate a lot of detail about the specific market or product, which will add realism to the simulation.

A number of partial equilibrium models have been developed to simulate international trade policy changes. These include the Agricultural Trade Policy Simulation Model (ATPSM) developed by UNCTAD, the Static World Policy Simulation Model (SWOPSIM) of the US Department of Agriculture and the SMART model bundled into the World Integrated Trade Solutions (WITS) system.[2]

[1] This is, for example, possible when either the demand and supply functions are perfectly elastic.

[2] WITS is a software developed by the World Bank, in close collaboration with UNCTAD. WITS provides access to the major trade and tariffs databases: COMTRADE maintained by the UNSD, TRAINS maintained by UNCTAD and the IDB and CTS databases maintained by the WTO. WITS is a data consultation and extraction software with simulation capabilities.

Box 1: A partial equilibrium analysis of the impact of a tariff

In a partial equilibrium (PE) analysis of the impact of introducing a tariff on a commodity, the focus will be on the market for the commodity. Cross-price effects in other markets are ignored as well as overall resource limitations and budget constraints.

The chart on page 7 represents a very simple partial equilibrium model. The DD and SS curves are the domestic demand and supply for the product, say wheat, in a certain country. Domestic demand for a product falls with higher prices (this is reflected in a downward sloping demand curve), while the opposite is the case for domestic supply (therefore, the supply curve is upward sloping). Assume that p_w is the world market price of imports. Initially, consumption is at d_0, domestic production at q_0 and imports will therefore be represented by the distance d_0-q_0.

Suppose that the home country introduces a specific tariff, t, on wheat. When a tariff is levied on imports, the domestic price will increase. If markets are competitive and the country is "small" (that is, variation of its demand for imports does not affect the world price for the commodity)[3], the price increase will be equal to the tariff. In the new equilibrium, the domestic price for wheat will be equal to p_w+t. d_1 and q_1 will be the new demand and supply and d_1-q_1 the new demand for imports.

Domestic demand and the demand for imports decline, while the domestic supply increases. The trade effect is larger the more responsive both supply and demand are to price changes (i.e. the more elastic the domestic supply curve SS and demand curve DD are).

How are welfare effects analysed in the context of a partial equilibrium model? Welfare analysis relies on the idea that the demand (supply) represents the quantity that consumers (producers) are willing to buy (sell) at a given price. It follows that for any given price the area below the demand curve and above the price (above the supply curve and below the price) represents what consumers (producers) "gain" since they are able to buy (sell) at a price below (above) the price they would be willing to pay (sell for). Economists call this area consumers' (producers') surplus.

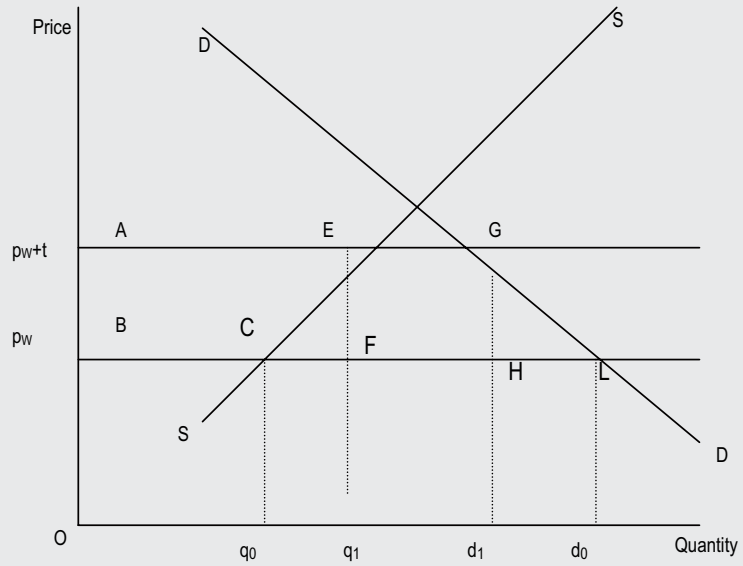
What are the welfare effects of imposing a tariff? There are three agents in this economy: consumers, producers and the government. A simple way to evaluate the overall welfare impact of a tariff is to sum up gains and subtract losses for the three agents.[4] Who gains and who loses? Consumers lose, as they consume less at a higher price. The area AGLB represents their loss (defined as the variation of consumers' surplus). Producers gain, as they sell more at a higher price. Their gain is reflected in the chart by the area ABEC (the variation of producers surplus). The government gains the tariff revenue. This is given by the volume of imports times the tariff. In the chart this is the area EGFH. Overall, the imposition of a tariff reduces welfare. The sum of the areas CEF and GHL is the dead-weight loss of a tariff. For a given tariff, the size of the overall loss will depend on the elasticities of the demand and supply curves.

Graphical representation on next page.

[3] An additional complication arises if, for example, the importing country is large and the contraction in imports causes the world price to fall. In this case, once the measure is removed, the effect on imports would be smaller than before due to a simultaneous rise in the world price.

[4] An alternative would be to give different weights to the various agents.

The impact of introducing a tariff: a graphical representation



2. General equilibrium

A general equilibrium analysis is able to account for all the linkages between sectors of an economy. These could be inter-linkages between industries, both backward and forward, or they could be linkages between household expenditures and incomes. A general equilibrium model imposes income/expenditure and resource constraints thus ensuring that households are on their budget lines and the total amount of primary factors employed in production does not exceed a country's factor endowments.

(a) Linkages in the economy

The *ceteris paribus* assumption of partial equilibrium models can be restrictive, particularly if the analysis involves more than one market and if account is to be taken of income effects, the substitutability and complementarity of products as well as shifts in the factors of production among sectors. A general equilibrium model captures the fact that markets are linked and events that take place in one market have effects on other markets that need to be taken into account since they can feed back to the original market.

These linkages work through a number of channels. One channel is through the consumer. A reduction of the tariff on wheat for example will increase the quantity of wheat demanded by consumers and simultaneously reduce demand for products that are substitutes to wheat (say rice) and increase demand for products that are complements (say butter) to it. Changes in relative prices will also affect the composition of demand though their income effects. Another channel is through producers. A fall in the tariff on wheat will reduce the returns from wheat farming leading to a decrease in the quantity of wheat supplied by domestic producers. This will release factors of production - land, capital and labour - employed in the wheat sector to other sectors (say rice) whose production may expand. Since quantity demanded of wheat increases while quantity supplied decreases, the change can only be accommodated by rising imports.

All these changes set up ripple effects through the rest of the economy. Resources released from the wheat sector are now available for use by other sectors in the economy. They will flow to such sectors as the rice sector (remember that the demand for rice has gone up) and maybe to the export sector as well. There will therefore be changes in the pattern of production, consumption and trade that go well beyond the wheat sector, although the most significant change may still occur in that sector. For trade economists,

the gains from reducing tariffs on wheat come from freeing up resources so that they could be employed in sectors where their contribution to the economy is greater. The only reason why the resources in question were employed in the wheat sector in the first place was because trade protection allowed producers there to pay more for the additional resources.

By way of contrast, a typical partial equilibrium analysis would only stop at the wheat market.[5] It would capture the increase in quantity demanded of wheat, the reduction in domestic production and the increase in wheat imports. But it would fail to capture what occurs in the markets for wheat complements and substitutes, and especially would fail to capture the link between consumer income and expenditures on these other goods. A partial equilibrium analysis would not take into account how other sectors (e.g. exportables) may expand using the resources released from the wheat sector.

A general equilibrium approach is ideal for analysing the effects of multilateral trade liberalisation or regional integration. This is because multiple countries and markets are involved and tariffs would be changing in all of those countries and markets.

(b) Circular flow

Some of these economic linkages are captured by the circular flow picture of the economy's operation. There are two important institutions involved in the circular flow: households, who are the consumers and the owners of factors of production such as land labour and capital, and firms. Households sell the services of factors of production to firms. So, there is a flow of these factor services from households to firms. In exchange, firms sell goods and other services to households. Hence, there is a reverse flow of products and other services going from firms to households.

The circular flow could also be described in terms of payments and receipts instead of goods and services. Payments in the form of rent, wages, interest and profit are paid by firms to households, which receive the payments as income. So, there is a flow of payments from firms to households. Note that this means that firms do not retain any profits (if any) and that these are redistributed to their rightful owners – households. Households in turn spend on goods and services produced by firms, which receive these as revenues; so there is a reverse flow of payments going from households to firms.

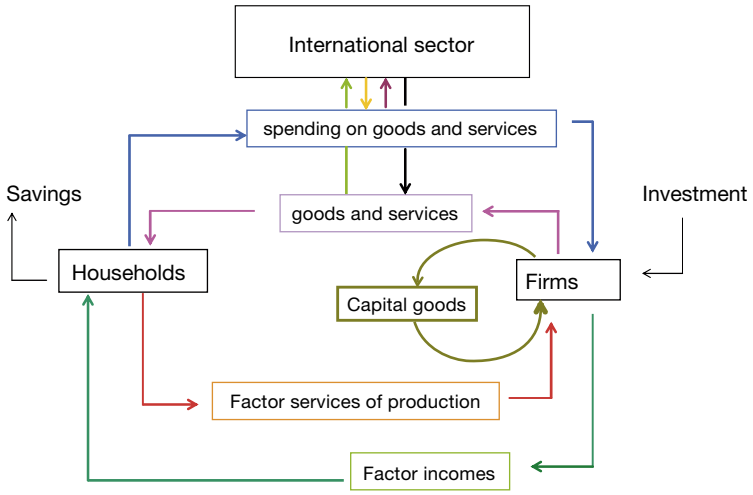
In a closed economic system, the value of these flows should be equivalent. This is reflected in accounting identities. Total expenditures on goods and services must equal total income received by owners of factors of production. If households save part of their income, this foregone consumption must be equal to investment which allows an economy to increase its productive potential over time.

In dynamic models where the time path or sequence of equilibria that the economy tracks is important, investment determines how fast the economy grows. In dynamic models, the distinction between stocks and flow has to be made. Savings by a household at any point in time is a flow. The household's wealth however is a stock and it is formed from the sum of all previous savings by the household. An analogous relationship holds between the economy's investments and its capital stock. Investments at any given time are a flow; capital stock is the accumulation of all past investments made by the economy. Hence, changes to the economy over time occur through the effect that these changes in flows have on stock variables.

Chart 1 above describes the flow of goods and services/expenditures and receipts in an open economy with three sectors – households, firms and the international sector. Each economic transaction that involves an exchange of goods or services must be matched by a corresponding flow of expenditures and receipt of payment. For example, the transaction involving households purchasing goods produced by firms is depicted as both a flow of goods (pink arrow) and a flow of payments (blue arrow). The flow of goods moves from firms to households: the flow of payments moves in the opposite direction from households to firms.

[5] It is possible to build a partial equilibrium model with multiple sectors and countries, and to take into account some of the linkages between sectors. But, the partial equilibrium model will not consider the link between income and expenditure.

Chart 1: Circular Flow in an open economy



The link between the domestic economy and the international sector is captured in the four sets of arrows that lead to and out of the international sector. The international sector is a source of additional goods and services, i.e. imports (black arrow), to the domestic economy. This is matched by a payment flow from domestic residents to foreigners (short brown arrow). But some of the goods and services produced in the domestic economy also go to the international sector as exports (green arrow). This flow outward of goods and services is matched by an inward flow of payments to domestic producers (yellow arrow). If no capital flows are allowed between the domestic economy and the rest of the world, the value of exports must equal the value of imports.

(c) Optimizing behaviour in general equilibrium analyses

In general equilibrium analysis, the underlying assumption is that of optimizing or "rational" behaviour by economic agents. This is also a maintained assumption in partial equilibrium models, but it is more apparent and explicit in general equilibrium models. So households maximize utility subject to an income constraint and firms maximize profits. This assumption is responsible for generating downward-sloping demand curves and upward-sloping supply curves. Optimizing behaviour by economic agents also lays the foundation for analysing the welfare effects of different equilibria and the policy measures that produce those outcomes.

The indicator for assessing the efficiency of an economic system is consumer welfare. This is because the material resources of any economy are there to satisfy human needs. The role of firms or producers is to transform these resources as efficiently as possible into those goods and services that households desire. In other words, the role of firms and of the assumption of profit maximization is to ensure that society produces all that it is capable of producing (i.e. it is on its production possibility frontier and not within). As we explained in the circular flow subsection above, households are the ultimate owners of all factors of production and they receive all factor payments as income - wages, interest, rent as well as profits.

III. COMPUTABLE GENERAL EQUILIBRIUM MODELS OF TRADE

A CGE model is a general equilibrium model which uses the power of today's computers to calculate numerically the effects of a particular change that is introduced to the model (e.g. a change in trade policy). It preserves the optimizing assumptions and links between markets that are the hallmarks of the standard general equilibrium model. The attraction to analysts of a CGE trade model is that it arrives at a numerically precise answer while ensuring that the results are theoretically consistent. However, the results of CGE simulations are only as good as the specification of the models and the data that are fed into them. Because information about an economy and the way that it will react to changes are never perfect, one can have legitimate reservations about precise model results. The precision achieved in some simulations can be spurious and the analyst may be better off by obtaining a range of possible estimates based on alternative model specifications and parameter assumptions.

Moreover, there is often a black-box feel to CGE models since the process by which a policy change is transformed into an outcome is not very clear. How confident can one be of the number that comes out of this black box? How robust is the result to alternative assumptions about key structures of the CGE model? Where do the gains from trade come from? One way of lifting this veil is to examine closely the various components that go into the creation of a CGE model, the data that are used to fit it, and the key assumptions that underlie a particular simulation. The concepts underlying the welfare analysis could be better explained. And greater understanding of the welfare results from a CGE model can be obtained if it is broken down into its different components. This will allow identification of the sources of welfare changes, such as for example, changes in the terms of trade, scale economies or a more efficient allocation of resources.

A. Short history of CGE modelling

Quantitative or numerical models of the economy have been around for a long time. The earliest of these were input-output models of the economy (Leontief, 1941). Through input-output models, detailed descriptions of inter-industry linkages in the modern economy became available for the first time. These could be used to describe the circular flow of production across the economy and to predict how much production was required in specific sectors in order to meet the final demand requirements of households, investors and government. In the aftermath of the Second World War, when many post war economies were still grappling with major supply shortages and a host of poor and capital-scarce countries were just emerging from colonial rule, these models became particularly relevant and important for development planners.

But the intellectual underpinning of CGE models was provided by economists working on the formalization of general equilibrium theory. The initial attempt in this direction was provided by the Lausanne school. Walras' (1896) formulation of general equilibrium was expressed in mathematical terms as a system of simultaneous equations representing market equilibrium conditions, i.e., equality between supply and demand in each market in the economy. The second major advance was the axiomatic approach adopted in the Arrow-Debreu model of general equilibrium (Arrow and Debreu, 1954; Debreu, 1959). They specified the conditions to prove the existence of a competitive equilibrium. More importantly, they established a key link between a market equilibrium and welfare. First, a market equilibrium is Pareto-efficient.[6] Second, any Pareto-efficient outcome can be achieved by a market equilibrium and a suitable reallocation of endowments. These modern results provided firm theoretical under-pinnings to the conjecture by Adam Smith. In the *Wealth of Nations*, Smith (1776) had famously suggested that an economy where each person "intends only his own gain" would be led as if by an "invisible hand" to promote the general good.

An important step leading to modern-day CGE models was the development of numerical methods for computing solutions to computable general equilibrium models. The first CGE model was probably that of Johansen (1960) which was

[6] This means that a competitive equilibrium achieves an outcome where it is not possible to make an individual better off without making somebody else worse off. Note that this is a concept of economic efficiency that says nothing about the distribution of income (welfare) among the population.

a linear model that could be solved quite easily by elementary methods in linear algebra (i.e. matrix inversion). However, while Johansen's contribution is important, Scarf is usually acknowledged as the catalyst behind the transformation of the general equilibrium model from a purely theoretical construct to a useful tool for policy analysis.[7] He not only contributed to general equilibrium theory (Debreu and Scarf, 1963), but also developed numerical techniques for the computation of equilibrium prices in non-linear models (Hansen and Scarf, 1973). This allowed the modeller to escape from the narrow confines of a system of linear equations. Beginning in the 1980s, improvements in software, the increase in computing ability and its democratization have made CGE modelling more accessible to a wider circle of academics and policy-makers.

The earliest full-blown global trade model was the Michigan model of world production and trade (Deardorff and Stern, 1986), which had been intended to examine the employment impacts of the Tokyo Round. Other global trade models include McKibbin-Sachs Global model (McKibbin and Sachs, 1991), G-Cubed (McKibbin and Wilcoxen, 1992) and SALTER (Jomini et al., 1994) and the Multi-regional Global Trade Model (Harrison, Rutherford and Tarr, 1996). Among today's more widely known and used CGE models of trade are the Global Trade Analysis Project (Hertel et al. 1997) and the Michigan model.

B. Structure of a CGE model of trade

1. Market structure

The large majority of CGE models assume that product and factor markets are perfectly competitive. This means households and firms make their decisions, regarding the purchase and sales of products and factors of production, taking the prices of these goods and factors as given, i.e. outside their control. Neither a single household nor firm is able to affect prices by its behaviour. Perfect competition also means that in equilibrium firms do not make economic profits.

In some recent CGE models, monopolistic competition is allowed, usually in the manufacturing sector. The idea is that some products are differentiated, as for example cars, which come in different models or types (sedan, coupé, SUV), and that consumers prefer this differentiation. Within the relevant range of output, production of each of these differentiated goods is subject to increasing returns to scale. Although existing firms have market power (their output decision affects price), entry by new firms which is equivalent to the introduction of a new differentiated product, ensures that in equilibrium no economic profits are made.

Although the assumption of product differentiation and monopolistic competition makes a CGE model more complex, it allows the model to capture the very large role that intra-industry trade plays in the trade of developed countries. Older models of international trade, such as that of Heckscher-Ohlin, which assume homogeneous products would be unable to explain the importance of intra-industry trade. CGE models based on the hypotheses of constant return to scale and homogeneous goods explain intra-industry trade by assuming that goods differ by country of origin. This is known as the Armington assumption.[8] The advantage of product differentiation models is that the degree of product differentiation is determined within the model, rather than exogenously by the value of the Armington coefficients. In a CGE model with product differentiation, policy changes affect an economy also through the impact on the number of varieties available to consumers. Since consumers love variety, the larger the range of products available in the market the greater their well-being.

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[7] The citation from the American Economic Society, reads in part: "Scarf's path-breaking technique for the computation of equilibrium prices has resulted in a new sub-discipline of economics: the study of applied general equilibrium models. His students and a large number of other researchers have applied general equilibrium models to issues such as the analysis of tax reforms, trade policies, economic integration; and development. Scarf was the catalyst behind the creation of this subfield of the profession and in the transformation, of the general equilibrium model from a purely theoretical construct to a useful tool for policy analysis." See AER (1992).

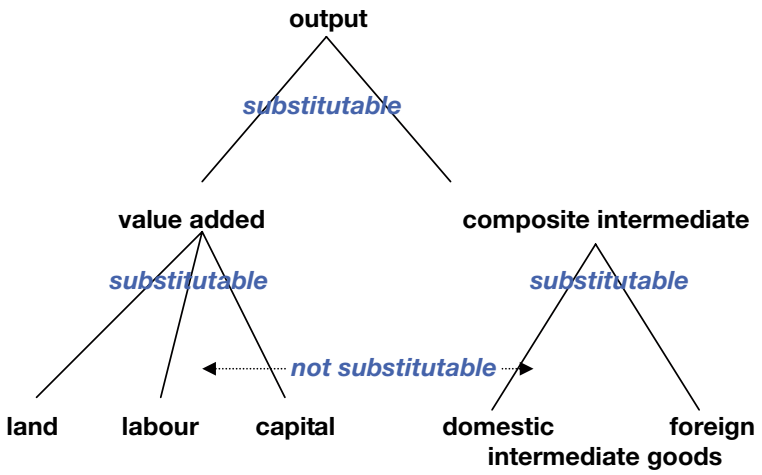
[8] This assumption makes it possible to account for the existence of two-way trade, that is bilateral exports and imports of goods in the same product category. Otherwise, the hypotheses of perfect competition and homogeneous products would only allow three possibilities for a country in a given production sector: it is an exporter only, importer only or it is self-sufficient.

2. Production and firm behaviour

The production side of a CGE model is represented by a set of goods (outputs), the inputs which are required to produce them and the technology of production. In most CGE models, the production technology is divided into two levels – an intermediate and a final level. In the intermediate level, goods are used as inputs to produce a composite intermediate good; primary factors (land, labour and capital) are also used to produce a new item called value added. The final level involves using both the value added and the composite intermediate good to produce the (final) output. See Chart 2 for an example of this technology. The intermediate level is characterized by no substitution possibilities among the intermediate inputs and the primary factor of production. However, substitution is possible among primary factors and among intermediate goods. The final stage, which in essence creates the final product, also allows for substitutability between value added and the composite intermediate goods. This two-level structure affords a far better description of production in modern economies than the traditional production function involving just primary factors since most goods are made up of many finished components and parts sourced from other suppliers. The important parameters that describe this technology are the fixed coefficients of the intermediate input stage and the elasticities of substitution.

Control over the production sector of the economy is exercised by profit-maximizing firms. Using prices of goods and the factors of production as market signals, they make their decisions on how much of each good to produce. They purchase primary factors from households and intermediate goods from other firms and use these to produce the goods which, in turn, are sold back to households. Revenues received from sales of products are used to pay the owners of the primary factors of production in the form of rent, wages and interest and to pay suppliers of intermediate inputs. But because markets are perfectly competitive, economic profits are driven to zero.

Chart 2: Nested (two-level) production function



3. Households

Households are the consumers as well as the owners of factors of production. As owners of land, labour and capital, they receive rent, wages and interest paid out by firms. This income is then spent on goods and services that households consume. Some of the income may be paid as taxes to government directly (e.g. income tax) or indirectly (e.g. tariffs on goods, sales tax, etc.) and some of it may be saved. Consumption yields utility to households.

The utility maximization problem is often posed in terms of a representative household. With the objective of maximizing utility, it must decide on how much of its income to allocate to the goods and services that are available in the market. All of its endowments of land and capital are made available to firms (a full employment assumption) at the going market price for these factor services. Posing the optimization problem in this way, however, presumes that all households in the economy are identical and, thus, sidesteps interpersonal welfare comparisons (the issue of inter-country comparison of welfare is pursued in a later discussion below). However, issues involving the distribution of income can still be analysed since changes in factor prices will reveal how distribution is affected, i.e. whether labour gains against property owners, etc. Moreover, where impacts on individual households are important, like in the case of the impact of a policy change on poverty, CGE analysis can be complemented by country-specific case studies to establish the potential effect on different household groups or different regions within a country (see Hertel and Winters, 2005).

4. Government

In CGE models, governments function to collect taxes and tariffs, disburse subsidies and purchase goods and services. These activities are not necessarily assumed to satisfy some optimization goal, unlike the case of consumers and firms. However, changes to these policy instruments provide the exogenous shocks that lead to adjustments to the rest of the economy which the CGE model seeks to capture. It is then possible to conduct a welfare analysis of these policy changes and to rank the available policy choices.

5. International Trade

In a CGE model with international trade, the model will include links with other countries, which will also have their own sets of consumers, producers and governments. The introduction of a foreign sector requires treatment of one key issue - substitutability between imports and domestic products.

Almost all CGE models assume that the foreign and domestic products are not perfect substitutes so that products in international trade are differentiated by their country of origin (the Armington assumption). This means that wheat grown in the US is different from wheat grown in Australia. And so even with free trade between both countries, world prices for US wheat and Australian wheat need not be equalized and each country can simultaneously export its own wheat and import the wheat of its trade partner.

The differentiation by country of origin has implications for both consumer and firm choices. For example, in the case of the firm some of the intermediate goods that it purchases will be imported. The choice between domestic and imported intermediate inputs depends on the prices of the goods and the Armington elasticity, which is a measure of the substitutability between domestic and imported products. Furthermore, the imported product is also a composite good made up of imports coming from individual trade partners. For consumers, preferences are now defined over goods which are a composite of domestic and imported goods. Again, how much of domestic production or imports is purchased depends on the relative prices and the Armington elasticity.

On the export side, the country sells a differentiated product in the world market. One consequence of product differentiation by country of origin is the omni-presence of terms of trade changes. The terms of trade refers to the ratio of a country's export and import prices. Each country is the unique supplier of its differentiated product. This means the prices of its export goods depends on the amount demanded in the world market. A country can only export more if its export price were to fall to entice foreigners to buy more of its good. Thus, because of the Armington assumption, changes in trade policy tend to produce significant terms of trade changes in

CGE models. The possibility of terms of trade changes has important implications for the gains from trade liberalization.

6. Equilibrium and welfare

Solving a CGE model involves searching for the set of prices that produces market equilibrium. In equilibrium, demand for goods equals their supply. The demand for factors of production equals the available endowments. Consumers have chosen the utility-maximizing basket of goods given their incomes while firms have chosen production levels that maximize their profits.

Different settings of the exogenous variables such as tariff levels will produce different market equilibria. For the policy-maker, it is important to be able to evaluate these different possible outcomes. A CGE model provides the policy-maker with the required measure in the form of consumer welfare. Each setting of the trade measure is associated with a particular equilibrium and a corresponding value of consumer welfare. The policy-maker should prefer that policy setting which produces the equilibrium where the consumer's welfare is highest.

Various indicators of welfare have been used in the context of CGE models of trade.[9] One of the most important and commonly used indicator is *equivalent variation*. Consider the following situation. A country is examining whether it should remove the tariff on an imported product or not. The equivalent variation of removing the tariff is the increase in income, using current prices, that would have the same impact on the welfare of households as the removal of the tariff.[10] Equivalent variation has an appealing feature since it is a monetary measure of the change in welfare, i.e., capable of being expressed in dollars and cents. Not only is a monetary measure more intuitively comprehensible, it also provides an important means of dealing with the problem of interpersonal comparisons of welfare in a multi-country model. It provides a standard for evaluating various alternatives to whatever policy is currently in place.

In a single country CGE model, the problem of interpersonal comparisons of welfare is bypassed by assuming a representative household whose welfare then becomes the metric by which policy alternatives are evaluated. "Society's" welfare is identified with the welfare of that representative household. But in a CGE model of international trade, there will always be more than one country which means that, at a minimum, two representative households must be assumed. The use of equivalent variation allows one to conduct a welfare analysis of multilateral trade liberalization even if it is not possible to compare the welfare of different representative households.[11]

Suppose that a specific multilateral trade liberalization scenario has been simulated and the results indicate that one set of countries would see their level of welfare (as measured by the equivalent variation) increased compared to the baseline while another set of countries would see their level of welfare decline. By adding up these measures of equivalent variation, it is possible to assess the global welfare impact of this specific trade liberalization scenario. If this global total is positive, it is in principle possible for the winners to make transfers to the losers, that would leave the latter as well off as before the trade liberalization and thus remove their objection to policy change, and still have enough left over for the winners to experience net gains. Thus, the liberalization policy is desirable from a global welfare perspective. If the global total is negative however, there is no possible way of effecting

[9] See Martin (1997) for a discussion of these different measures of welfare.

[10] An alternative way of characterizing equivalent variation is that it is equal to the amount of income, measured in current prices, that consumers would be willing to forego and still have the same level of well-being as before the tariff was removed.

[11] There are three different measures of changes in welfare following a trade reform. One is the value of the actual transfer from outside the system to the private sector that would have the same welfare effect as the reform. A second one is the equivalent transfer from abroad to the government, and the third one is the money metric measure (the income that consumers would be willing to forego and still have the same level of well-being as before the reform). In a recent paper, Martin and Anderson (2005) argue that unless the measures of welfare change used are those based on external compensation, they cannot be added up (unless standardised), thus strongly limiting the ability of making comparisons across countries of models where the money metric measure of welfare is used. This is because the marginal welfare effect on households of a transfer from abroad differ across countries depending on the tax profile of the countries. Note that this includes the GTAP model, often used in simulations of trade policy.

transfers from the winners to the losers that will leave all countries at least as well off as before. Thus, the liberalization policy is undesirable from a global welfare perspective.

Note that this welfare evaluation has been conducted without having to weigh individual countries' wellbeing and making judgements about whether one country should count more than another should. So long as the change in trade policy has the potential to increase global incomes enough so that winners can "bribe" losers to accept the change in policy, that change is desirable because in principle all can stand to gain.

7. Investments and dynamics

The distinguishing feature of a dynamic CGE model is that growth of output is possible. In a dynamic CGE model, households choose a consumption plan (a sequence of consumption decisions) during the period under consideration which maximizes the discounted stream of their utilities. This means that in some periods, households may consume more than they earn (dissave) while in other periods, they may consume less than they earn (save). For their part, firms choose a production plan (a sequence of production decisions) that maximizes their discounted stream of profits. The availability of savings from households makes it possible for firms to turn these savings into new capital stock thereby augmenting their productive capacity. The growth rate in a dynamic CGE model is endogenously determined by the savings and investment behaviour of households and firms.

8. Model closure

When building a model to analyse the impact of a trade policy, analysts need to make some choices. One of this is to define the "model closure". The choice of the closure will be determined by the specific nature of the problem and by the variable the modeller intends to shock. Consider, for example, the case of a good produced in a small economy and on which the government levies an import tariff. In this case the domestic price of the good is set by the world market price plus the import tariff, while imports are determined by the model's equations of domestic demand and supply (see Box 1). Given the price, it is possible to calculate the quantity demanded and supply domestically, with imports being derived as the difference between demand and supply. In this set up, prices are exogenously fixed by the analyst, while quantities are endogenously determined by the model. The modeller can simulate the impact of a tariff cut, simply by solving the equations for the demand and supply for the new price (that is, the world price plus the new tariff rate).

Alternatively, it may be the case that the market for a certain product is protected by a quota and the modeller is interested in simulating the impact of changes in the volume of the quota on the economy. In this situation, given the world price and the quota, the market equilibrium condition "demand equal supply plus imports" (the latter given by the value of the quota) will determine the domestic price prevailing in the market. At that price, the demand and supply will precisely generate the level of imports determined by the quota. In this set up, the quantity of imports is exogenous to the model, fixed by the specific country policy, while prices are endogenously determined by the model.

It is interesting to note that under certainty, the economic impact of a tariff or a quota is equivalent. It is equivalent to set a tariff to a level that yields a certain level of imports (for example, in terms of Chart 1 in Box 1, the specific tariff t yields imports equal to d_1q_1) or set a quota to the level that generates the same domestic price (setting a quota equal to d_1q_1 would raise domestic prices to p_w+t). It is for this reason that sometimes economists work with the tariff equivalent of a quota. In this case, the impact of changes in the quotas are simulated through variations in their tariff equivalents. The choice between working with quotas directly or working with their tariff equivalents is one of model closure. In the former case the quantity of imports is exogenous and domestic price is endogenous. In the latter case, the opposite will be true.

Different model closures are also often used to represent various assumptions about the labour market, especially to allow for unemployment. If one assumes that the labour market is perfectly flexible and there is full employment, then, one will adopt a closure that makes the wage rate endogenous with employment being exogenously determined by the labour endowment of the economy. In contrast, if one reckons that the labour market is characterized by involuntary

unemployment, then the appropriate closure rule would make employment endogenous and require that the wage rate be fixed exogenously, which could be at some level above the equilibrium level.

Mathematically, the need for "model closure" springs from the requirement that the number of endogenous variables in a model should be equal to the number of independent equations so that the model can be solved. Hence if a model has *n* independent equations and m variables, where $m > n$, then one way of interpreting closure is that it involves choosing which *n* variables from among the *m* total variables are to be made endogenous. The remaining m-n variables will have to be kept exogenous.

9. Where do the gains from trade come from?

Despite their complexity, the gains from trade in CGE models spring from exactly the same sources as economic theory describes. So long as the economies are not exact replicas of one another, prices of factors and goods will not be identical across countries before trade is opened up. The prices of certain goods will be cheaper in one economy and more expensive in another. This creates the basis for mutually beneficial exchange. Thus, opening to trade will allow consumers in one economy to demand those goods that are produced more cheaply in another economy and for producers in the latter to respond by reallocating factors of production to those goods that are in demand internationally. Thus, gains from trade come from allowing factors of production within a country to be allocated to sectors that are more productive.

These gains can be enhanced or reduced by terms of trade changes, which are more prominent in CGE models because of the Armington assumption (see above). As was noted above, the Armington assumption means that products are differentiated by country of origin. A country will always be a "large" as opposed to a "small" country in a CGE model because it is the only supplier of its exportable. Hence, increasing its export to the world market requires a fall in the price of the export good (a deterioration in its terms of trade).

If the CGE model has a monopolistically competitive sector (or characterized by other form of imperfect competition) with increasing returns to scale, additional welfare gains come from the economies of scale induced by trade opening. Trade liberalization allows countries to expand the scale of their production which lowers the average cost of production.

Finally, if the CGE model is a dynamic model then additional welfare gains are possible from improvements in productivity and from an increase in the rate of capital formation. Both these forces should lead to a higher rate of economic growth.

C. Operationalizing the model

To fully operationalize a CGE model of international trade requires building the associated social accounting matrix (SAM) and obtaining estimates of important behavioural parameters governing consumer demands, production technology, and the substitutability between imports and domestic products. The final step involves calibrating the model.

(a) Social accounting matrix

The first step to operationalize a CGE model is to organize the data on the structure of the entire economy in a way that takes into account the fundamental relationships between all agents in the economy and across all sectors. The social accounting matrix is a tool that helps to take into account of all these interactions in a systematic way and without errors. The SAM builds on the circular flow conception of the economic system where each expenditure must be matched by a corresponding receipt or income. As its title suggests, the relationships between sectors in a SAM are represented in the form of a table containing rows and columns (see Table 1 for an example of an open-economy SAM). The rows correspond to the income or receipts while the columns correspond to the outlay or expenditures of a sector. Each sector of the economy will appear as a row (recipient of income) and as a column (as a source of expenditures) which means that the SAM is a square matrix. Given that income of a sector must equal its expenditure, the sum of the entries in the ith row must equal the sum of the entries in the *i*th column.

A SAM is constructed using several basic sources of economic information: the economy's input-output table, the national accounts, government

budgetary accounts, balance of payments and trade statistics. The input output table provides information on the production sector of the economy, showing detailed inter-industry linkages and the contribution made by primary factors of production to each sector. Thus we know how much steel, rubber, plastics, etc. goes into the car industry. The macroeconomic accounts provide a breakdown of aggregate demand according to consumption, investment, government spending and the international sector (exports and imports). The trade account usually contains data on the destination and product composition of exports and imports. These have to be reconciled with the national accounts as well as with the input-output table. This integration means that the resulting SAM, for example, shows not only how much steel, rubber, plastics, goes into the car industry but how much of each of those inputs are sourced domestically and how much sourced from abroad and from which trade partner. The government fiscal accounts provide information on public expenditures and revenues. Integrated with the other accounts in the SAM, it is possible to obtain information on government spending on domestically produced goods and imports and to determine how much revenues are generated from taxes applied to international trade (tariffs).

In a CGE model of trade, the SAMs of different countries will need to be collected, standardized and then combined. This requires using SAMs from the same base year and converting all values into a single currency. When information are missing or data are inconsistent (like when expenditures exceed incomes, demand differs from supply or consumers' expenditure classifications do no match production classification), analysts need to "adjust" data. This could be a sizeable challenge for multi-regional trade models given their large size. For example, the current version of GTAP (version 6) has 87 regions and 57 production sectors. A huge effort has to be mounted to collect, standardize and reconcile the data to produce a SAM for a CGE model of this size.

It is important to note that CGE models are built using value data. The general practice is to define quantity units as the amount that can be bought for one unit of currency (say one euro or one dollar) in the baseline dataset. This means that in most cases, baseline prices will all be set to unity. In CGE models, therefore, only relative prices are important, not absolute prices.

Table 1: Example of a social accounting matrix for an open economy

Receipts	**Expenditures**								
	Activities	Commodities	Factors	Enterprises	Households	Government	Capital Account	Rest of World	TOTAL
Activities		*Gross output*							*Total sales*
Commodities	*Intermediate goods demand*				*Household consumption*	*Government consumption*	*Investment*	*Exports*	*Aggregate demand*
Factors	*Vale added*							*Factor service exports*	*Factor income*
Enterprises			*Gross profits*			*Transfers*			*Enterprise income*
Households			*Wages*	*Distributed profits*		*Transfers*		*Foreign remittances*	*Household income*
Government	*Indirect taxes*	*tariffs*	*Factor taxes*	*Enterprise taxes*	*Direct taxes*				*Government revenues*
Capital Account				*Retained earnings*	*Household savings*	*Government savings*		*Capital transfers from abroad*	*Savings*
Rest of World		*imports*	*Factor service imports*		*Transfers abroad*	*Transfers abroad*	*Capital transfers abroad*		*Foreign exchange payments*
TOTAL	*Total costs*	*Aggregate supply*	*Factor expenditure*	*Enterprise expenditure*	*Household expenditure*	*Government expenditure*	*Investment*	*Foreign exchange receipts*	

Source: Reinert, K. A. and Roland-Host, D. W. (1997).

(b) Behavioural parameters/elasticities

After all information about the expenditures and revenues and the interactions of all agents have been included into a SAM, the modeller needs to provide the value of the exogenous parameters (called behavioural parameters) that characterize the behaviour of producers and consumers. These parameters measure the responsiveness of producers and consumers to relative price and income changes and therefore have an important bearing on the outcome of a CGE simulation. There are at least three (often more) types of behavioural parameters which are needed. First are the elasticities of substitution in value added which govern the substitutability of the primary factors of production. Second, are the Armington elasticities which determine the substitutability of the domestic vs. the imported composite product. Third, are the demand and income elasticities of the households or consumers.

One of the more important criticisms levelled against CGE models is the quality of the information used to derive these behavioural parameters. Hertel et al. (2004) have admitted that the history of estimating the substitution elasticities governing trade flows in CGE models has been "checkered" at best. In some cases, the CGE model builders do not statistically estimate these parameters themselves but take them, usually without much change, from other sources. For example, the substitution and Armington elasticities of the GTAP model are taken from the SALTER project (Jomini et al. 1991) while income elasticities were taken from FAO (1993) and Theil, Chung and Seale (1989). In the Michigan model, the elasticities are taken from Deardorff and Stern (1990). Ideally, these parameter values should come with additional information (e.g. standard errors, functional form, etc.) which could provide some guidance about the reliability of these estimates. While databases may be regularly updated, the estimates of the parameters are not, so some of the behavioural parameters are based on estimates that are currently about 15 years old.

(c) Calibrating a model

The final stage for operationalizing a CGE model consists in calibrating all the remaining unknown parameters. Calibration involves choosing the values of a subset of the parameters in such a way that together with the assembled SAM and the values of the behavioural parameters, the model is able to reproduce exactly the data of a reference year – the baseline. All simulations of the CGE model will be based on a comparison with this baseline. Usually the parameters that are calibrated are share or scale parameters.

D. Assessing CGE simulations

The purpose of the class of CGE simulations in which we are interested is to determine the effects of a change in trade policy on the endogenous variables of the model – prices, production, consumption, exports, imports and welfare. The simulation represents what the economy would look like if the policy change or shock had occurred. The difference in the values of the endogenous variables in the baseline and the simulation represents the effect of the policy change. So the model should be able to foretell the effect on trade and production patterns if the trade policy was changed. Furthermore, based on the change in welfare, the policy-maker would be able to judge whether the country benefited from the change in policy or not.

What are policy-makers to make of CGE simulations and to what extent can they be relied on? Earlier in this paper, we noted the importance that modellers have placed on the ability of models to improve the policy formulation process. CGE modelling seemed to have had an important impact on the community of Australian trade analysts and trade policy-makers (Powell and Snape, 1993). Powell and Snape's description of the Australian experience suggest that modellers can be effective partners of policy-makers. Economic models may not have moved Australian policy towards trade liberalization. The country was probably already headed towards that direction when the ORANI model began to be used. But economic modelling provided the necessary analytical support for the policy of liberalization, and at the very least, it improved the language of the policy discourse. Everything else being held equal, those who have numbers normally triumph against those lacking them. And those who have better numbers can expect to succeed more often. Various agencies of the US federal government (ITC, ITA) use a variety of trade models. Many international organizations that deal on a routine basis with international trade issues employ them more and more. While there are indications to

show that CGE models are now being more widely used by trade ministries around the world, it is more difficult to determine how much all this has improved trade policy formulation.

Is a CGE simulation a forecast? A forecast involves predicting the future values of the endogenous variables; but this would require making a number of assumptions about the likely evolution of all the exogenous variables in a model. In contrast, simulations are hypotheticals of the form: "If exogenous variable *t* (for tariff) changes by *x* per cent, endogenous variable *w* (for welfare) changes by *y* per cent." The analyst is not necessarily wedded to a particular view about the likelihood of the exogenous variable changing by *x* per cent, not to mention all the other exogenous variables in the model.

Thus, one answer to the question is that CGE simulations are not forecasts. But CGE models are clearly more valuable to policy-makers the more accurate are the results of the simulations. It is also clear that many CGE simulations, for example of multilateral trade negotiations, are meant to estimate the magnitude of the economic effects. They are not primarily intended to educate policy-makers or to improve policy formulation; instead, they are meant as positive (and not prescriptive) contributions to economic science. Clearly, the numbers that come out of the simulations are meant to be important.

There are a number of ways to instill greater confidence in these simulation results. One is with sensitivity analysis. This involves changing the model's parameters, or specifications, to determine whether the simulation results are significantly affected. If a subset of the parameters of the model has been econometrically estimated, then information regarding the standard errors of those estimates could be drawn upon in the sensitivity analysis. In other words, the parameter values could be "randomly" drawn from a population with the same probability distribution as those derived in the econometric estimation.

While many of the simulations that are subsequently surveyed in this study may have undertaken sensitivity analyses, they have not been reported in a systematic and informative way in the papers. But clearly, some idea of the frequency distribution of the simulation results would be very illuminating because it gives the range of the estimates and some indication of whether they tend to cluster around some value.

Kehoe (2003) has emphasized the need for systematic *ex-post* evaluations of CGE simulations. The modeller has a responsibility to confront the predictions of his CGE model with the actual data. Economics makes progress when models are validated by outcomes. But, progress is also made when models are falsified by the data and puzzles are thrown up. The emphasis he puts on validating simulation results arose from his review of CGE simulations of the effects of NAFTA. All three models reviewed – the Michigan model, the Cox-Harris model and the Sobarzo model – greatly underestimated the expansion of intra-NAFTA trade. Kehoe concludes that one major reason for the anomaly was over-reliance on a model structure of imperfect competition and product differentiation. This structure implied that the largest increases in intra-NAFTA trade would occur in sectors in which there already was significant (intra-industry) trade. But it turned out that most of the growth in intra-NAFTA trade was in sectors which were hardly traded before 1993.

He noted that the reason why this structure was relied on in the Michigan Brown-Deardorff-Stern model and the Cox-Harris model was that they had been used to analyse the Canada-U.S. Free Trade Agreement. They were just subsequently extended to include Mexico for the NAFTA analysis but retained the original market structure. Since one purpose of new trade theory is to explain the predominance of intra-industry trade in the commercial links between industrialized countries, one likely conclusion is that the CGE models configured to analyse the effects of NAFTA were inappropriate to the task because Mexico's economic circumstances were so different from the US and Canada.

It is important to note that *ex-post* evaluations are routine for macroeconometric forecasting models. The modeller compares the model's forecast with the actual outcome. Since a forecast is conditional on the assumptions made about the behaviour of exogenous variables, one possible explanation for a large gap between the forecast and the actual outcome is that one or more of the exogenous variables changed dramatically during the forecast horizon. For example, the country may be a large oil importer and takes oil prices as given, i.e. it is an exogenous variable in the

forecasting model. A relatively low price of oil was assumed in the forecast. But during the forecast period, there was a sudden surge in oil prices. An *ex-post* validation of the forecast would involve using the actual value of exogenous variables, including the oil price, in the model and running the forecast again. If the use of actual instead of the assumed (low) oil prices significantly narrows the gap between the *ex-post* forecast and the outcome, the model is not invalidated. However, if after inputting actual values of the exogenous variables into the model the *ex-post* forecast does not significantly diminish the forecast error, then the model needs to be looked at again.

While there is need for undertaking more *ex-post* validation of CGE models and simulations, one should not underestimate the difficulties involved. In *ex-post* validations, one may need to distinguish between a "timeless" and a dated comparative static CGE simulation.[12] In timeless comparative statics, a model calibrated for a particular year (let us say in 1996) is "shocked" by changing various exogenous variables (let us say the Uruguay Round commitments), and the results of the simulation are then compared with the base-year solution. This is the standard comparative static analysis that one encounters in economics textbooks. This represents a "what if" question tied to the base year of the analysis. It poses the question: "What would the economy have looked like in 1996 if the Uruguay Round commitments were implemented that year?" In contrast, a dated comparative static analysis would involve a CGE simulation for a period some years away from the base year of the model (let us say in year 2004). To do this, one would need to project or forecast the values of all or some of the exogenous variables from the base year 1996 to the simulation year 2004. This represents a "what if" type of question tied not to the base year of the analysis but to a later period. It poses the question: "What would the economy have looked like in 2004 if the Uruguay Round commitments were fully implemented that year, given that the changes to the exogenous variables materialized as projected?"

Ex-post validation of a timeless comparative static simulation would involve comparing the simulations results with actual data, let us say, in the year 2004. But this would require purging the year 2004 data with all extraneous intervening events, such as the IT boom and bust, the global slowdown of 2001, the adoption of the euro, the growth of preferential trading arrangements, etc. *Ex-post* validation of a dated comparative static analysis requires comparing actual 2004 data with the solution of the model for the year 2004. But this would still be conditional on the projections of the exogenous variables being sufficiently close to the actual paths they took; otherwise, some purging of intervening events would still need to be undertaken.

Ex-post validation of CGE models would also need to involve some intermediate variables like GDP or trade flows since one will never observe actual realizations of welfare.

CGE models are valuable as a tool for confirming policy-maker's insights or validating intuition about the likely economic effects of a policy; alerting policy-makers to unanticipated consequences of a policy; understanding how a policy works its effects through the economy; and developing a global rather than a local perspective about the impact of the policy. But a more systematic validation of CGE simulations, through sensitivity analyses and *ex-post* evaluations, is needed to help improve confidence in the predictive value of the results.

[12] The distinction comes from Sherman Robinson in the context of a commentary he made on Kehoe's paper. We are indebted to Robert Stern for providing us with a copy of the comments.

IV. COMPUTABLE GENERAL EQUILIBRIUM SIMULATIONS OF MULTILATERAL TRADE NEGOTIATIONS

A. Looking back at Uruguay round CGE simulations

The Uruguay Round of trade negotiations provided one of the first opportunities for the use of CGE models to simulate the effects of multilateral trade negotiations. This section distills the lessons learned from that body of work.[13] It provides an overview of the CGE models used at the close of the UR by international organizations and the simulation results.

Estimates of the impact of the Uruguay Round were produced before, during and after the completion of the negotiations. Early studies conducted by the WTO estimated gains worth US$500 billion annually from the Uruguay Round. A study by the OECD estimated gains of US$200 billion only from agriculture liberalization. But the preliminary estimates were significantly higher than estimates produced after the Uruguay Round was concluded. One of the most important explanations for this discrepancy was that the actual commitments contained in the final agreement implied a substantially lower degree of liberalization than assumed in the policy experiments conducted in those studies, especially relative to agriculture. Later studies, conducted at the end of the UR on the basis of the actual agreement, revised these estimates downwards.

Table 2 presents some of these studies conducted after the completion of the Uruguay Round. A number of factors could be identified to explain differences in the simulation results. First of all, different studies covered different aspects of the Uruguay Round. For example, the Rural Urban North South (RUNS)-based models (Burniaux and van der Mensbrugghe, 1991), developed by the OECD and the World Bank, especially focused on the agricultural sector. Fifteen out of the 20 sectors modelled covered agricultural products, with three of the remaining five sectors being important agricultural inputs (fertilizers, energy and equipment). Most of the industrial liberalization takes place in a single aggregated sector, "other manufactures" thus making it impossible to adequately capture the reallocation taking place across different manufacturing products. Due to the high level of aggregation of the manufacturing sector, possible gains deriving from the phasing out of textile quotas and other non-tariff barriers in industrial products could not be modelled. As a consequence, overall global gains were mainly driven by agriculture liberalization. In the study by Goldin and van der Mensbrugghe (1996), agricultural liberalization yielded 85 per cent of total gains. This is in striking contrast with those of other studies, where the impact of manufacturing liberalization is better accounted for, so that the contribution of agriculture liberalization to overall gains of the Round is estimated to be less than 10 per cent (like in Francois et al. 1996). An attempt to quantify the impact of services liberalization is made in only two studies (Brown et al., 1996 and Nguyen et al., 1995).

The degree of regional aggregation in the models also affected the distribution of the gains. Important differences in the CGE estimates stemmed from whether sub-Saharan Africa was singled out or not. Agricultural reforms, and in particular, the removal of subsidies, would lead to higher food prices, thus negatively affecting net food importing countries. In models with a high level of regional aggregation, this effect does not appear in the results, as losses are compensated for by the positive welfare gains of other countries in the region. Therefore, it would be misleading to claim that CGE simulations show that there are no losers from trade liberalization when the simulation entails a high level of regional aggregation. Yet, overall positive gains suggest that there is a margin for cross-country compensation, although in practice there is no reason to suppose that such compensation would occur.

A second factor that explains different CGE results is the different assumptions about market structure. Two approaches dominate. One approach assumes that products are differentiated both across firms and countries. In this case, each firm has a certain degree of market power, so competition among firms is imperfect. Estimates of the degree of market power and scale economies are required to calibrate the model. Errors in the estimates of these parameters add to the degree

[13] For an assessment of Uruguay Round's estimations see also Francois (2000) and Whalley (2000).

of uncertainty of the results and their reliability. However, these models may provide a better approximation of reality than those based on perfect competition. An alternative approach is to assume that products within the same product category produced domestically are homogeneous, while products originating in different countries are imperfectly substitutable. This assumption is compatible with perfect competition, therefore economies of scale do not need to be estimated. In contrast, this approach requires the estimation of the so called Armington elasticities, that is, trade substitution elasticities.

The third important element driving differences in results in the analysis of the impact of Uruguay Round is the assumption about dynamics in the models. Some models hold capital stock fixed (static models) while other models allow for capital accumulation in response to changes in investment. In general, models where capital stock changes with investment generate larger overall effects than those where capital is fixed. The reason is as follows. If trade liberalization results in higher savings, investments will increase. This in turn will add to capital and increase output. This process will take place over time. Therefore, the results portrayed in this case refer to a longer time horizon than in the case of static models. In static models, the adjustment process is not modelled. And there is no clear indication of how long after the full implementation of a policy change it will take for the effects to be realized. It is commonly believed that the effects of a static model should be realized within 5 to 10 years after the full implementation of the policy change, as time is required for adjustments in employment to take place. When capital also needs to adjust, there is some convergence in thinking that the time required will be longer - within 10 to 15 years.

Table 2: CGE studies of the Uruguay Round

Publications	Data/ Evaluation	Model Structure	Sectors Liberalized	Results
Brown, Deardoff, Fox and Stern (1996)	data and evaluation at 1990	▪ Michigan model ▪ 29 sectors (1 Ag, 1 proc. food, 1 Prim, 20 Manuf., 6 Services) ▪ 8 regions ▪ perfect competition, CRS, Armington elasticities in Ag. Monopolistic competition and IRS in Manuf. ▪ static	Industrial Tariff cut according to schedule. MFA not covered. Agriculture tariffs including NTB-equivalents cut according to commitments Services: NTBs cut by 25 per cent	▪ GDP growth: US 0.9 per cent, EU 0.9 per cent Japan 1.4 per cent Australia and New Zealand 3.6 per cent Mexico 2.8 per cent Asian NICs 3.6 per cent ROW 1 per cent
Francois, Mc Donald and Nordstrom (1996	data version 1992	▪ GTAP model ▪ 19 sectors ▪ 13 regions ▪ Model1: CRS, perfect competition ▪ Model2: IRS, monopolistic competition ▪ saving-driven investment (i.e. dynamic model)	▪ Industrial Tariff cuts according to schedules, MFA quotas lifted ▪ agriculture tariff cuts according to commitment, subsidies cut by 36 and 24 per cent in developed and developing countries respectively	▪ GDP growth: World 0.45 (model1) 0.9 (model2) US 0.6, EU 0.5 Japan 0.4 Australian and New Zealand 0.9 Latin America 1.9 East-South Asia 1.8 ▪ Decomposition of welfare effect 10 agriculture, 50 textile and clothing, 40 other manufacturing ▪ Trade growth: increase by 6 per cent (Model1), approx 15 per cent (Model2)

Publications	Data/ Evaluation	Model Structure	Sectors Liberalized	Results
Goldin and van der Mensbrugghe (1996)	1985-93 data are used to validate the model. Projections are made for the period 1993-2002	▪ RUNS model ▪ 20 sectors (15 of which agricultural sectors) ▪ 22 countries ▪ perfect competition¨ ▪ static	▪ industrial tariffs cut according to schedules ▪ agricultural reforms: tariffs including NTBs cut according to schedules. Subsidies cut by 36 per cent in OECD and 24 per cent in other countries.	▪ GDP growth: US 0.1 per cent, EU 0.6 per cent, Japan 0.4per cent Australia and New Zealand 0.1, Mexico -0.5 Upper Income Asia 1.3 ▪ Decomposition of welfare effect 85 per cent from agriculture.
Hertel, Martin, Yanagishima and Dimaranan (1996)	1992 data, evaluated at 2005 Using exogenous of regional growth of capital, population and technology the world economy is estimated with and without the Uruguay Round policy change	▪ GTAP model ▪ 10 sectors ▪ 15 regions ▪ CRS, perfect competition, Armington trade elasticities	▪ Industrial and agricultural tariffs cut according to schedules. MFA quotas are lifted.	▪ GDP growth World 0.89 per cent US&Canada 0.4 EU 0.7 Japan 1.04 Lat. America NICs 3.8 ▪ Trade growth World 59 per cent US and Canada 48 per cent EU 42 per cent Japan 22 per cent ▪ Decomposition of welfare effect Ag 5per cent Industrial tariff 81 per cent MFA 14 per cent
Harrison, Rutherford and Tarr (1995)	1992 data and evaluation	▪ GTAP model ▪ 22 sectors ▪ 24 regions ▪ M1: CRT,PC, Armington ▪ M2: IRT, monopolistic competition intraregional, Armington-based trade ▪ M1 both static and dynamic	▪ Industrial and Agriculture tariff cut according to schedule ▪ Export (domestic) subsidies cut by 36 (20) per cent and 24 (13) per cent in developed and developing countries respectively.	▪ GDP growth World. 0.4 (M1 static) 0.7 (M1 dynamic) 0.42 (M2 static) M1 regional results: US 0.4 EU 0.7 Japan 0.7 Lat. America 1.7 South-East Asia approx. 2.5 ▪ Decomposition of welfare effect M1 static: Agr 68 per cent, Ind. Tariff 18 per cent, MFA 15 per cent M1 dynamic: Agr 38 per cent, Ind. Tariff 49 per cent, MFA 12 per cent M2 static: Agr 61per cent, Ind Tariff 23 per cent, MFA 17 per cent.

B. CGE simulations of the Doha negotiations

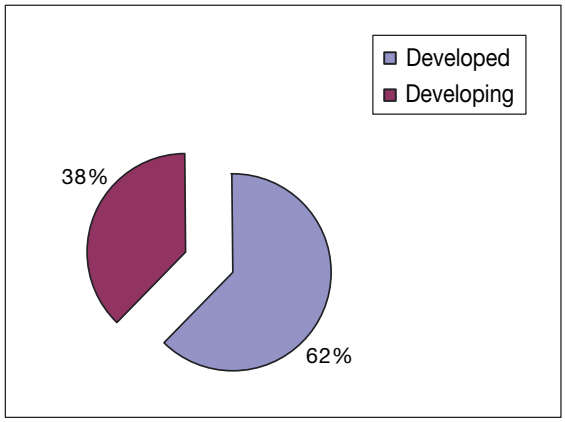
Given the large number of CGE simulations of the Doha negotiations, it was necessary to be selective about the papers included in this survey. In choosing from the growing literature on the topic, the following criteria have been adopted. First, the survey includes only global or multilateral simulations and thus excludes studies that focus on only a single country or region. Second, it includes papers published in journals or produced by international or multilateral institutions. Third, while the survey seeks to ensure that a range of trade models is represented, it only includes those CGE models whose technical specifications and data sources are publicly available. Fourth, the papers are chosen so that they provide sufficient coverage of those issues that are the subject of liberalization discussions in the Doha negotiations - agriculture, non-agricultural goods, services and trade facilitation. Finally, the scenarios being simulated should be as close as possible to the alternatives being considered in the negotiations. In practice, this criterion has proven rather difficult to apply because even at this late date, the formulas for tariff reduction are still far from being agreed. The most recent studies focus on scenarios with features like the Framework Agreement (Anderson and Martin, 2005). Furthermore, the services negotiations are based on the "request-and-offer" modality making a formula approach unworkable. Based on these criteria, this survey includes only the following papers: Anderson, Martin and van der Mensbrugghe (AMV, 2005), Anderson, Dimaran, Francois, Hertel, Hoekman, and Martin (ADFHHM, 2003), Brown, Deardorff and Stern (BDS, 2003), Cline (2004), Francois, van Meijl and van Tongeren (FMT, 2003), OECD (2003), UNCTAD (2003) and World Bank (2003).[14]

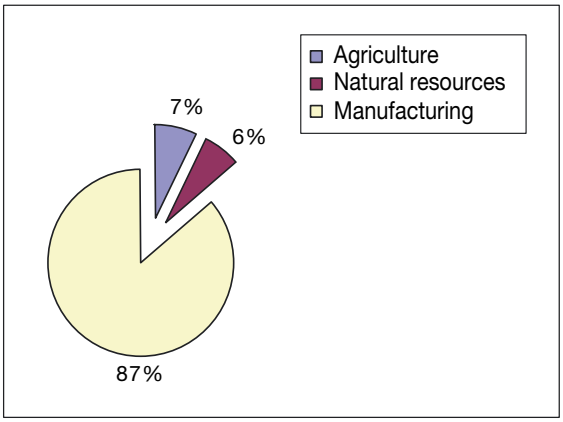
Table 3 summarizes some basic features of the models, data sources and scenarios of the simulations. There are at least five sources of differences in the simulation results (see Table 4). These include the baseline data and level of protection, the nature of the models (whether they assume only constant returns to scale or also allow increasing returns to scale), the depth of liberalization (whether full or only partial liberalization), whether the models are static or dynamic and the scope of liberalization (whether services and trade facilitation are included or not).

We focus the discussion on several major issues: (i) overall welfare gains; (ii) benefits from liberalization of agricultural trade, non-agricultural trade, and services trade; (iii) benefits from trade facilitation; and (iv) the distribution of gains between developed and developing countries.

[14] A survey of recent CGE simulations is also provided in Anderson (2005).

Chart 3: Structure of world merchandise trade, by level of development and product.





Source: GTAP database 6.

A better intuition for the simulation results could be obtained if some basic information about the structure of world trade and tariff protection is kept in mind. One convenient feature of the simulations considered in this study is that they all draw upon the GTAP database (versions 4, 5 or 6). Although some of the papers construct baselines of a post-Uruguay Round world - requiring them to make projections about how the global economy looks like prior to the conclusion of the Doha negotiation - the information contained in the database remains valuable in giving an idea of what the gains are from lowering tariff protection, where the sources of the gains come from and how they may be distributed among countries.

The latest version of the GTAP database is version 6. The base year is 2001 and it includes data on tariff preferences.[15] Using information from the GTAP database version 6, Chart 3 shows that developed countries accounted for 62 per cent of world merchandise trade in 2001 and developing countries for the remainder. Eighty-seven per cent of world merchandise trade was in manufactured goods, 7 per cent in food and agricultural products and the remainder in natural resources and energy. Similar shares result from using GTAP database 5.[16]

[15] The data source is MacMaps a product of the joint work between the *Centre d'Etudes Prospectives et d'Information Internationales* (CEPII) and the International Trade Centre (ITC). The inclusion of preferences in the new database has important consequences for the results of simulations. Of these, the most important is that the estimated gains to developing countries from multilateral liberalization would tend to be lower as those who benefited from preferences experience an erosion of those gains.

[16] In GTAP database version 5, with a base year of 1997, developed (developing) countries accounted for 66 (34) per cent of world trade.

Table 3: Basic model structure of CGE simulations of the Doha Round

Publications	Data	Baseline	Model Description	Measures Liberalized	Simulation Scenarios
Anderson, Martin and van der Mensbrugghe (2005)	GTAP Database version 6	2015 –extrapolated from 2001 by first moving to a new 2005 baseline that account for policy reforms already implemented (EU expansion to 25 members, Uruguay Round implementation, including the elimination of quotas on textile and clothing, accession of China and Chinese Taipei to WTO); then, the world economy is projected to 2015 using exogenous population, labour force growth, saving-driven capital accumulation and labour-augmenting technological progress	▪ No. of sectors 25 ▪ No. of regions: 27 ▪ LINKAGE model, a recursive dynamic model (van der Mensbrugghe, 2004) ▪ constant returns to scale and perfect competition	Agriculture - Tariffs - Export subsidies - Domestic subsidies (cut by 28 per cent for the US, 18 per cent for Norway, 16 per cent for the EU and 10 per cent for Australia) Manufacturing goods tariffs	(i) elimination of all merchandise trade barriers over the 2005-2010 period (ii) a progressive reduction formula with a marginal agricultural tariff rate reduction of 45, 70 and 75 per cent cuts for developed countries and 35, 40, 50, an 60 for developing countries for the respective bands. No cut for LDCs. (iii) adds to Scenario (ii) the "Sensitive Products" option allowed for in the July package (2 per cent of agricultural tariff lines for developed countries and 4 per cent for developing countries, subject to just a 15 per cent cut) (iv) adds to Scenario (iii) a tariff cap of 200 per cent for agricultural products (v) add to Scenario (ii) liberalization of non-agricultural products (50 per cent cut of bound rates for developed countries and 33 per cent for developing countries) (vi) like (v) but developing countries also cut bound tariffs by 50 per cent
Anderson, Dimaranan, Francois, Hertel, Hoekman and Martin (2003)	GTAP Database version 4	2005 - extrapolated from 1995 using projections of labour force growth, investments in human and physical capital. On the trade policy front, data updated to take Uruguay Round implementation (including the ATC) and China's accession into account. Standard GTAP trade elasticities were doubled given the long-term nature of the simulations.	▪ No. of sectors: 4 ▪ No. of regions: 19 ▪ Standard GTAP model with perfect competition and constant returns to scale	Agricultural tariffs Manufactured goods tariffs	Elimination of all tariffs in agricultural and manufactured goods

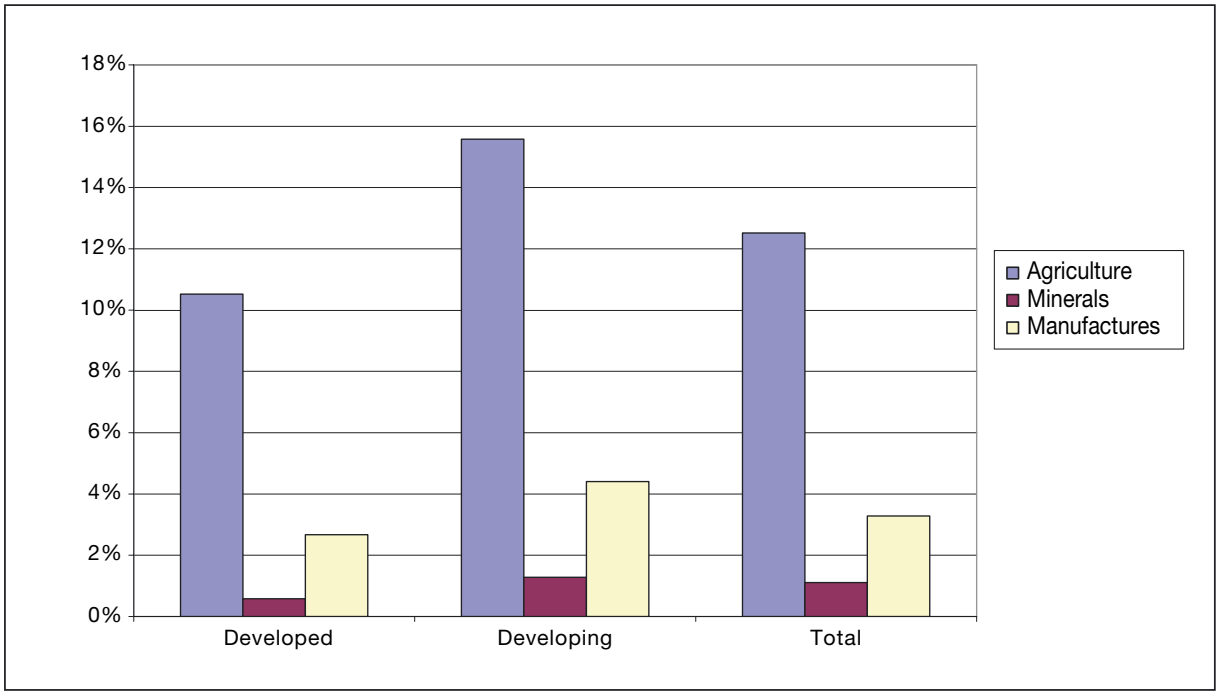
Publications	Data	Baseline	Model Description	Measures Liberalized	Simulation Scenarios
Brown, Deardorff and Stern (2003)	GTAP Database version 4	2005 - extrapolated from 1995. Services barriers are estimated from data on gross operating margins of services firms listed in national stock exchanges.	▪ No. of sectors:18 ▪ No. of regions: 20 ▪ Increasing returns and monopolistic competition in manufactures but perfect competition and constant returns in agriculture ▪ Michigan model	Agriculture - Domestic subsidies - Export subsidies - Tariffs Manufactured tariffs Services barriers	(i) 33 per cent reduction in agricultural tariffs, production and export subsidies (ii) 33 per cent reduction in manufactured goods tariffs (iii) 33 per cent reduction in services barriers (iv) Scenarios (i)+(ii)+(iii) (v) Global free trade in agricultural and industrial goods and services
Cline (2004)	GTAP Database version 5	1997 but agricultural tariff data is updated to 1998	▪ No. of sectors:22 ▪ No. of regions: 25 ▪ perfect competition and constant returns ▪ Harrison-Rutherford-Tarr model	Agriculture - Tariffs - Export subsidies - Input subsidies Manufacturing - Tariffs - Textile quotas	Complete elimination of tariffs applied to agriculture and manufactures, export subsidies and input subsidies on agriculture, and textile quotas
Francois, van Meijn and van Tongeren (2003)	GTAP Database version 5.2	1997 Protection data is modified using tariffs in WTO IDB and WITS; takes into account Uruguay Round implementation, China's accession and EU enlargement. Services barriers are estimated using a gravity equation	▪ No. of sectors:17 ▪ No. of regions: 16 ▪ Allows for increasing returns and monopolistic competition in manufactures but assumes perfect competition and constant returns in agriculture ▪ Allows for capital accumulation (dynamics)	Agriculture - OECD Domestic subsidies - Export subsidies - Tariffs Manufactured goods tariffs Services barrier Trade facilitation	(i) Linear: 50 per cent reduction in agricultural and manufactured tariffs, export subsidies, OECD domestic support and services barriers. Trading costs are reduced by 1.5 per cent (ii) Swiss: reduction in agricultural and manufactured tariffs is based on the Swiss formula with a coefficient of 0.25. 50 per cent reduction in OECD domestic support, export subsidies and services barriers. Trading costs are reduced by 1.5 per cent (iii) Complete liberalization and a reduction in trading costs of 3 per cent
OECD (2003)	GTAP Database version 5	1997 but protection data benchmarked to 1998 using data in OECD tariffs database	▪ No. of sectors: 10 ▪ No. of regions: 10 ▪ Standard GTAP model with perfect competition and constant returns to scale	Agricultural tariffs Manufactured goods tariffs Trade facilitation	(i) Linear tariff reductions by all regions - free trade in agricultural and manufactured goods and trade facilitation - free trade only in manufactured goods and trade facilitation - 50 per cent reduction in tariffs on agricultural and manufactured goods and trade facilitation

Publications	Data	Baseline	Model Description	Measures Liberalized	Simulation Scenarios
					(ii) Differential participation in liberalization - Cuts of 100 per cent and 50 per cent respectively in manufactured and agricultural tariffs by developed countries only and trade facilitation - free trade by developed countries; 50 per cent cut by developing countries; trade facilitation (iii) Swiss formula - Swiss formula coefficient of 25 and trade facilitation - Swiss formula coefficient of 15 and trade facilitation - Swiss formula coefficient of 5 and trade facilitation
UNCTAD (2003)	GTAP Database version 5	1997 Modified using TRAINS to take preferences into account	▪ No. of sectors: 6 ▪ No. of regions: 12 ▪ Standard GTAP model with perfect competition and constant returns to scale	Agriculture - Agricultural tariffs - Export subsidies	(i) 50 per cent reduction in agricultural tariffs (ii) Elimination of export subsidies in agriculture (iii) 50 per cent reduction in processed agriculture tariffs (tariff escalation)
World Bank (2003)	GTAP Database version 4				Agricultural tariff peaks are cut to 10 and 15 per cent respectively in high-income and developing countries. Manufacturing tariff peaks are cut to 5 and 10 per cent respectively in high-income and developing countries. Average agricultural tariffs are cut to 5 and 10 per cent, respectively, for high-income and developing countries. Average manufacturing tariffs are cut to 1 and 5 per cent, respectively, for high-income and developing countries. Elimination of export subsidies, tariff rate quotas and anti-dumping. Decoupling of domestic support

If tariff protection were uniform across countries, then 62 per cent of the welfare gains from removing all tariff barriers would accrue to developed countries and 38 per cent to developing countries. Furthermore, if tariff protection was uniform across product sectors then 87 per cent of the welfare gains should come from manufactures and only 7 per cent from agriculture. However, there are significant differences in the level of tariff protection both among products and among countries (see Chart 4). The average tariff on agricultural goods was about 12.5 per cent, 3.3 per cent on manufactures and 0.11 per cent on natural resource and energy products. Developing countries had higher average tariffs in each product category than developed countries.

Thus, negotiations that succeeded in reducing the highest rates of protection could raise developing countries' share of the welfare gains even though they account for slightly less than forty per cent of global merchandise trade. Significant reforms in agriculture could also lead to large welfare gains in that sector even though it represents less than a tenth of world merchandise trade.

Chart 4: Structure of tariff protection, by group of countries and by products



Source: GTAP database 6.

1. Overall welfare gains

All of the simulations that are surveyed in this study show overall welfare gains from multilateral trade liberalization in the Doha negotiations. Therefore, the models are unambiguously clear that multilateral trade liberalization would bring global benefits.

But there is a large range in the estimated welfare gains of between US$2.2 trillion and US$117 billion in 1997 dollars (we do not include the UNCTAD simulation since it only focuses on the agricultural negotiations).[17] These figures range between 7.2 per cent and 0.4 per cent of world GDP in 1997.[18] These differences arise from the coverage of the simulation (merchandise

[17] Some of the reported simulation results are in 1995 dollars and so need to be converted into 1997 dollars. The US GDP implicit price deflator is used to convert 1995 dollars into 1997 dollars. Data on the US GDP implicit price deflator is taken from Economic Report of the President: 2005 (Washington, D. C.: United States Government Printing Office), Table B3, p. 212.

[18] We use the global GDP figures reported in GTAP database version 5.

Table 4: Overall welfare gains from removal of all barriers

(in 1997 US$ Billions)

STUDY	AGRICULTURE	NON-AGRICULTURE	SERVICES	TRADE FACILITATION	TOTAL
ADFHHM	✓	✓			263.5
AMV	✓	✓	✓		264.8
BDS	✓	✓	✓		2,154.5
Cline	✓	✓			227.8
FMT	✓	✓	✓	✓	367.3
OECD	✓	✓		✓	173.6

Note: Check mark indicates inclusion of the sector in the simulation.

trade, services, facilitation), the depth of the liberalization, whether all countries contribute to liberalization, whether dynamics are included and the structure of the models themselves.

The outlier here is the BDS or Michigan simulation, which simulates the global removal of barriers in both merchandise trade and services, employing a model both with dynamics and with monopolistic competition and increasing returns to scale in manufacturing. The other simulations produce more modest outcome with predictions of overall welfare gains that cluster between US$170-370 billion.

As a general remark, it is important to highlight that, with the exception of the OECD study, all the studies reported in the chart above are simulations employing a certain per centage cut on applied rates. But WTO negotiations are on bound and not applied rates. For many countries (especially developing countries) tariff bindings are much higher than applied rates. Therefore, a commitment to cut bound rates by one third, say, may not result in any cut on applied rates.[19]

[19] See Jean, Laborde and Martin (2005) for an indication of the consequences on applied tariff rate cuts of alternative tariff cut formulas on bound rates. Notice however that the study is based on data aggregated at the six digit level, while negotiations deal with tariff rates at the tariff line level.

2. Distribution of the gains

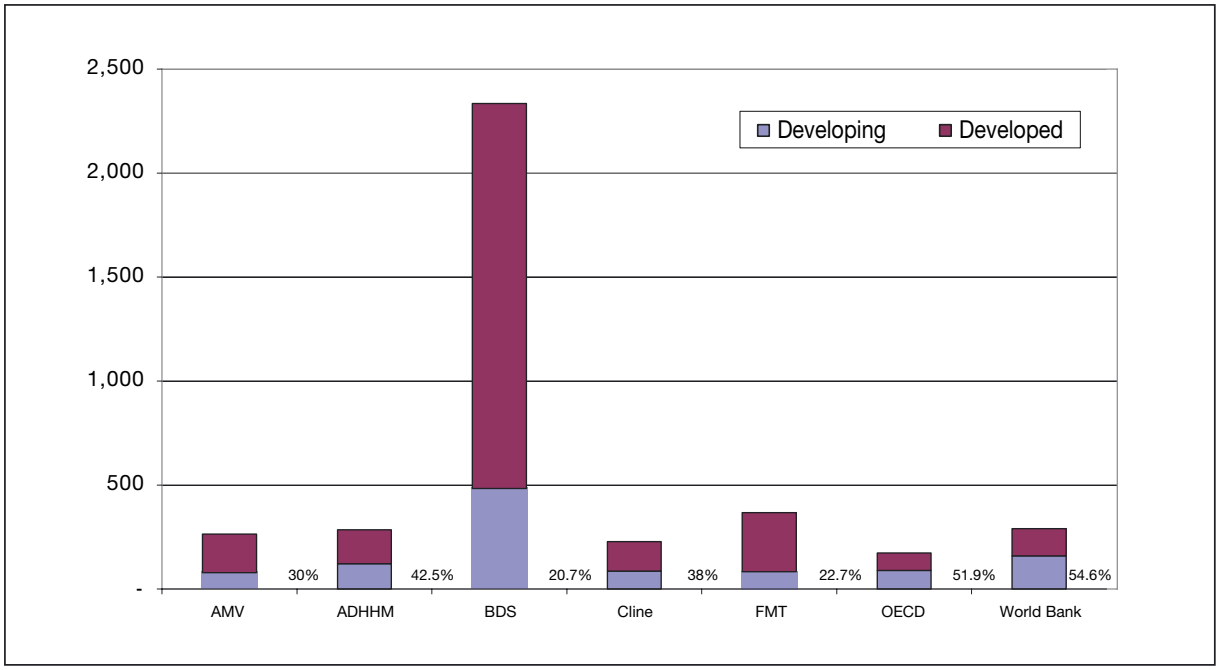
An important concern of developing countries in the current negotiations is whether they gain from liberalization and how much those gains are. Chart 5 shows that developing countries as a whole gain from multilateral trade liberalization but that the magnitude of those gains as well as their share shows some variability.

Four of the six simulations (ADFHHM, Cline, OECD and World Bank) produce results which show a hefty share of the welfare gains going to developing countries. It amounts to about 40 per cent in the ADFHHM and Cline simulations and slightly more than half in the case of the OECD and World Bank studies. Developing countries' share of the welfare gains exceeds their average share of world trade. Note that the models in these simulations are more conventional, with no dynamics and with constant returns to scale.

In contrast, the BDS, AMV and FMT simulations give the lowest share of the gains to developing countries at just about a fifth, smaller than developing countries' share in world trade, even though the simulations involve the removal of all barriers, which means that developing countries have to liberalize the most given their higher average tariffs. In the studies by BDS and FMT, a major reason for this difference has to do with the assumption that there are increasing returns to scale in manufacturing and the presence of dynamics. This is discussed in detail in the next subsection on agricultural liberalization. In the

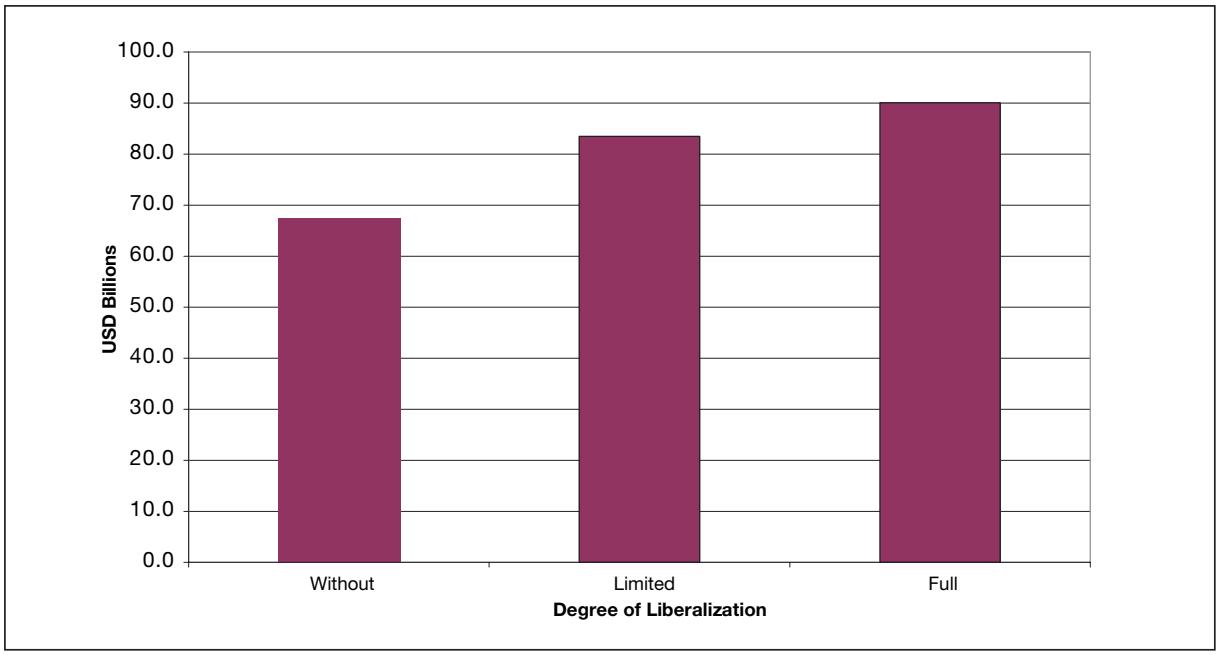
study by AMV, the relatively low share of gains accruing to developing countries compared to other studies is in part due to the inclusion of preferences in the data base. Preference erosion following multilateral liberalization is, for some countries, a source of welfare losses.

Chart 5: Overall welfare gains from multilateral liberalization (in 1997 billion dollars)



Note: Percentages indicate the share of gains accruing to developing countries

Chart 6: Welfare gains of developing countries and degree of their liberalization



Source: OECD (2003)

Economic theory suggests that, everything else being equal, a country which liberalizes more stands to gain more. The OECD study simulates how developing countries' welfare gains vary with the amount of liberalization they achieve. The simulation results are consistent with the theoretical presumption as developing countries' welfare rises with the degree of the liberalization they achieve (see Chart 6).

3. Agricultural liberalization

Simulations of trade reform in agriculture produce the greatest variance in results. Two of the papers (BDS and UNCTAD) generate simulations which show welfare losses from agriculture liberalization. One other paper (FMT) shows that trade reform can have quite opposite welfare effects on developed and developing countries. However in the three other simulations (ADFHHM, Cline, World Bank) surveyed in this study, agriculture is the sector where the greatest welfare gains are derived.

The BDS simulation shows a decrease in welfare from the liberalization of agricultural trade *alone*. This is driven by the assumption in the model that while there is monopolistic competition and increasing returns to scale in manufacturing, agriculture is characterized by perfect competition and constant returns to scale. Trade liberalization in agriculture leads to a re-allocation of resources into that sector from the increasing returns to scale manufacturing sector. This process raises marginal and average costs in manufacturing, i.e. introduces negative scale effects.

FMT finds that combining monopolistic competition, increasing returns and dynamics produce negative effects from agricultural trade liberalization over the longer-run. They find that agricultural exporters such as Australia, New Zealand and the Mediterranean countries who are close to the EU and are usually expected to gain from liberalization in the protected EU agricultural markets, do not emerge as clear winners from agriculture liberalization. The gains for South America are very limited relative to expectations. The explanation for these results is similar to that given in the Michigan model above, with which it shares the same basic features.

They also find that a reduction in domestic support in OECD countries lowers welfare in developing countries, although global welfare increases. This is true whether only partial or full liberalization is contemplated. This occurs because net food-importing developing countries, which do not have the resource base to develop their food sectors, lose from the higher prices brought about by the withdrawal of government support for agricultural production in industrial countries.

In the UNCTAD simulation of the removal of export subsidies, global welfare declines. Western Europe, Latin America and Oceania gain while all other regions lose from the removal of export subsidies. This result is puzzling since the authors employ the standard GTAP model, which assumes constant returns to scale and perfect competition in all sectors. Hence, one expects the removal of a trade distortion to increase global welfare rather than reducing it. The authors explain the outcome as being "mainly associated with a worsened allocation of resources within countries, because the elimination of export subsidies would not necessarily improve the allocation of resources while other major distortions remain in place." Their other simulations – 50 per cent reduction in agricultural tariffs and removal of tariff escalation – produce welfare gains for both developed and developing countries, with the latter gaining more from elimination of tariff escalation.

On the other hand, the ADFHHM, Cline and World Bank studies, which employ static models with perfect competition and constant returns to scale, show that close to two-thirds of the welfare gains come from agricultural trade liberalization. The ADFHHM and Cline studies simulate a more ambitious scenario - all tariffs are eliminated - while the World Bank study simulates only partial liberalization. Nevertheless, the estimated gains from agriculture are in the same order of magnitude – between US$130.5 billion and US$192 billion – and the gains are larger than in manufactures.

These results suggest that differences in assumption about market structure and the presence of scale economies are important in determining whether the world gains from liberalization in agriculture or not. Similar to some of the results of CGE simulations of the Uruguay Round, net food importing developing countries are vulnerable to a deterioration in the terms of trade, if food prices rise in world markets as agricultural subsidies are reduced in industrial countries.

4. Non-agricultural market access

All the studies find that the welfare gains from liberalization of manufactured goods are positive ranging from a low of US$54.2 billion to a high of US$276.8 billion. Whether one assumes increasing or constant returns to scale is immaterial to the eventual outcome.

Interestingly, the FMT simulation shows developing countries suffering a welfare loss from liberalization of manufactured products even though the world as a whole gains. This is explained by what happens to China as a result of manufacturing liberalization. Once its WTO accession is fully implemented, it will have realized most of the effects of its trade policy reforms. The negative results for China follow from an erosion of its terms of trade, driven by growth in textile and manufacturing exports, combined with increased competition from other low wage countries.

5. Services liberalization

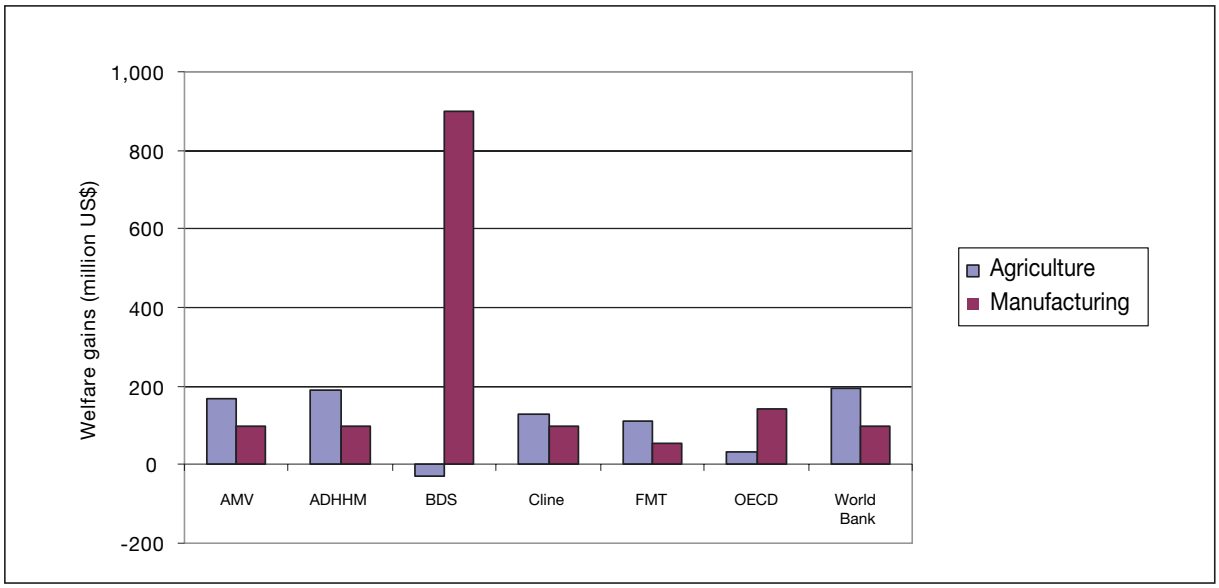
Only the BDS and FMT papers include simulations of the services negotiations. There is an important challenge posed to CGE modelling by services liberalization. Unlike merchandise goods, there are no easily measurable barriers like tariffs on services trade. Instead, barriers exist in the form of various types of limitations on foreign service suppliers.[20] Hence, an important problem for current CGE modellers is how to convert such restrictions into "tariff equivalents".[21]

Two different methods are employed in these papers to infer the magnitude of services barriers, which are both based on work by Francois and Hoekman (1999). The first method uses a gravity equation to obtain measures of services barriers. Given the paucity of services trade data, only a gravity equation of US bilateral services exports was estimated. The difference between the fitted and actual value of US services exports to a particular trade partner is then calculated and compared ("normalized") with the residuals from US-Hong Kong, China and US-Singapore services trade, which are assumed to be the

[20] Examples of these barriers include limitations on the number of foreign service suppliers, on the value of their transactions or assets, on the number of their operations or on the quantity of their output, on the number of natural persons that they may employ, or on their level of equity participation.

[21] Another important challenge is that services negotiations in the WTO are based on "requests and offers" and not on formula cuts. The outcome of the negotiations would be new or improved commitments on services- related measures. The problem is to convert these commitments into an estimate of the "bound tariff equivalent". Whether the services negotiations actually result in some liberalization depend on whether the "bound tariff equivalent" is lower than the "actual tariff equivalent".

Chart 7: Sources of welfare benefits in liberalization of merchandise trade



"free trade" benchmarks. Positive "normalized" residuals indicate the presence of a barrier to trade in the partner, which is then converted into the tariff equivalent by assuming a demand elasticity of -4. The second method uses data on gross operating margins of services firms listed on national stock exchanges. The services firms selected have operations in many markets around the world. The size of their gross operating margins in various markets provide some sense of the relative profitability of activities, and therefore, the relative magnitude of any barriers to entry that may exist. These margins are then compared to the margins of manufacturing firms operating in the same markets. If the margins are the same, they assume that services firms receive the same amount of trade protection as manufacturing firms. Thus, the tariff equivalent of the service barrier is presumed to be equal to the tariff protection received by the manufacturing sector. If the gross margins are different, let us say the manufacturing firms are half as profitable as the services firms, then it is assumed that services firms receive twice the tariff protection that is extended to the manufacturing firms.

BDS used the tariff equivalent estimates based on the gross operating margins of services firms in Hoekman (2000) while FMT estimated the tariff equivalents using a gravity model. But, the results from the gross operating margin approach should not be that different from the tariff equivalents that are obtained by running gravity model regressions (Hoekman, 2000). Given this and that both the BDS and FMT models have similar structures, with monopolistic competition and increasing returns to scale, it is troubling that the simulations should produce quite dramatic differences in estimates. BDS calculate the static welfare gains from services liberalization (33 per cent cut in the tariff equivalent) to be over US$440 billion while FMT estimates the static gains at US$24 billion (with a 50 per cent cut in the tariff equivalent). The estimates of the gains from the two simulations differ by a factor of nearly 20.

6. Trade facilitation

Results from trade facilitation are reported in this survey although great caution should be attached to them. In both the FMT and OECD studies, the assumption is that the current practices and formalities, which are to be the subject of WTO negotiations on trade facilitation, are nothing more than a deadweight loss that adds to the cost of trade. So trade facilitation has been modelled in a rather *ad hoc* manner as a reduction in these trade costs. This reduction in cost ranges between 1.5 per cent and 3 per cent of the value of world trade in FMT and is equal to 1 per cent of the value of world trade in the OECD study.

Because of the way that trade facilitation is introduced in the simulations, quite predictably it produces large welfare gains in the two papers. It is the single largest source of welfare gains in FMT - bigger than the gains that could be achieved from further market opening in agriculture, manufactures or services. In the OECD study, trade facilitation makes up between 44 per cent and 65 per cent of the welfare gains from Doha, again swamping the expected benefits from market access in manufactures, agriculture and services combined.

The reason for the cautionary warning is not that "trade costs" are unimportant impediments to trade. The recent survey by Anderson and van Wincoop (2004) for example suggests that trade costs, defined broadly as all costs incurred in getting a good to a final user other than the cost of production, are quite large. Note that their definition includes transport costs, policy barriers (tariffs and non-tariff barriers), information costs, contract enforcement costs, foreign exchange costs, legal and regulatory costs and distribution costs (wholesale and retail). They estimate the *ad valorem* equivalent of the international component of these trade costs to be 74 per cent for a representative rich country. Rather, the problem is that the mechanism by which the WTO negotiations on trade facilitation will reduce relevant components of these trade costs is not spelled out at all in the models. That the biggest gains from the simulations would come from the most opaque part of the modelling should raise a warning flag.

C. What can we learn from CGE simulations of multilateral trade negotiations?

What can we learn from this survey of simulations of the Uruguay Round and the ongoing Doha negotiations?

One of the important lessons from the CGE studies of the Uruguay Round is the need to reflect accurately the negotiating scenarios in

the simulations. The scenarios embedded in the simulations prior to the conclusion of the Uruguay Round turned out to be overly ambitious and produced large estimated welfare gains. Given that up to this point in time - mid-2005 – there are still no clear liberalization formulas in the various areas of negotiations, there is a need to be cautious about the estimates of the gains from the Doha negotiations. Many of the papers surveyed in this Study simulate the dismantling of all trade barriers. This is probably useful in establishing an upper bound to what the potential gains are from moving to free trade. But the round will stop well short of free trade.

Simulation results from the liberalization of merchandise trade are more reliable. Data on bound and applied tariffs are widely available and formula approaches to reducing tariff barriers lend themselves easily to CGE simulations. The results of the simulations in the papers surveyed in this study are not too far apart. The same confidence cannot be extended to areas outside merchandise trade. Although some of the studies produce huge gains from services liberalization, these results are suspect given the absence of good and accepted estimates of barriers to services trade. A great deal of analytical work is needed in order to incorporate trade facilitation in CGE models and to link that with the precise content of the ongoing negotiations in the WTO.

Greater attention needs to be paid to assumptions about market structure. They seem to be important in determining how large the gains are from agricultural liberalization. Kehoe's (2003) critique of some of the simulations of NAFTA raise the question of how appropriate models of monopolistic competition and increasing returns to scale are in analyzing trade liberalization between developing and developed economies.

It is important to achieve a fine level of regional disaggregation in the simulations to identify the winners and losers from multilateral liberalization. It is inconceivable that multilateral trade liberalization would not end up increasing global welfare on the basis of plausible liberalization scenarios, but it is very likely that specific regions or countries will lose out. Some of the later Uruguay Round simulations as well as a number of the Doha round simulations, which have been surveyed in this Study, highlighted the vulnerability of net food importing countries. Some hint at losses for major agricultural producers as well.

More systematic use of sensitivity analysis is needed in the studies and the results of the analysis need to be reported in an informative way. Does the sensitivity analysis strengthen the simulation results that are reported in the paper? Or do they raise doubts about the robustness of the simulation results? What particular parameters are of particular concern?

Finally, *ex-post* validation of CGE models is needed to increase confidence in the numerical results. The modeller has a responsibility to confront the predictions of his CGE model with the actual data. While there have been reviews of the Uruguay Round simulations and "lessons" drawn from them, it is not clear to what extent those lessons have been applied to the current simulations of the Doha round.

V. GRAVITY MODELS

Gravity models are econometric models of trade which acquire their name from their similarity to the Newtonian theory of gravitation. Newton's law states that the force of gravity between two bodies is positively related to the mass of the attracting bodies and inversely related to the square of their distance. The gravity model of trade predicts that the volume of trade between any two countries will be positively related to the size of their economies (usually measured by GDP) and inversely related to the trade costs between them.

In gravity models, a number of variables are generally used to capture trade costs. For example, distance and dummies[22] for island, landlocked and common border are used to reflect the hypotheses that transport costs increase with distance, they are higher for landlocked countries and islands, but are lower for neighbouring countries. Dummies for common language, adjacency or other relevant cultural features, such as colonial history, are used to capture information costs. Search costs are probably lower in trade between countries whose business practices, competitiveness and delivery reliability are well known to one another. Firms in adjacent countries, countries with a common language or other relevant cultural features are likely to know more about each other and understand each other's business practices better than firms operating in less similar environments. For this reason, firms are more likely to search for suppliers or customers in countries where the business environment is familiar to them. Tariff barriers are generally included in the form of dummies for the existence of regional trade agreements. Very few studies use information on bilateral tariffs.

The gravity model has proven to be popular among empirical trade economists. Gravity models have been used to study a range of trade questions - some of which are of direct concern to trade policy-makers and some which are less so. Gravity models have been used widely in the literature on preferential trade agreements and currency unions. Recent studies have also relied on gravity models to estimate whether membership to the GATT/WTO increases trade. They have also been used to examine statistically the link between trade and growth and trade and the environment.

There are a couple of reasons for the central role played by the gravity model in empirical work on international trade. The first has to do with the high explanatory value of the model in explaining bilateral trade flows.[23] The second reason is that it provides an easy method to test the role that other variables play in affecting trade. Some analysts claim that given the high explanatory power of the standard variables used in the gravity model, obtaining significant results on additional variables is likely to indicate that these additional variables are actually important for trade.

However, the goodness of fit of gravity models cannot be a justification for using this model in an *ad hoc* manner. One cannot simply plug an additional policy variable into the standard gravity model (where bilateral trade is explained by the importer and exporter GDPs, populations and bilateral distance) and interpret the coefficient of this variable as the response of trade to a change in policy without a theoretical framework in mind. An important point made in the recent economic literature (Anderson and van Wincoop, 2003) is that a structural interpretation of regression coefficients requires a structurally consistent approach to estimation. Lack of theoretical underpinnings significantly weakens the credibility of a model, as it introduces a certain degree of subjectivity in the interpretation of the estimated coefficients. Moreover, the good performance of standard gravity variables in explaining the profile of bilateral trade across countries does not necessarily imply that these variables explain the part of the variation in the data relevant to the policy variable. In addition, the arbitrary addition of a variable may generate econometric problems of estimation. For example, if the new variable is highly correlated with another explanatory variable, it may be difficult to correctly identify

[22] Dummies are variables that only assume the value zero or one. For example, a dummy denoting whether the importing country is an island takes the value one for all observations when the importing country is indeed an island and zero otherwise.

[23] The R^2 which measures the explanatory power, is usually between 65 to 95 per cent, depending on the sample (Bergstrand, 1998). This is exceptional given the cross-section nature of the data.

the respective contributions of the two correlated variables to trade.[24]

The latest debate over structural gravity models has stressed the importance of introducing multilateral resistance terms in the estimated equations and including observations of countries that do not trade in the data set. The next subsection looks at these issues in detail.

A. The theoretical underpinning of gravity models

The first empirical study of trade using the gravity model was probably Tinbergen's (1962), although there was no explanation for the use of the model nor for showing how it was related to theoretical explanations of international trade. Prominent models of international trade at that time included the Ricardian model, which relies on differences in technology across countries to explain trade patterns and the Heckscher-Ohlin (HO) model which relies on differences in factor endowments among countries as the basis for trade. It was assumed then that standard Ricardian and HO models were incapable of providing a foundation for the gravity model.

The first important attempt to provide a theoretical basis for gravity models was the work of Anderson (1979). He did so in the context of a model where goods were differentiated by country of origin[25] and where consumers have preferences defined over all the differentiated products. This structure would imply that, whatever the price, a country will consume at least some of every good from every country. All goods are traded, all countries trade and, in equilibrium, national income is the sum of home and foreign demand for the unique good that each country produces. For this reason larger countries import and export more. Trade costs are modelled as "iceberg" costs, that is only a fraction of the good shipped arrives to destination, the rest having melted in transit. Clearly, if imports are measured at the c.i.f. value, transport costs reduce trade flows. In the empirical literature these transport costs are assumed to be monotonically increasing with distance. Subsequent elaborations included introducing monopolistic competition in the model (Bergstrand, 1990). Models with monopolistic competition overcome the undesirable feature of Armington models whereby goods are differentiated by location of production by assumption. Firm location is endogenously determined and countries are specialised in the production of different sets of goods.

Recent work has shown that, far from being a purely econometric tool without a theoretical basis (an early criticism against the gravity model), gravity models can arise out of a range of trade theories.[26] Deardorff (1998) shows that a gravity model can arise from a traditional factor-proportions explanation of trade and derived a gravity-type relationship from it. Eaton and Kortum (2001) derive a gravity-type equation from a Ricardian type of model. Anderson and van Wincoop (2003) draw it from a model of monopolistic competition in differentiated products and Helpman et al. (2004) obtained it from a theoretical model of international trade in differentiated goods with firm heterogeneity.[27]

This recent research has highlighted the importance of deriving the specifications and variables used in the gravity model from economic theory. Only then can the proper inferences from estimations using the gravity equation be drawn. For example, the important contribution of Anderson and van Wincoop's paper has been to highlight that controlling for relative trade costs is crucial for a well-specified gravity model. Their theoretical results show that bilateral trade is determined by *relative* trade costs, that is the propensity of country *i* to import from country *j* is determined by country *i's* trade cost toward *j* relative to its overall "resistance" to import (weighted average trade costs) and to the average "resistance" facing exporters to country *j*, and not simply by the absolute trade costs between country *i* and *j* (Anderson and van Wincoop, 2003).

[24] This problem is known as multicollinearity. In gravity models, multicollinearity often emerges when a policy variable is correlated with GDP per capita, like in the case of quality of infrastructure or institutions. In this case changes in the specific functional form of the gravity equation or in the variables used for the estimations may deliver very different results for the coefficient of the policy variable.

[25] This is the Armington assumption.

[26] For a study on which economic theory finds more support in the data see Evenett and Keller (2002).

[27] This is a model built along the lines of Melitz (2003) where firms face fixed and variable costs of exporting. Firms vary by productivity, and only the more productive firms will find it profitable to export.

In terms of the empirical gravity model this implies that after controlling for country size and bilateral distance, trade will be higher between country pairs that are far from the rest of the world than between country pairs that are close to the rest of the world. Thus, multilateral resistance terms (often proxied with remoteness indexes in the empirical trade literature) need to be added to the standard gravity variables. Alternatively, unbiased estimates of the impact of distance and other bilateral variables on bilateral trade flows can be obtained by replacing the multilateral resistance indexes with importer and exporter dummies (Anderson and van Wincoop, 2004).[28] These country dummies will capture all country specific characteristics and will control for a country's overall level of imports/exports.

It is important to note in this context that when country-specific dummies are introduced into the gravity model, it is no longer possible to estimate the separate role of variables that vary across countries but not bilaterally (such as GDP, population, quality of infrastructure, institutions etc.). Moreover, other policy variables in the model only explain the distribution of a country's trade across trading partner, but not the overall level of trade. And the responsiveness of trade to a policy variable reflects the degree of substitutability of traded goods.[29]

Another issue that has recently received attention both in the theoretical and empirical literature on the gravity model is the evidence that half of all country pairs do not trade with one another and that bilateral trade is not symmetric. A recent study by Helpman et al. (2004)[30] develops a theoretical framework that determines both the set of a country's trading partner and the volume of trade. The model is one of international trade in differentiated products and heterogeneous firms, where firms face fixed and variable costs of exporting. Zero trade between a country *i* and a country *j* occurs when the productivity of all firms in country *i*, say, is below the threshold that would make exporting to country *j* profitable. Differences in trade costs across countries and firm heterogeneity also account for asymmetries between the volume of export from *i* to *j* and that from *j* to *i*.

Many empirical studies drop zero trade observations from the sample of countries. Often this is simply the consequence of the log-linear[31] specification of the gravity equation. On the basis of their model, Helpman, et al., argue that disregarding zero trade observations has important consequences for the empirical analysis, as it generates biased estimates. They also argue that the standard specification of a gravity model, by imposing symmetry of trade flows (that is, that the volume of imports from A to B equal imports from B to A), is inconsistent with the data, and also biases the results. To solve the problem, they propose a two-stage estimation process to obtain unbiased and consistent estimation of their gravity equation. In the first stage, the probability that two countries trade is estimated. In the second stage, a gravity model augmented for importer and exporter country fixed effects is estimated that also includes one variable that controls for the sample selection bias and another one that controls for unobserved firm heterogeneity. They also show that this procedure changes significantly some of the traditional results of the gravity model: the coefficient on distance falls and that for common language becomes non-significant.

B. Applications of gravity models

It may be instructive to examine how the gravity equation is used to answer questions about the effects of regionalism or GATT/WTO membership. This illustrates both the strengths as well as the weakness of the model.

In the following sections we survey some work utilizing gravity models. Where evidence is contradictory, we shall consider why. These

[28] These dummies are often called country fixed effects.

[29] See Hummels (2001) for estimates of substitution elasticities.

[30] For other explanations for the prevalence of zero bilateral trade flows, see Anderson and van Wincoop, 2004; Evenett and Venables, 2002; and Haven and Hummels, 2004.

[31] In the log-linear specification all variables appearing in the gravity equation are in logarithms. This specification is often chosen, because it allows an easy interpretation of the estimated parameters: the parameters of an equation estimated in logarithms are elasticities. For example, the estimated parameter for the GDP, in a gravity equation estimated in logarithms, is the elasticity of trade to GDP and it indicates the percentage change in trade following a 1 per cent increase in GDP. However, since the logarithm of zero cannot be calculated, zero observations need to be dropped from the sample before running a regression.

include the importance of capturing asymmetries across countries and the appropriate degree of disaggregation. More recently, the relevance of including observations of countries that do not trade with each other has also been investigated.

1. Regionalism

Gravity models have been widely used to investigate the impact of preferential trading arrangements (PTAs) on trade among the members of the integration scheme. The basic idea is to include an additional dummy variable in the standard gravity model that captures variations in the levels and direction of trade due to the formation of a preferential trading arrangement among a group of countries. It is assumed that the "normal volume of trade" between a pair of randomly selected countries can be explained by size (GDP, population, land area) and distance (broadly defined as trade costs) between two countries. If the preferential trade arrangement increases the trade among the members of the arrangement above its "normal" value, then the intra-bloc dummy variable (a variable that represents the existence of a preferential agreement between two countries)[32] will get a positive and statistically significant coefficient.

Gravity models are also used to capture the trade diverting effects that the creation of a regional block can have on non-members. For this purpose, a second dummy variable (extra-bloc dummy) is added to the basic gravity equation to indicate when trade occurs between countries where only one of the two is party to a regional agreement. If countries outside a certain regional trade agreement trade relatively less than normal with countries that belong to a regional block, then the dummy variable will take a negative and significant coefficient.

It is important to be cautious about drawing any inferences regarding economic welfare from the econometric results obtained from gravity models. In general, it is not possible to conclude that the economic welfare of the members of a PTA has increased just because the estimates from a gravity show that the PTA has increased trade among the members.[33]

Economic theory suggests that the overall welfare effects of a PTA depend on the balance between trade creation and trade diversion. Trade creation takes place when, as a result of the preferential rate established by a PTA, domestic production of a product is displaced by the imports from a member country, where the good is produced at a lower cost or additional demand for imports is created. Trade diversion occurs when as a result of preferences, imports from a low cost country outside the regional trade agreement are displaced by imports from a higher cost partner country.

Trade creation and trade diversion have opposite effects on welfare. Trade creation generates welfare gains for member countries without imposing any losses on non-members. Consumers resident in the preferential area will pay less to purchase the same product, so they enjoy a welfare gain. And these gains outweigh the loss in producer surplus and tariff revenues which occur as a result of the elimination of protection from competition from PTA partners. In contrast trade diversion generates a welfare loss. Trade diversion not only represents a cost for the exporting country outside the preferential agreement (that will see its exports reduced), but it also represents a cost for the importing country in the preferential trading arrangement. Consumers pay a lower price than before the preference was introduced, but the government loses tariff revenue. This generates a loss for the country as a whole.

In other words, economic theory implies that free trade agreements increase trade among members through trade creation (increased trade as a result of relative efficiency) and through trade diversion (increased trade as a result of preference). Therefore, an increase in intra-PTA trade arising from the establishment of a PTA does not mean that overall the preferential trade agreement has increased the welfare of the PTA members. The increase in intra-PTA trade needs to be analysed

[32] This variable will take the value 1 when both the importer and the exporter country belong to the same regional trade agreement and zero otherwise. It captures the additional effect on trade due to the preferential treatments of imports from the region.

[33] There is a large literature of CGE models analysing the welfare implications of regional trade agreements (see World Bank, 2004 and Brown, Deardorff and Stern, 2003).

in conjunction with the result on trade diversion. For example, if there is no evidence of trade diversion, a positive and significant coefficient on the PTA-dummy can be imputed only to trade creation, hence the PTA is welfare improving. However, if there is evidence of trade diversion, overall welfare effects cannot be derived from the impact of the PTA on bilateral trade volumes. As shown in Box 2 the link between trade effects and welfare is weak. A gravity model measures trade effects but not welfare effects.

Box 2: The link between trade outcomes of a RTA and welfare

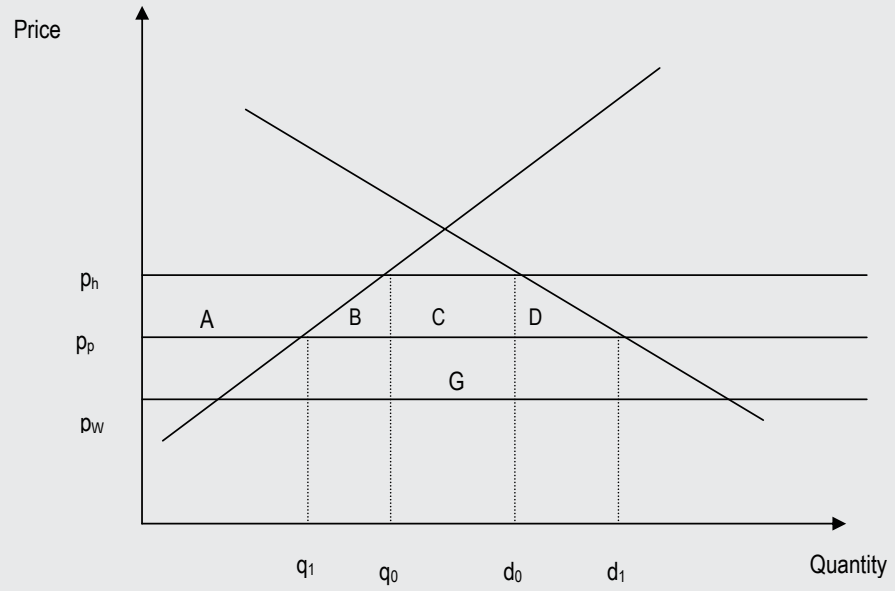
A partial equilibrium model of the type presented in Box 1 can help explain the difference between trade effects and welfare effects following the creation of a PTA.

Consider a three-country model, where the home country (H) is assumed to be small compared to the partner (P) and the rest of the world (W). It faces an infinitely elastic supply at prices p_p and p_w; that is, at these prices country H can import whatever quantity it demands, but it cannot affect the price. Before forming a customs union, H is assumed to have a non-discriminatory *ad valorem* tariff τ on imports. Assume W is the least-cost source of foreign supply, before the regional trade agreement. Then, H will import d_0-q_0 at the price $p_h=p_w(1+\tau)$.

Suppose now that country H and P form a FTA. Country H will now import from P, since p_p is less than p_h (the price it would have to pay for imports from W, since tariffs from the rest of the world did not change). Consumers will now pay p_p and imports will rise to d_1-q_1. As a result of the FTA, overall imports increase by q_0-q_1 plus d_1-d_0 and domestic prices fall. Consumers gain as they can consume a higher quantity for a lower price (the area A+B+C+D represent this gain). Producers lose (area A) and the government lose tariff revenue (area C+G). The area B plus D is the trade creation effect of the FTA and it constitutes an increase in welfare. The area G is the trade diverting effect of the FTA and it is a reduction in welfare. The overall welfare effects of an FTA will depend on the balance between trade creation and trade diversion. But this is only weakly related to the variation in the patterns of trade.

Geographical representation on next page.

Trade creation and trade diversion: a geographical representation.



Analytically, trade diversion is:

Area G= $(p_p-p_w)(d_0-q_0)$

trade creation

Area B= $(p_h-p_p)(q_0-q_1)/2 = \varepsilon\, q_0\, (p_h-p_p)^2/2$

Area D= $(p_h-p_p)(d_1-d_0)/2 = -\eta\, d_0\, (p_h-p_p)^2/2$

where $\varepsilon > 0$, $\eta < 0$ represent the supply and demand elasticity, respectively, and $p_h=p_w(1+\tau)$ has been normalized to 1

net welfare effects

Area (B+D-G) = $[p_w\tau-(p_p-p_w)]^2(\varepsilon\, q_0-\eta\, d_0)/2-(p_p-p_w)(d_0-q_0)$

The net welfare equation shows that welfare increases:
(i) the more elastic (the flatter) are the demand and the supply curves;
(ii) the lower the difference in production efficiency between P and W;
(iii) the higher is τ; and
(iv) the lower the pre-RTA level of outside imports relative to domestic demand or supply.

Numerous analyses of the economic effects of specific PTAs, undertaken in recent years, show mixed results.[34] A glance at the recent literature shows conflicting conclusions about the impact of PTAs on trade. Table 5 shows the details of a number of studies on preferential trade agreements using a gravity model.

Table 5: Gravity model applications to regional trade agreement

Publications	RTA	Data	Model	Results
Frankel (1997)	EC, EFTA, NAFTA, MERCOSUR, Andean, ASEAN, ANZCERTA.	63 countries, 1965-1994 (5 year interval)	Traditional log-linear on levels of variables, augmented with an intra-bloc and extra-bloc dummy. Dependent variable: total trade	Net trade creation is estimated for the EC MERCOSUR, ANZCERTA, ASEAN. Andean, NAFTA and EFTA have no significant impact on intra-PTA trade. Trade diverting effects are found for EFTA and NAFTA. Much larger EC impact on internal trade in agricultural products.
Bayoumi and Eichengreen (1995)	EEC, EFTA	1956-92 annual, 21 industrialised countries.	Two model used: a) traditional level gravity model; b) first difference version of the gravity model. Both models are augmented with an intra-bloc and extra-bloc dummy Three subsamples used: 1956-73, 1965-80, 1975-92 Dependent variable: real imports deflated using US GDP deflator	EFTA is found to be net trade creating. For the EU both trade creating and trade diverting effects are found.

[34] See OECD (2001), *Regional Integration: Observed Trade and Other Economic Effects*, Working Party of the Trade Committee, TD/TC/WP(2001)19/Rev.1, for an extensive review of the empirical evidence on the trade effects of RTAs.

Publications	RTA	Data	Model	Results
Soloaga and Winters (2001)	EC, EFTA, NAFTA, MERCOSUR, Andean, CACM, LAFTA/LAIA ASEAN, GCC	1980-96 annual non-fuel imports, 58 countries.	Traditional log-linear on levels of variables, augmented with three dummies: an intra-bloc, and two extra-bloc dummies: one on imports and one on exports. Two sets of estimations: a) one for each year; b) pooled data on average values for 1980-82, 1986-88 and 1995-96. From this they test changes in the coefficients before and after blocs' formation. Real exchange rate variable added to the pooled regression. Dependent variable: imports	Estimates on level show: a negative intra-bloc dummy for the EU, EFTA and ASEAN; positive intra-bloc effects for CACM, LAIA, ANDEAN and MERCOSUR; non-significant for NAFTA. Estimates on first differences show: EU and EFTA are net trade diverting, MERCOSUR and CACM are net trade creating.
Dee and Gali (2003)	Andean, APEC, EFTA, EC, GCC, LAFTA/LAIA, MERCOSUR, SPARTECA, CER, AFTA and a set of bilateral agreements.	1970-97, Tobit estimation.	Traditional log-linear on levels of variables, augmented with three variables: an intra-bloc, and two extra-bloc variables one on imports and one on exports. However, rather than being zero-one dummies, these variables take the value of the Member Liberalization index (an index of the coverage of the RTA), whenever the RTA is in force. The model also includes country-fixed effects and time dummies. Dependent variable: exports Two sets of estimates: including or not bilateral tariffs among regressors.	Nearly all RTA are found to have *net* trade diverting effects. Net trade creating results are found only for Andean, LAFTA/ LAIA, US-Israel and SPARTECA.

A lot of the variability of the results can be explained by the specific modelling approach chosen, the extent of sectoral aggregation, the sample of countries, the type of analysis (cross section, time series or pooled), the time period and the quality of the data used.

Let us first turn to the modelling approach used. When comparing across different models it is important to pay attention to the exact definition of dummy variables. All applications of the gravity model to regionalism include an intra-bloc dummy. Most applications only include one extra-bloc dummy variable and in general, this variable is defined in a way that it captures the diversionary effects of a regional trade agreement both on imports and exports.[35] However, some applications add two extra bloc dummies to the standard gravity equation (like in the paper by Soloaga and Winters, 2001): one capturing

[35] That is, the extra-bloc dummy takes the value 1 when either the importer or the exporter country belong to the regional trade agreement. Notice that in some cases this extra bloc dummy may be defined in a way to include the case of both the exporter and the importer belonging to the same regional trade agreement. In this case, the extra-bloc dummy capture the overall level of openness of the bloc and the intra-bloc dummy should be interpreted as the additional bloc trade after controlling for overall openness.

diversion of imports of RTA member countries from non-members and the other one capturing diversion of RTAs member countries' exports.[36] This alternative specification allows for imports and exports being affected differently by the creation of a regional trade agreement and may prove to be a better specification of the model.

In order to get the correct interpretation of the parameters, it is also important to look at whether country fixed effects are included in the regressions. Estimations with country fixed effects are among the most credible.[37] Yet, it should be kept in mind that these models cannot measure the impact of the removal of tariff barriers on the overall level of trade, but only estimate how the relative distribution of imports/exports across trading partners may change.

As a general remark, it is worth adding that dummy variables capture the effects of a certain category of omitted variables in the regression. For example, country-specific dummy variables capture the overall effect of all variables that are unique to that country (GDP, population, quality of infrastructure, institution, etc.). Similarly, intra-regional-bloc dummies capture all regional-specific characteristics. It may be the case, however, that there are characteristics of a region, aside from freeing trade among its members that are omitted from the explanatory variables in the regression, but which facilitate intra-regional trade (for example a good regional transport network that reduces transport costs). In order to take this into account, it may be necessary to test the significance of changes in the intra-bloc dummy's estimated coefficients before and after the bloc's formation. The "traditional" trade-creating effect will be identified by an increasing overall propensity to import from members (this is the approach followed in the paper by Soloaga and Winters, 2001).

The degree of disaggregation of data used in the analysis is another important factor. As the margin of preference resulting from a regional trade agreement differs across sectors, we should expect a different effect of the regional-bloc dummy across sectors. When aggregated data is used for the analysis of the overall impact of an RTA, some the sectoral effects offset each other. For example, the NAFTA bloc dummy is not significant when estimated on aggregated merchandise trade data, because a large percentage of trade between Canada and the US was free even before the Agreement entered into force (1989). If the sectors that benefited most from the liberalization were small, aggregate data would probably not change in a significant way so as to be picked up in the econometric analysis.

It is important to note that when estimations are run using disaggregated data, the "standard" gravity approach of explaining bilateral trade with source and destination country GDPs might be unreliable, because the exporter's GDP does not reflect a country's comparative advantage in a certain sector. More credible alternatives may be the use of output data for the exporting industry or the use of sectoral country-specific fixed effects (dummy variables that control for country specific characteristics at the sectoral level). In the latter case, a caveat needs to be borne in mind, that is that fixed effects control for the average level of sectoral exports, hence any other policy variable in the gravity equation only explains variations from the mean. When fixed effects are used in the gravity regressions, the average level of trade is taken as given, the coefficients of policy variables, such as the regional trade dummy, therefore, cannot be used to predict the impact of a policy change on the overall level of trade.

Another factor to take into account when analysing differences across studies about the impact of regional trade agreements on trade using a gravity model, is the sample of countries. The set of countries included in a gravity model defines the counterfactual on the basis of which a certain hypothesis is tested. In a gravity model the standard gravity equation defines the counterfactual (that is, what would have been the normal level of trade had the regional trade agreement not been implemented). Since the counterfactual changes according to the set of countries in the sample, the results of estimations may change. In this context, it is illuminating

[36] One dummy takes the value one when the importer is a member of the RTA, the other one takes the value one when the exporter is a member of the RTA. Again notice that the extra-bloc importer (exporter) dummy can be defined in a way to include only imports from (exports to) non-members or as well imports from (exports to) members.

[37] Recall that Anderson and van Wincoop (2004) argue that they provide unbiased estimates for the coefficient of the variables with bilateral variations.

that while in general a positive and significant effect of the formation of the European Union on intra-European trade is found in samples of OECD countries, frequently a negative or non-significant effect is estimated in large cross country data samples.[38] This counterintuitive result has led many analysts to doubt the effectiveness of standard gravity models in explaining the "normal" level of trade in large cross-country samples.

Different results can at times also be explained by the different types of sample: only cross-sectional data or data pooled over time. For example, Frankel (1997) does not find a significant impact of NAFTA on intra-NAFTA trade when the analysis is run on the cross-country sample, while he estimates that the NAFTA bloc increases trade by 43 per cent with respect to otherwise similar countries, when data are pooled over 1970-92.

Another factor affecting the estimation results of a gravity model is the choice of the time period. For example, the pattern of devaluations in Latin American countries can partially explain the variety of results relating to Latin American regional blocs. The estimation carried out by Soloaga and Winters indicates that, over the period 1980-1996, members of MERCOSUR, CACM, LAFTA, Andean Group respectively traded among themselves about 9, 45, 3 and 7 times more than predicted by the gravity model. On the other hand, estimates obtained by Frankel (1997) show that over the period 1965-90 the Latin America bloc effect was not always significant. In particular, the MERCOSUR bloc effect began to be significant in 1980. The Andean Group showed a significant positive sign in 1992, when the Andean Pact was reinforced. Another paper (Gilbert et al.) finds that the MERCOSUR dummy is not significant over the period 1986-1998.

Finally, the quality of data is a very important factor in empirical estimations. Missing data, measurements errors and sample selection bias can be the source of differences in estimation. Some of these problems arise from the data sources themselves. For example, bilateral trade data fail to distinguish between zero trade and missing data. Therefore, traditionally gravity models have been estimated on a sample of countries reporting positive trade flows among themselves. However, as we will discuss in the next subsection this can be the source of serious bias in the estimations.

Moreover, information reported by the exporting country often does not match that of the importing country. Therefore, gravity model estimates might differ significantly depending on whether the chosen dependent variable is imports, exports or total trade. In general, import data are considered to be more reliable than export data. This would seem to suggest that using import data might be preferable, because export data may suffer from measurement errors. Measurement errors may result in inefficient estimators. That is, the estimated standard deviations of the coefficients (used to estimate whether a coefficient is significant or not) is larger than it should be. Therefore, it cannot be ruled out that what appears to be non-significant variables are actually significant, although the coefficients are still consistent.

However, imports are recorded using c.i.f. prices, that is, including transport and insurance costs. The problem with a c.i.f valuation of imports is that variables measuring transport costs, such as distance, are correlated with the error term, thus yielding inconsistent estimates of the distance coefficient.[39] This problem does not arise when exports data are used for the regressions as exports are evaluated at f.o.b prices. The choice between using import or export data is therefore a choice between efficiency and consistency.

Overall, in the light of the discussion on the theoretical underpinning of a gravity model, it should be emphasized that a large part of the studies of the impact of regional trade agreements on trade using the gravity model neglect country specific multilateral resistances and zero trade observations.

[38] See for example Soloaga and Winters (2001).

[39] Consistency is a desirable property of estimators, where as the sample size increases the estimator converges (tends to come closer and closer) to the true value of the parameter that is being estimated.

2. GATT/WTO membership and trade

An interesting example of apparently conflicting empirical evidence resulting from the use of gravity models is provided by the recent papers on the impact of GATT/WTO membership on trade. To the surprise of most, in a recent paper published in one of the most important economic journals, Rose (2004) argues that there is no evidence that GATT/WTO membership increases a country's trade. Rose estimates a standard gravity model augmented for a dummy indicating whether both or one of the two trading countries are WTO Members. He used a wide data set covering 178 countries over 50 years and implemented a series of sensitivity tests. The result is surprisingly robust.

A number of reasons have been advanced to explain these results. Rose's study does not take into account that:

- before the establishment of the WTO, accession to the GATT did not require a significant reduction in the Member's own trade barriers if it was a developing country: between 1950 and 1994, 63 developing countries joined the GATT under GATT Article XXVI:5c.[40] No negotiations took place before entry and, therefore, they did not have commitments to liberalize their trade regimes;

- a transition period for tariff reduction is generally allowed for (usually 5 to 10 years), so that there might not be a significant reduction in tariffs at the time of GATT/WTO membership;

- in many circumstances, countries benefited already from MFN treatment or preferential tariffs before the accession to GATT/WTO;

- in other cases, acceding countries removed important barriers to trade incompatible with WTO prior to accession. For example, China substantially lowered its applied average tariff before entering WTO and was granted nine more years to implement tariff cuts; and

- many developing countries are exporters of fuels and minerals, and have a comparative advantage in agriculture. Fuels and minerals always faced low tariffs in developed countries on the one hand while agriculture still remains a highly protected sector.

Many of these features of the GATT/WTO system were meant to smooth the adjustment process triggered by the accession to WTO, in particular for developing countries. But at the same time they tended to blur the impact of WTO membership on trade flows. Most developing countries already had MFN or even preferential access to developed countries before entering the WTO and benefited from special and differential treatment after joining the WTO. It is more logical then to expect a clearer impact of GATT/WTO membership on developed countries. This is indeed what Rose finds. There is a positive and significant effect of GATT membership when the sample is confined to developed countries.

Recent economic literature has pointed to two major issues neglected in Rose's papers: the failure to distinguish country and sector asymmetries in terms of *de facto* liberalization and the omission of zero trade observations.

Subramanian and Wei (2003) introduce fixed effects and asymmetries between countries and sectors in their gravity equation and find that GATT/WTO effectively promotes trade but unevenly. That is, GATT/WTO membership appears to have a significant effect on trade for developed countries, but does not appear to have had a significant impact on the trade of developing countries. Moreover, GATT/WTO did not impact positively on trade in protected sectors, such as agriculture and textile and clothing. Finally, WTO membership has a relatively stronger effect on new Members (those that entered after 1993) than on old Members (those that joined before the Uruguay Round). It is important to note also that Rose's results show a positive effect of WTO membership on bilateral trade when country-fixed effects are introduced. The paper simply doesn't stress this result.

[40] GATT Article XXVI:5c states: "If any of the customs territories, in respect of which a contracting party has accepted this Agreement, possesses or acquires full autonomy in the conduct of its external commercial relations and of the other matters provided for in this Agreement, such territory shall, upon sponsorship through a declaration by the responsible contracting party establishing the above-mentioned fact, be deemed to be a contracting party."

Tomz et al. (2004) also show that GATT/WTO membership has a positive impact on trade, when the fact that some countries are at least as liberalized as WTO Members. They find that a group of countries, called non-member participants, defined as colonies of formal Members, new sovereign states and provisional applicants to WTO are *de facto* at least as liberalized as WTO Members. They further show that bilateral trade between two countries that are either formal GATT/WTO Members or non-member participants is 45 per cent higher than otherwise.

There are factors, which change over time, that are omitted from the gravity model. One of these is the number of zero-trade observations in the sample. World trade increases both because trade volumes between a pair of trade partners increase and because countries that did not trade with each other before enter new trade relationships. Most estimations using the gravity model restrict their analysis to those country pairs for which positive trade is observed.[41]

Recent empirical work has highlighted that this approach may lead to biased estimates due to the sample selection bias. This bias arises because the sample that is used for estimation is no longer random, i.e., some types of observations will be over-ly-represented while other types are under-represented. For example, if GATT/WTO membership not only affects the volume of trade between existing trading partners but also generates *new* trading relationships, that is two countries are more likely to trade with each other if they are both GATT/WTO Members, dropping zero trade observations will imply losing information on those who start new trade relationships. Hence, the effect of WTO membership will be underestimated.[42]

Felbermayer and Kohler (2004) and Liu (2004) explore the role that the omission of information about countries that do not trade with each other has on Rose's results. They formulate the problem as follows. They assume that the observed values of bilateral trade are the outcomes of an underlying trade model where bilateral trade is the maximum between zero and the predictions of a gravity equation. Then, they apply the Tobit procedure (the appropriate procedure for a censored regression analysis)[43] to estimate unbiased and consistent coefficients for the gravity equation. They both find that GATT/WTO membership has a positive and significant effect on trade. Their estimates though differ significantly. This is because of a problem with the data. The IMF Direction of Trade Statistics (DOT) database does not allow one to distinguish between zero trade and missing information. So the authors have used two different ways to fill the missing data: imposing zero trade on all observations where no positive trade is recorded or drawing information from other data sources. Since zero and missing trade observation sum up to about half of the bilateral trade relationship, these different assumptions have a strong impact on the results.

The work by Helpman et al. (2004) also stresses the importance of including information about countries that do not trade with each other in order to get unbiased estimates of the parameters of the gravity model. They, however, also stress that there is not just a problem of sample selection bias due to the zero trade. There is also a missing variable in the standard gravity model specification. This is the proportion of firms exporting to each destination country. This variable is endogenous

[41] As explained in footnote 15, this is often simply the consequence of opting for a logarithmic specification of the gravity model.

[42] Felbermayer and Kohler (2004) argue that excluding zero trade observations in the sample may also result in an estimated increasing role of time-invariant variables, such as distance, and propose this as one explanation of the so-called "distance puzzle". The argument is as follows. If only positive trade observations constitute the sample for estimation, forces of attraction will be overestimated and trade-inhibiting forces underestimated. As the number of zero trade cases fall over time, then the underestimation bias of the trade-inhibiting forces will also fall over time, thus resulting in an increasing inhibiting effect of distance over time.

[43] In econometrics, censoring of data occurs when the values of the dependent variable are constrained to lie within a range and to cluster at the endpoints of the range. This is characteristic for example of the annual expenditures on durable consumer goods (cars, refrigerators, etc.). These goods are purchased infrequently so the data for many years will show expenditures equal to zero, but during a year when a purchase is made, the expenditures will be very large. Tobin was the first to raise the problem of censored data in economics and to show that ordinary least square estimation (OLS)- the estimation procedure commonly used in regression analysis and benchmark for many studies, based on the minimisation of the squared differences between the observed values and the value predicted by the fitting line- led to biased and inconsistent estimators. He proposed an alternative estimator (the Tobit) that was both unbiased and consistent.

to the model and is determined by unobservable factors (the cut off conditions for exporting). In order to get consistent estimates, they develop a two-stage procedure where they first estimate the proportion of exporting firms and the sample selection bias. Then, they estimate a gravity model where along with separate exporter and importer dummies, the two new control variables are introduced. They find a very strong positive and significant effect of WTO membership on the formation of bilateral trade relationship and on the volume of bilateral trade.

Table 6: What is the impact of GATT/WTO membership on trade?

Publication	Data	Model	Results
Rose (2004)	178 countries 1948-1999 (with gaps)	Dependent variable: average bilateral trade (exports + imports) deflated by US CPI	WTO coefficients: 0.04 (OLS) 0.15 (OLS country fixed effects)
Subramanian and Wei (2003)	Aggregated data: 5-year period from 1960 to 2000, 172 countries Sectoral data: HS 4-digit in 1990, 1995 and 2000 for 147 countries.	Dependent variable: imports deflated by US CPI for urban areas Gravity model with separate exporter, importer fixed effects and year fixed effects	i) increased trade by 65 per cent for developed countries, not significant for developing ii) increased trade by 32 per cent for developing countries new Members, no impact on developing countries old Members iii) increased trade 85 per cent in unprotected sectors when the importer is a developed country, no significant in protected sectors WTO coefficients: i) 0.5 industrial country ii) 0.3 new Member iii) 0.6 unprotected manu
Helpman et al. (2004)	158 countries, all 1980s	Dependent variable: bilateral imports (Feenstra database) Two estimated models: Probit equation for the presence of a trading relationship. Gravity model with exporter, importer and year fixed effects	WTO increases both the volume of trade and the probability to trade significantly WTO coefficients: 0.3 (OLS fixed effect on import volumes) 0.23 (on probability of trading)
Liu (2004)	total 210 countries over the period 1948-2003	Dependent variable: bilateral imports	WTO coefficients: positive and significant 2.1 OLS, 1.45 OLS fixed effects, 4.52 Tobit random effects
Felbermayer and Kohler (2004)	period: 1950-1997, countries 76 in 1950, 181 in 1997.	Dependent variable: average bilateral trade deflated by US CPI, include zero trade observations.	WTO increases both the volume of trade and the probability to trade significantly WTO coefficients: 0.27 OLS, 0.46 Tobit (on bilateral trade volumes) 0.07 –no significant (on probability of trading)

3. Trade, Growth and Environment

Gravity models have also been used to examine the relationship between trade and growth (Frankel and Romer, 1999) and trade and environmental quality (Frankel and Rose, 2002). In these studies, the use of the gravity equation is motivated by the need to solve possible bias in the estimation caused by two-way link between trade, on one side, and growth and environmental quality on the other side.

With a general equilibrium model of trade and environment or trade and growth, it is possible to examine whether a change in trade policy (considered an exogenous variable) results in a deterioration or improvement of environmental quality or of an acceleration in economic growth (endogenous variables).[44] But in the absence of such a general equilibrium model, including both trade and environment or trade and growth in an ad hoc regression to investigate this question is likely to produce biased and inconsistent estimates.[45] This is because an important requirement of ordinary least squares[46] to generate unbiased and consistent estimates is that the independent variables be exogenous or predetermined. But this would not be possible in an ad hoc regression because it would not specify the links by which changes in trade policy work their way through to environmental quality or to economic growth. Both sets of variables (trade and environment or trade and growth) are therefore endogenous in the regression and there are likely to be two-way and not just uni-directional links between the two. The endogeneity problem means that if one obtains a statistical result that shows countries which trade more have better environmental quality or higher growth rates, it would not be possible to rule out the possibility of reverse causation - of countries with better environmental quality trading more or of intrinsically high growth countries trading more.

In the absence of a fully-specified model of trade and growth or trade and environment, the next best approach is to employ suitable instruments for the possibly endogenous explanatory variable, in this case trade. An ideal instrumental variable is one that is highly correlated with the explanatory variable but which is uncorrelated with the error term in the regression.[47] Since a number of the standard variables used in gravity equations (distance, landlocked, island, common language, common border, colonial relationship) provide ideal instruments for trade, gravity models have been used to shed additional light on the relationship between trade and growth, and environment.

In the 1990s, there was a spate of cross-country econometric studies, many incorporating the latest theoretical advances in new trade theory, which examined the relationship between trade and economic growth.[48] These multi-country studies generally concluded that greater outward-orientation or openness to trade improved growth prospects. However, Rodriguez and Rodrick (1999) have criticized this literature pointing out that measures of openness to trade often included the exchange rate, fiscal stance, and monetary policies that should be mainly considered as macroeconomic policy tools. But as Frankel and Romer (1999) point out using only trade policies in the regression does not solve the problem. Countries that adopt more liberal trade policies are also more likely to adopt stable exchange rate, fiscal and monetary policies. To be able to sort out and identify only the effect of trade openness on growth, Frankel and Romer (1999) used a gravity model to provide an instrument for trade openness. The study concluded that increasing the ratio of trade to GDP by one percentage point raises per-capita income by between one-half and two per cent.

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[44] For an example of statistical estimation using a general equilibrium model of trade and environment, see Antweiller, Copeland and Taylor (2001).

[45] An estimator (of a parameter) is said to be biased if its expected value (or average) does not equal the value of the parameter. An estimator is said to be inconsistent if its value does not converge to the value of the parameter even as the sample size increases without bound.

[46] The method of least squares (or OLS) is the most used estimation technique. Intuitively, it consists in estimating the coefficients of a specified equation in a way that the predicted values from this equation are as close as possible to the actual values. This is achieved by choosing among all possible values of the coefficients those that minimize the sum of the square differences between predicted and actual values.

[47] The method of instrumental variables dates to the work by Philip Wright (1928). See Stock and Trebbi (2003) for a history of that development.

[48] See Baldwin (2000) for a survey of that literature.

Frankel and Rose (2002) employed a gravity model to investigate the link between trade and environment. They find that trade has a beneficial effect on air quality, with more open economies seeing reduced levels of nitrogen oxide and sulphur dioxide levels. They do not find as strong an effect of trade on other environmental indicators, but neither do they find that trade causes any harmful effects on them. The positive effect on the environment arises from trade's impact on output or income and the working of the Environmental Kuznets curve[49]. For every one percentage point increase in openness (exports plus imports as a share of GDP), the authors find that output is increased by 1.6 per cent. Beyond a certain per capita income level, these increases in income lead to an improvement in environmental quality.

C. What can we learn from gravity models?

The discussion above has highlighted the importance of integrating theory with estimation. Because they provide a good fit to the data, standard gravity models (where bilateral trade is estimated as a function of importer and exporter GDP and bilateral distance), there is a temptation to employ the models in an ad hoc fashion, e.g. simply including a variable of interest. But employing gravity models in this way makes it difficult to draw correct inferences from the estimation results. Only by carefully working out the theoretical questions at issue can the empirical analysis be directed to the appropriate choice of the regressors and the estimation method. A number of lessons about the appropriate use of gravity models need to be stressed:

1. A large number of studies that use the "standard" gravity approach simply plug in an additional variable, the policy variable of interest, in an ad hoc manner. This approach is popular because the standard explanatory variables already account for a large part of variation of trade across countries and over time. But the lack of theoretical foundations undermines the credibility of the results.

2. The property of standard gravity models of explaining a large percentage of thevariation in the data does not guarantee that the part of the variation relevant for the policy variable is properly controlled.

3. Many studies do not take into account that relative, as well as absolute, distance and trade costs matter for understanding bilateral trade.

4. There are many countries which do not trade with one another. Disregarding zero trade observations introduces a sample selection bias in the estimations.

5. Most studies fail to take into account that not all firms, and not all exporting firms, export to all destinations. Changes in bilateral trade flows are not only due to changes in volumes of the same traded goods, but also to changes in the number of traded goods. Failing to take into account changes in the proportion of firms that export from a source to a destination country may bias the estimations.

6. Many studies look at the impact of country-specific policy variables, such as quality of infrastructure and quality of institutions, on trade using a standard gravity model augmented for the policy variable. To the extent that this policy variable is correlated with other explanatory variables in the model (like, for example, GDP per capita). It will not be possible to identify which variable is driving the results.

Among the most credible studies are those that use policy variables with bilateral variations (like, for example, applied tariff data, dummy variables indicating the membership in a free trade area) and that rely on country-specific fixed effects (dummy variables that capture country-specific characteristics). This approach is becoming increasingly popular. However, these models can only predict changes in the direction of trade but

[49] Kuznets (1955) believed that as per capita income increases, income inequality also increases at first but, after a certain level of per capita income, income inequality falls as economic growth continues. This changing relationship between per capita income and income inequality can be represented as a bell-shaped curve, known as the Kuznets curve, for which Kuznets won the Nobel price in economics in 1971. More recently, the name Environmental Kuznets curve has been adopted to indicate the relationship between the level of environmental degradation and income per capital, as there is evidence (for some pollutants) that it follows the same bell-shaped relationship as does income inequality and income per capita in the original Kuznets curve. The rationale is that in the early stages of development environmental degradation increases as income per capita increases as a consequence of the greater use of resources and emission of pollutants. As the level of development increases, though, consumers evaluate more a better quality environment and cleaner technologies become available, thus leading to a reduction in the level of environmental damage.

cannot predict how the overall level of a country's trade would respond to a change in policy,. This is because the use of country fixed effects controls for the overall level of trade.

Two further points need to be made concerning the use of gravity models. One, gravity models explain the direction of bilateral trade flows and do not imply anything about welfare. Two, gravity models are *ex post* analysis models. They explain how a policy already implemented has worked in the past, but they are not intended to be used for predictions. Predictions on the basis of gravity models can be made, using the model estimated for simulations, but the variance tends to be very high.

Finally, it is important to bear in mind that the results are likely to depend on a number of estimation choices. The previous sections have discussed the following issues bearing on these choices:

- whether the dependent variable is imports, exports or total trade,
- whether data are aggregated or disaggregated,
- the extent of sectoral disaggregation,
- the sample of countries,
- whether the analysis is run on cross country, time series or pooled data,
- the choice and the length of the time period,
- how zero and missing trade observations are treated, and
- whether fixed effects are country specific, exporter and importer specific or country-pair specific.

VI. CONCLUSIONS

Given the growth in the use of quantitative economic methods to deal with trade policy questions, two important and widely used tools – computable general equilibrium (CGE) models and the gravity equation – have been discussed in this study. The objective was to introduce these tools to policy-makers and to discuss how policy might be made against the background of better information with the use of these methods.

CGE modelling has a clear link to trade policy-making. CGE models have been widely used to simulate multilateral negotiations as well as the formation of preferential trading arrangements. Because CGE models incorporate many of the underpinnings of general equilibrium theory, they offer a rigorous and theoretically consistent framework for analysing trade policy questions. This is the main benefit they give to policy analysts. The numbers that come out of the simulations should only be used to give a sense of the order of magnitude that a change in policy can mean for economic welfare or trade. But much more can be done to create confidence in the results. The simulations should benefit from more systematic and informative employment of sensitivity analysis. More importantly, *ex-post* validation of CGE models is needed to increase confidence in the numerical results. The outcome of *ex-post* validation can improve model specifications and help ascertain which specifications are more appropriate to employ in particular simulation scenarios.

To some extent, the challenge faced by the gravity equation is opposite to that of CGE models. While the main challenge for CGE models is to generate simulation numbers which one can be confident about rather than the theoretical foundation underlying them, the opposite seems to be the case with gravity models. They perform very well empirically. But for the correct inference to be drawn from the estimations, the specification and variables used in the gravity model must conform to the requirements of economic theory.

Correctly specified gravity models can illuminate questions that are important for trade policy-makers. For example, what are the trade effects of WTO membership? How will entering a proposed preferential trade arrangement affect a country's trade? How will non-members' trade be affected? Does more trade lead to faster growth? Does trade improve the environment?

Three important theoretical requirements that needed to be taken into account in gravity models were highlighted in this study. First is the importance of relative distance and trade costs. Second is that liberalization, whether multilateral or regional, creates new trading relationships and not just increases in the volume of existing trade. Third, trade is dynamic and this shows itself in new products and new firms that enter international commerce.

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