

**APPLIED GENERAL EQUILIBRIUM MODELS:
AN ASSESSMENT OF THEIR USEFULNESS
FOR POLICY ANALYSIS**

Antonio M. Borges

CONTENTS

Introduction	8
I. History and brief survey	9
II. Strengths and weaknesses of the general equilibrium approach	15
A. Strengths	15
B. Weaknesses	19
III. The "state of the art" – directions of current research	23
IV. Operational aspects and constraints	26
Conclusion: Assessment of general equilibrium models for policy analysis	30
Bibliography	33

Antonio M. Borges is Professor of Economics at INSEAD; he has prepared this paper under contract with the OECD Economics and Statistics Department.

INTRODUCTION

Applied general equilibrium modelling is nowadays one of the most active areas of research in economics. It has generated much interest among policy makers and policy analysts as a new methodology capable of providing coherent answers to complicated questions in a systematic way. The popularity and prestige of this fairly new approach in applied economics have occasionally led to exaggerated optimism about its usefulness to handle any issue or answer any question. Applied general equilibrium models are a powerful and informative tool to deal with important practical policy issues; but they should be developed with great care and used with prudence. A careful and comprehensive model requires substantial resources, which certainly does not make it a fast and ready instrument to handle trivial problems. Its usefulness is unquestionable for certain types of issues, while dubious for others.

Based on the Walrasian tradition, applied general equilibrium models describe the allocation of resources in a market economy as the result of the interaction of supply and demand, leading to equilibrium prices. The building blocks of these models are equations representing the behaviour of the relevant economic agents – consumers, producers, the government, etc. Each one of these agents demands or supplies goods, services and factors of production, as a function of their prices. Assuming that market forces will lead to equilibrium between supply and demand, the general equilibrium model computes the prices that clear all markets, and determines the allocation of resources and the distribution of incomes that result from this equilibrium.

As they become more sophisticated and complex, applied general equilibrium models incorporate many elements from other modelling traditions. Current disaggregated models include, for example, production submodels which are derived from Leontief input-output structures or consumption submodels equivalent to expenditure systems typical of other large models. What distinguishes the general equilibrium approach from these other models is the endogenous determination of prices, derived from an assumption of equilibrium that integrates all markets and all dimensions of the economy.

I. HISTORY AND BRIEF SURVEY

The theoretical superiority of the general equilibrium approach has always been accepted. The possibility of including in a single model all relevant aspects of a problem – all interdependences and feedbacks among the variables, in particular all income and substitution effects – is obviously more attractive than the abstraction from certain effects assumed secondary or negligible, and the *ceteris paribus* assumptions, which are inevitable in partial equilibrium analyses. But this theoretical superiority did not materialise in practical applications until very recently. In fact, the complexity of a general equilibrium model, even with a simple structure, makes its analytical solution impossible – except in very special cases of little practical interest. And numerical solutions simply did not exist – again with exceptions of limited relevance.

It was only in the early 1970s that a major breakthrough made possible the development of fairly detailed and complex general equilibrium models, which could be solved computationally. The breakthrough was the introduction of an algorithm for the solution of the general equilibrium problem – that is, for the computation of equilibrium prices – which was developed by Herbert Scarf (1969). The most striking aspect of this algorithm was its general nature. In fact, it was guaranteed to converge, that is, find the equilibrium vector of prices, under the most general conditions. Since the algorithm is based on the proof of existence of equilibrium prices, and actually follows the steps used in that proof, it is guaranteed to work without any constraints on the specification of the model, apart from the general requirement that excess demand functions be continuous and that Walras' law be observed'.

Although this first algorithm was not very efficient from the computational point of view, it made possible the development of applied general equilibrium models, by providing researchers with a solution method which imposed very few and unimportant restrictions. Gradually, advances in the power of modern computers made larger and larger models possible. Subsequently, the algorithm was improved and more and more refined versions were introduced. A whole new line of research was started – in mathematical economics and later in operations research – to develop more powerful and simpler versions of general equilibrium algorithms, and many alternatives now exist, including simple but efficient versions for microcomputers. But the root remains the initial algorithm that Scarf presented, as is evident in surveys such as Scarf (1984) and Todd (1984).

Once a solution method existed, the first applications immediately followed. Naturally, the areas where the applied general equilibrium model was first introduced

were those where a rudimentary analytical general equilibrium approach had been used before and had provided stimulating results. The tax incidence model of Harberger (1962), and the two-factor, two-good, two-country model of international trade of Johnson (1954) and Meade (1955) had generated considerable interest, in spite of the substantial simplifications of their analytical versions. The new computational method made possible the application of the general equilibrium approach of these models to much more detailed and complex structures. Moreover, because it did not rely on infinitesimal calculus, the computational model did not have to assume small changes and could therefore more convincingly address policy issues involving large changes.

The first applications of the computational general equilibrium model were by Shoven and Whalley and addressed policy issues in the areas of tax reform and international trade, following the tradition of the earlier analytical models. The flexibility of the solution algorithm permitted computational models which became increasingly more sophisticated and realistic, and which provided a numerical answer to complicated questions of great practical interest. The development of the models progressed from disaggregate production structures based on the Leontief input-output approach, to flexible production and consumption structures, disaggregation of the household sector in various classes to handle distributional issues, introduction of intertemporal choice and labour-leisure choice for a more complete approach to many policy issues, and finally the consideration of issues of expectations as well as departures from perfect competition. The literature on general equilibrium modelling applied to tax and trade policy issues is surveyed comprehensively in a recent article by Shoven and Whalley (1984).

Shoven and Whalley's work has usually focused on measures of the efficiency and distributional impact of tax reform proposals, or of trade liberalisation policies. Following the tradition of Harberger, but using for the first time a full general equilibrium approach, Shoven and Whalley (1972) identify the conditions under which capital bears the burden – or more than the full burden – of the additional tax on corporate capital in the U.S., as opposed to the conditions under which the burden falls on labour. In subsequent versions and applications of their models, they study proposals for integration of capital income taxation with personal income taxation and evaluate the gains and the distributional consequences of each proposal; they also study the replacement of personal income taxation by consumption based taxation – or, equivalently, the introduction of full saving deduction from personal taxable income – and conclude that efficiency gains would be very substantial in present-value terms. See, for example, Shoven and Whalley (1972), and Ballard, Fullerton, Shoven and Whalley (1985).

The work of Whalley (1980; 1982) in international trade policy also contributed interesting and important results. Assessing the consequences of trade liberalisation as proposed in various rounds of GATT negotiations, Whalley (1982) finds that the gains are fairly small – less than 0.1 per cent of GNP – and concludes that non-tariff barriers are far more important than tariffs. He also identifies gainers and losers for each of the liberalisation scenarios studied.

Other researchers developed models the properties of which are in many respects similar to the Shoven-Whalley versions. Three main lines of research should be mentioned in this context, all of them strongly focused on policy concerns. The first one is the multisector energy model of the United States economy, developed by Hudson and Jorgenson (1974) and later improved and extended by Jorgenson and various associates. Representative articles are Hudson and Jorgenson (1978), Jorgenson (1984), Jorgenson and Fraumeni (1981), Jorgenson and Slesnick (1983) and (1985). This approach, although initially not as close to the original Walrasian model, made two substantial contributions: it introduced more sophisticated functional forms, representing a better approximation to reality, and leading eventually to a thorough treatment of technological progress; and it was based on full econometric estimation of the parameters of the various submodels, which had not – and still has not – been the case for any other model.

Jorgenson has generally developed and extended his model with the objective of studying specific policy questions, in particular in the area of energy policy. Of special interest is the utilisation of his model to study implications of energy price changes which can only be evaluated in a general equilibrium context. Jorgenson emphasizes in his work the degree of substitutability between energy and labour, and of complementarity between energy and capital, which is reflected in the parameter estimates he obtains for his production submodel. He then argues that higher energy prices reduce the demand for capital and increase the demand for labour, leading to lower rates of return to capital and higher real wages (other things equal). Within the framework of his general equilibrium model, he then studies the long term impact of these changes in relative prices on economic growth, concluding that lower rates of return to capital and thus lower investment may be one of the most important consequences of higher energy prices, leading to slower economic growth.

A second line of research was initiated by Manne (1977) and was also applied to the energy policy area. Its main novelty was the comprehensive treatment of dynamic issues, by basing the solution to the model on full intertemporal optimisation and by specifying with some care the constraints and costs associated with partial adjustment on the part of economic agents. The work of Manne and of

his co-authors was later extended to other areas – in particular trade and development policy – but it kept its initial identifying peculiarities: simple functional forms and parameterization, low level of disaggregation and strong emphasis on dynamic issues. A good example is the three region model of trade and economic growth in Manne and Preckel (1983), which is based on a very simple structure, but which provides many insights into key issues in trade between developed, less developed and oil-producing countries. The model is used to analyse the consequences of higher oil prices and worsening terms of trade for economic growth, and shows that the impact is much more serious on less developed countries, suggesting that additional help from developed countries would be in the interest of both regions.

The models developed by Manne do not have the same degree of detail attained in the work of Shoven and Whalley or Jorgenson. Manne's main objective is to simulate alternative scenarios in order to highlight key relationships important for policy. In other words, instead of attempting to compute precise numerical measures of the impact of a policy decision, Manne emphasises the pedagogical role of the model, since it shows better than other forms of presentation the importance of some of the feedbacks or interactions which are usually not taken into account in policy debates. This aspect may well be one of the most important factors of success of applied general equilibrium models, and one of the main reasons why they are considered so useful. In fact, the models often simply provide a coherent structure to study important relationships, which are sufficiently complex to be beyond the power of descriptive, non-formal approaches, or even simpler models. In this case, the usefulness of the model comes not so much from its accuracy, level of detail and empirical verifiability, but rather from the fact that it provides policy analysts with a tool that enables them to study interdependences and feedbacks, which it is important to understand, and which are beyond the reach of simpler approaches.

The third line of research which has contributed significantly to the applied general equilibrium approach has evolved from the multisector planning models, particularly popular among development economists and supported by the World Bank (Blitzer, Clark and Taylor, 1975). The need for disaggregated models to analyse important structural issues had always been recognized among economists and policy makers dealing with the problems of the less developed countries. The initial approach was based on extensions of the Leontief model, complemented with more or less sophisticated models of consumer expenditures and international trade. To achieve a fully consistent framework the research evolved towards the concept of social accounting matrices, a comprehensive method of representing all transactions among every type of economic agent in a country. Having reached this

point, it was simple to adopt the general equilibrium assumptions, which permitted the treatment of the basic policy questions related to economic development with more depth and a higher degree of consistency. **A** representative survey of this type of work is the book by Kervis, De Melo and Robinson (1982), published by the World Bank, but many other more recent contributions can be quoted. **A** complete bibliography is presented in Devarajan, Lewis and Robinson (1986).

Of the three lines of development mentioned so far, this last one is perhaps the least dominated by concern for theoretical elegance, and therefore the one with the greatest reliance on *ad hoc* specification. It is, however, the approach closest to practical policy issues, since the models are not merely used to make a scientific or academic point about a policy decision, but rather to provide crucial information for the preparation of decisions which governments have to make and on which the World Bank has to provide advice. Typical issues addressed by these models are questions of trade policy – the introduction of tariffs or export subsidies in a particular country – of industrial policy, of price controls, etc. In general, the results obtained have been useful in the policy debate, providing a better understanding of the key factors explaining certain outcomes and simulating the impact of alternative options. **As** an example, an applied general equilibrium model of the Turkish economy was used to simulate the effects of a 50 per cent tariff on imports versus an export subsidy of 50 per cent. The results of this exercise indicate that the two policies are far from equivalent, that the final outcome depends on the degree of flexibility in the production structure of the country – that is, the extent to which resource allocation changes when relative prices change – and that, as a consequence, the export subsidy has much more impact on the structure of economic activity than the tariff.

Apart from these major types of contributions to the development of the general equilibrium approach, many other efforts have been made to apply the approach to new problems or new countries, as well as to combine in new models some of the advantages of each of the main lines of research. Some examples – which in no way represent an exhaustive list – may illustrate these efforts.

The U.S. energy policy model developed by Borges and Goulder (1984) represents an attempt to combine the **Shoven-Whalley** tradition with the more sophisticated flexible functional forms used by Jorgenson in his models, plus the specific constraints associated with the existence of exhaustible resources. This research led to somewhat more realistic results concerning the impact of higher energy prices or the effects of tax-based energy policy options.

A rather different approach was followed in Australia, in the development of the **ORANI** model, a detailed multipurpose model of the economy, capable of addressing large and small issues – from the impact of foreign investment to the

consequences of a subsidy to a particular industry (Dixon, Parmenter, Sutton and Vincent, **1981**). This model has proven to be useful for policy analysis.

References should also be made to the general equilibrium modelling tradition in Norway, following the initial efforts of Johansen (**1975**). The various versions of Norwegian general equilibrium models are all characterised by great technical sophistication, creative solutions to the problems due to the openness of the economy and innovative applications in terms of policy planning. Recent papers are Munck (**1982**), Persson (**1984**), Longva, Lorentsen and Olsen (**1984**) and Frenger (**1984**).

The Deardoff-Stern (**1981**) model of international trade has become one of the best known models for the analysis of trade liberalisation issues. Identifying **34** industrial and developing countries, for which production, consumption and foreign trade submodels are specified, this large **multi-country** model has been used to assess the impact of lower tariffs, to quantify non-tariff barriers and to study the consequences of agricultural quota concessions. The results show how certain countries benefit, while others lose, from trade liberalization measures.

Finally, the work of Mohammad and Whalley (**1984**) has opened the way for a new type of application: the attempt to measure the inefficiency associated with certain types of government intervention and the distortions introduced on the behavior of agents. This approach is rather promising in terms of practical relevance for important policy decisions. It incorporates explicitly into the framework of the standard Shoven-Whalley model the "rent seeking" behaviour of economic agents who use productive resources not to increase output and national income but rather to enlarge their share in national income through the exploitation of distortions. A rather extreme example is the practice of distributing scarce import permits based on unutilised capacity: firms with more unutilised capacity of production have priority in the allocation of permits. Inevitably, over time, firms **start** overinvesting, in order to generate the excess capacity which will strengthen their claim to profitable import permits. In the case studied by Mohammad and Whalley, the most serious – and perhaps surprising – consequence of the existence of severe import licensing is a substantial worsening of the terms of trade for countries that apply it. Results of this nature have been useful in illustrating the substantial losses associated with certain types of inefficient government intervention and have stimulated further studies in a similar vein for different countries.

This brief survey of some of the main contributions to and applications of the general equilibrium approach cannot possibly be exhaustive. It is mainly intended as illustrative of the various types of applications, the different emphasis put by different modellers on technical sophistication or pragmatic realism, and the wide range of issues which can be handled with this powerful tool. A longer list of

references is provided at the end of the paper, but even that one will necessarily be incomplete, given the constant appearance of new contributions and applications. It may be appropriate therefore to review the main trends of research in this area that can be identified, in order to understand and predict in which way the general equilibrium methodology will evolve. However, before proceeding in that direction, it is perhaps advisable to assess the strengths and weaknesses of the methods and applications developed until now.

II. STRENGTHS AND WEAKNESSES OF THE GENERAL EQUILIBRIUM APPROACH

Shortly after being introduced, applied general equilibrium models had achieved a degree of acceptance and prestige which is in many respects unique. Moreover the high praise they have generated has come from both research economists and policy analysts, from theorists concerned with rigorous methodology as well as from practitioners focusing on usefulness and practical relevance. Part of this positive reaction is due to the inherent potential of the approach to respond to many needs in a superior way compared to previous methods. Another part is due to the fact that the first initial applications were very carefully chosen and implemented, thereby representing ideal examples of the advantages and possibilities of applied general equilibrium models. As new applications and extensions are proposed, it becomes clear that the results obtained are not always in line with the expectations, and that the approach has some limitations which must not be overlooked.

A. Strengths

Certainly the most important strength of the general equilibrium methodology is its solid microeconomic foundation. Typically a general equilibrium model specifies the behaviour of all the economic agents using widely-accepted principles of optimisation and choice, which are operational and remain the most frequently used basis for empirical work. The role of the model is to integrate the behaviour of all these agents in a systematic way, which then corresponds to a description of how markets will operate in equilibrium. Based on the existing knowledge of this particular body of theory, the general equilibrium model will use the standard

methods to describe all the relationships among variables, which precludes *ad hoc* specification and makes the structure more transparent. Such discipline imposed by general equilibrium methods is all the more important because of the complexity of these models. The simulation results are often unpredictable, that is, the various interdependences and feedbacks among the variables make it difficult to determine in advance what the results of a particular simulation will look like. This has led some economists to consider these models as "black boxes" which may generate any solution. But the theoretical foundation of such models makes it possible to trace back, in every case, the simulation results and determine which factors are crucial in explaining them. Moreover, the embodied theory also provides a precise check on the validity of the results, since it is impossible – except for errors – that the model will lead to results which are contrary to what the underlying theory predicts.

Related to the advantages of a coherent theoretical foundation is the issue of internal consistency. In the discussions of complex policy issues, a model often serves primarily to provide a structure within which the various factors under study can be accounted for. **No** model will produce any results that go beyond what has been built into it, either in terms of assumptions or of structure. The same is of course true of general equilibrium models. They allow the analyst to integrate into a single structure a whole series of effects which could not possibly be accounted for coherently in an informal manner. It is in the nature of the approach that all the components of a problem are taken into account, that all feedbacks are considered, that no markets or agents are neglected. Thus the models make possible the simulation of complex interrelationships, clarifying the role and impact of different factors, and enriching the analysis with new – and sometimes surprising – results. Moreover, the general equilibrium models ensure the internal consistency of the analysis. This makes general equilibrium models extremely useful in the case of economy-wide policy issues with many ramifications, sometimes acting in opposite directions, and generating feedback effects which are crucial to the final result.

A good example of the importance of analytically integrating all aspects of a policy decision is provided by the study of a windfall profits tax in the United States. Using their model of the U.S. economy, Borges, Goulder and Shoven (**1982**) study the distributional consequences of a tax on "windfall" profits accruing to owners of energy resources as world prices increase. Since the tax, as modelled, falls exclusively on profits, it would be expected that its impact on income distribution would be progressive, that is, incomes would be distributed more evenly with than without the tax. The general equilibrium approach, however, highlights the fact that the distributional effects depend on how the government uses the additional revenue. In fact, given that on average, American government expenditures are quite capital-intensive – considering direct and indirect capital requirements necessary to

supply the goods and services purchased by the U.S. government – if the additional revenue is spent in the same way as all other government expenditures, it will tend to increase the demand for capital and hence the price of capital and may in the end worsen the personal distribution of income. This type of analysis is impossible under partial equilibrium assumptions, since its main point is precisely the importance of a feedback effect from spending to factor prices.

The flexibility of the solution algorithms has made possible the development of highly disaggregated models, which also contributes to their practical usefulness. It is well known that many policy actions or exogenous shocks will have an overall impact on the economy which is much smaller than their effect on the structure of the economy. For example, it is a standard result in microeconomic theory that an increase in the supply of one factor of production – for example labour – will lead to an increase in total output in the economy; but this will be achieved by a more than proportional increase in the output of labour intensive goods and an actual decrease in the production of goods which are intensive in other factors of production. In other words, focusing on the overall impact on output neglects the important and substantial changes in its structure which are induced by an exogenous shock or policy decision. The renewed interest in structural issues has led to general equilibrium models which often have many sectors of production, groups of consumers, types of goods, etc. There are models of international trade with many different countries or groups of countries, as well as country models with some regional detail. The types of structural issues analysed include changes in the composition of output, with the necessary shift of resources from declining sectors to expanding sectors, changes in relative prices and their consequences, distributional issues – either by group of consumer, or by region or country, etc.

The level of disaggregation possible with general equilibrium models also contributes to their usefulness in another way. By specifying the economy in some detail, it is possible to include many structural aspects which correspond to distortions or market failures. The most pervasive example of this is, of course, the tax system. Taxes introduce inefficiencies, many of which can only be captured in a fairly disaggregated model with significant sectoral detail. The impact of taxes is sometimes crucial to other policy analyses as well, even those not related to taxes. This is because inefficiencies and distortions interact with each other in ways which are not obvious; and – as is well known from second best theory – removing one source of inefficiency does not necessarily lead to an overall improvement of the allocation of resources in the economy if other distortions persist. In fact, when many sources of inefficiency exist, the effects of some of them will tend to cancel out, and removing any one of them may actually worsen the situation. The following example illustrates this point: Ballard and Shoven (1985) have used a general

equilibrium model to study the introduction of value added taxation in the United States. They argue that, in general, the value added tax is less distorting than an income tax, and that replacing the latter by the former should improve the efficiency of resource allocation. However, they also take into account that any realistic value added tax will probably include different rates for different products, given the usual attempt to use indirect taxation also to pursue redistributive objectives. Specifying a structure of rates similar to what is common in European countries, they find that all efficiency gains are lost, and that the distortions caused by different rates for different products actually outweigh the gains inherent to the value added tax.

These results show that, for many important policy decisions, it becomes essential that the most serious sources of inefficiency be contemplated in some detail, so that these types of second best issues may be accounted for.

Another factor contributing to the attractiveness of the general equilibrium approach for certain types of studies is the fact that they are solved numerically and not analytically. Mathematical models are often based on differential calculus, which is only applicable if changes are infinitesimal. The approximation implicit in the use of calculus is acceptable if the policy changes contemplated are small. But very often the opposite is true: some of the most interesting policy issues involve very substantial changes in absolute and relative terms – for example when a tariff is eliminated or a new technology becomes available. The numerical solution of the general equilibrium models can handle these situations easily, since it does not depend on the assumptions of small change.

A final advantage of general equilibrium models – which has been of particular concern to researchers but which may also be important for policy analysis – is the possibility of deriving better measures of the welfare gain or loss associated with a new policy. Very often the impact of a policy decision is discussed in terms of very imperfect measures of welfare – such as income or gross national product. For many policies – especially when distributional issues are important – it is necessary to go beyond those rough estimates of the gains and losses associated with the change. For example, the introduction or increase of a tax on labour income will typically reduce after tax wage rates. People will be induced to work less, given that labour supply responds to wage changes, and total income will fall. If however the extra leisure time has some value, the impact on welfare will be smaller than what is measured by the fall in income. Another example is related to tax policy: some types of indirect taxation may leave unchanged the income of consumers or consumer groups: however, by changing the relative prices of goods they buy, they may have a very substantial impact on the pattern of their consumption and hence on the welfare they derive from it. Clearly, a more comprehensive measure of welfare than income or GNP is often needed, and general equilibrium models can contribute to

that objective. In particular, explicit welfare measures embodied in these models help explain how the situation of a consumer or group of consumers has changed, what factors contributed to improve or worsen it, and what is the relative weight of each one.

B. Weaknesses

The general equilibrium approach has, of course, some weaknesses which reduce its interest and which limit its applicability to carefully chosen areas or issues. The most frequently mentioned weakness is the lack of empirical validation of the models, in the sense that usually there is no measure of the degree to which the model fits the data or tracks the historical facts. General equilibrium models are usually very large, include a substantial number of parameters and often embody rather complex structures. They are not econometrically estimated – only Jorgenson's model is based on the estimation of a substantial number of parameters, which are obtained independently for each submodel. They use parameter values estimated independently and which are reported in the literature and are calibrated to a single data point, which is chosen to represent a situation close to general equilibrium. Because of the assumption of general economic equilibrium, which is seldom observed in all markets simultaneously, the results of the model do not pretend to forecast reality but rather to indicate long-term tendencies, around which the economy will fluctuate. Thus, the models cannot be used to replicate the evolution of the economy in the past as a means of checking their validity. To overcome this weakness, modellers should be extremely careful in the choice of parameters as well as of functional form. Only parameter values that correspond to a certain consensus should be used, and the types of functional forms used are normally simple and non-controversial – Cobb-Douglas and constant elasticity of substitution (CES) functions, for example.

Perhaps more fundamental is the fact that the general equilibrium assumption rules out the use of these models for many important policy decisions. In fact, it is not only assumed that all markets find their equilibrium but also that nothing happens until equilibrium is reached. In other words, no transactions take place in disequilibrium, as if all economic agents were to wait until equilibrium is found before they made any decisions. For some types of policy issues this assumption is not very important; for others, the main point is actually the situation of persistent disequilibrium and the fact that, as the economy continues operating without all markets clearing, additional costs may be incurred. Clearly, the general equilibrium approach is not very relevant to discuss macroeconomic issues related to stabilization policy. The approach may provide some insights in certain cases when

markets do not clear – for example, in understanding some aspects of the unemployment problem. But even in those cases it will never give a complete answer².

The following weaknesses of general equilibrium models are not inherent to the methodology, but are related to the types of models developed so far. They may be overcome in the future, although some of them may require a substantial research effort to provide acceptable solutions. The first problem is the treatment of intertemporal issues – saving and investment decisions – and of expectations. The first general equilibrium models in the Shoven-Whalley tradition computed static equilibria; they were subsequently improved to deal with dynamic aspects by computing a sequence of static equilibria. In these cases, economic agents made their decisions on a period by period basis, with the information available in the current period, but without looking ahead. Later, efforts were made to integrate more rational behaviour, including the extreme case of perfect foresight, leading to some interesting results concerning the impact of foresight on economic efficiency (Ballard and Goulder, 1982). Other models were developed incorporating the assumption of full intertemporal optimisation, as if every economic agent could predict the future exactly and adapt to it optimally. The initial approach of Shoven and Whalley may be more realistic, even though it underestimates the ability of individuals to adapt to the anticipated future change. The models based on full intertemporal optimisation and perfect foresight are more useful in a planning context, when it is important to determine the ideal course of action and then implement it. In any case, the treatment of expectations and the specification of the behaviour of economic agents taking decisions involving intertemporal choice remain an area of weakness of existing models.

The general equilibrium approach is directed towards long-term questions. Its results should be interpreted in that context. Therefore, it has not been applied to issues other than long term consequences of policy decisions or exogenous shocks. Because of this focus, traditional general equilibrium models do not deal with adjustment processes and the costs associated with them, along the path between today's situation – or the "base case" equilibrium – and the new scenario – often called the "revise case". In other words, the results of the simulation are presented as if the economy immediately adjusted to any exogenous change. Again, this weakness of existing general equilibrium models is not inherent to the methodology. It is possible to include adjustment costs into the structure of the models and it is expected that this will be done soon. But so far, the models that have been used to simulate policy issues have not dealt with the transition period but only with the final result. Clearly this is incomplete, because for many important policy decisions the transition problems are crucial and dominate the decision-making process.

Another aspect which has seldom been dealt with satisfactorily in general equilibrium models is the treatment of technological progress. The initial models of Shoven and Whalley did not include technological progress explicitly, except for a simple version of labour augmenting technological change, represented as an improvement in the efficiency of labour over time. Given that these models are designed to look at long term issues it is somewhat contradictory that their structure does not include a more careful treatment of technological change, the implications of which can be far reaching in the long run. On the other hand, it is difficult to predict technological progress or to assume that it will continue to proceed in the future at the same rate and with the same characteristics as until now. The only feasible solution has been to assume only the simplest form of technological change and to apply the models only in the cases when the impact of technological progress is not crucial. Two exceptions should be mentioned in this context: a Jorgenson/Fraumeni (1981) model of the U.S. economy has included a rather general treatment of technological progress – as measured by the residual term in the estimation of the contribution of each factor of production to total output – and in particular of the relationship between changes in relative prices of inputs and the change in the rate of technical progress as measured by the residual in growth accounting. The results reported are quite significant, because they indicate that a large part of pre-1974 technological progress was a result of the gradual decline in the relative price of energy. Thus, as relative energy prices increased in the 1970s, a lower rate of technological growth became inevitable, slowing down output and labour productivity growth. Manne's model (1977) of energy-economy interactions has dealt with the introduction of new technologies not available now, and their impact on resource allocation and output. Taking as exogenous the energy resource base, the model simulates the changes in the composition of energy supply, depending on the energy technologies available, plus the effect on the economy's long-term growth. It is thus possible to study the benefits from new technologies, as well as the costs of excluding certain options because of their negative external effects. Both of these examples remain exceptions, in the sense that they have not had many followers among general equilibrium modellers.

It has been a standard assumption of the first generation of general equilibrium models that all economic agents are on their budget constraints, that is, expenditures equal revenues. The implication is that there are no financial surpluses and no deficits. Even in the case of consumer saving, it is assumed that it always takes the form of purchase of capital goods, and therefore all of the consumer's income is spent. The most important consequences of this approach are that the government runs a balanced budget and that there are no international current account imbalances. Although some attempts have been made to relax this very

restrictive assumption, it is still the case that most models impose balanced budget and balanced current account assumptions, which immediately eliminates a whole series of important issues that would be interesting to investigate in the context of a general equilibrium approach. It is clear, in particular, that since all economic agents spend all their incomes in the purchase of goods and services, there is no scope for financial markets. Consequently, almost all of the existing models do not include money or monetary assets. Therefore, the models have been used to study resource allocation issues, but not financial or monetary policy issues. In particular, it would be impossible to discuss problems related to inflation in the context of the existing models.

Finally, most existing general equilibrium models have a very inadequate treatment of the foreign sector, and in particular of net trade flows. In fact, in the first generation of these models, the foreign sector was specified in a very simplistic manner, and included only the relationships necessary to close the model. The value of exports was guaranteed to equal the value of imports, and the price elasticity of exports and imports was constant and equal to 1. This is obviously too simplistic a view, acceptable only in the context of applications for which the foreign sector was thought to be of marginal importance. As the range of issues to which general equilibrium models were applied began to expand, it became evident that a more sophisticated treatment of the foreign sector was indispensable. In more recent versions of certain models, foreign trade is based on more flexible assumptions with respect to the price elasticity of imports and exports, derived from an offer curve approach, with an implicit endogenous exchange rate³. Alternatively, for small countries, the quasi "small open economy" assumption is often used, with import prices determined in world markets and export prices by local costs of production, but with a very high price elasticity of the demand for exports (Harris, **1984** and Borges, **1984**). In parallel, efforts have been made to include capital flows in these models – usually in the form of purchases of physical capital by foreigners (for example Goulder, Shoven and Whalley, **1983** or Borges, **1984**). Again, the weaknesses of general equilibrium models in the area of the foreign sector are not inevitable. They are related to the modelling strategy followed by the researchers, as determined by the needs of the particular applications that were made until now.

The specification of the foreign sector is related to an important issue in general equilibrium modelling, referred to as the choice of closing rules. In fact, in these models all flows have to be accounted for consistently and, having specified the behaviour of all other agents in the economy, the modeller has very limited freedom in specifying the last one. Since all markets are interdependent, the behaviour in the last market is essentially determined by what happens in all the other ones. Thus,

when closing the model – that is, when specifying the last element of it – all degrees of freedom are lost and any behavioural relationships must be consistent with what has been specified for the rest of the model. Naturally, since the last element of the model has this "residual" nature, it must be a relatively unimportant component, given the application in question. The initial general equilibrium models, focusing on tax incidence issues, tended to use the foreign sector to close the model – an acceptable choice, given the objective of the analysis. For other models, however, the choice of the last component is not as wise, since it may determine incorrectly the behavior of variables which may be crucial for the final outcome.

III. THE "STATE OF THE ART – DIRECTIONS OF CURRENT RESEARCH

Substantial research is under way to overcome some of the weaknesses of general equilibrium models and to extend their field of application. The power of the approach is now understood by most economists. As interest in complex long term issues of economic policy increases, the general equilibrium approach generates more and more interest and stimulates new research efforts. Today, new general equilibrium models are being developed and used far beyond the initial domain of application of the first Shoven-Whalley models, but with the same policy oriented emphasis and many similar structural traits. This section reviews recent developments along these lines, in order to illustrate the current evolution of the general equilibrium approach.

Perhaps the most substantial effort is presently concentrated on the development of more sophisticated submodels of asset markets within the general equilibrium framework. In the first versions of these models, the only asset considered was physical capital. No financial assets were taken into account, no financial intermediation existed, and therefore there was no modelling of portfolio choice. Recently developed models include a stronger emphasis on asset markets along two lines: either to deal with financial intermediation issues or to incorporate some costs of adjustment in the analysis of certain policy decisions. The possibility of incorporating financial assets and financial intermediation in general equilibrium models represents a substantial progress, since it will permit policy analysis under more realistic conditions, when some economic agents will be allowed to borrow and lend. This is of course particularly relevant to issues related to government deficits and the way those deficits are financed. It is also relevant to issues of

development aid and problems related to the financial crisis of less developed countries. (On the first issue see Borges, **1984**; on the second one, Chichilnisky, Heal and McLeod, **1983**). However, the existence of different financial assets with different rates of return and the modelling of portfolio choice only makes sense in the context of uncertainty, that is, if the differences among these assets and their rates of return are related to the degree of risk associated with each of them. Thus, the introduction in a systematic way of financial assets in general equilibrium models involves a major new step in modelling, since it requires that the deterministic simplicity of the first generation of models be abandoned in favour of a much more complex specification including substantial stochastic elements. Significant research efforts are under way in this direction, but apart from small steps no major results have so far been reported.

A second motivation for the introduction of asset markets is related to the attempt to capture the adjustment costs related to some policy changes through asset prices. In this area some new results have been presented, dealing with the consequences of tax policy (Summers **1982; 1983**). In fact, it is argued that, as taxes change, the rates of return to different factors of production may be modified; but eventually, in the long run, the mobility of factors will equalise all rates of return and the effects of the policy will lead to a new allocation of resources. During the transition, however, the change in rates of return translates into changes in asset prices, which describe the path towards the new long run equilibrium and which allocate the costs and benefits of the change. This approach combines capital asset pricing principles with the general equilibrium assumptions, leading to a new dimension in tax policy studies which is very promising since it focuses on issues close to the concerns of policy makers.

A second recent area of research attempts to improve the dynamic aspects of general equilibrium models. Some efforts have been devoted to a better specification of the production sector, to deal with problems related to imperfect mobility of capital (Fullerton, **1983**). For many policy issues – for example, in the area of energy policy – it is clear that the main consequence of a policy change is the impact it may have on the economic viability of certain types of physical capital, which may become economically obsolete. These issues can only be studied if specific vintages of capital are defined, with limited or no alternative use once the capital is installed. The costs associated with writing off a substantial amount of capital when it becomes obsolete due to a particular policy decision can then be accounted for properly, and the implications of the policy will be better understood.

Substantial progress has been made recently in dealing with very long term dynamic issues, involving several generations (Auerbach, Kotlikoff and Skinner,

1983; Goulder, 1985). The existence of overlapping generations, in different stages of their life cycles and with different resources and constraints is the key aspect of many long term policy issues, of which the best known is the financing of social security. Here the general equilibrium model is called upon to deal with a new type of disaggregation, classifying people according to the generation they belong to and modelling their behaviour differently, depending on the current stage of their life cycle. These models have made possible the analysis of fairly complex issues of trade-offs across generations, which are typical of social security reform, as well as government deficit financing, for example. This new approach obviously faces specific conceptual difficulties related to the problems of comparing welfare across generations. But it is a promising new development since it adapts the general equilibrium tools to a whole new range of issues which are of major concern to policy makers for some time to come.

Finally, another important area of research and development is the attempt to model consistently market structures which represent departures from the competitive standard, to analyse many important policy issues for which this feature is relevant. The tradition of general equilibrium models, as well as of general equilibrium theory, is based on the paradigm of a perfectly competitive economy, with prices determined by market forces and every economic agent behaving as a price-taker. Industries are modelled with no economies of scale and with no product differentiation. For many of the applications of these models, the assumption of a perfectly competitive economy is quite acceptable.

For other applications – in particular some of the most recent ones – it is clear that some of the key aspects of the questions are the result of departures from the competitive standard. Two specific areas should be mentioned in this context: trade liberalisation and industrial policy. The initial application of general equilibrium models to the study of the gains associated with trade liberalisation showed that, as a percentage of GNP, these gains were small. More recent research (Harris, **1984**), incorporating the possible existence of substantial economies of scale in production as well as the prevalence of monopolistic competition based on some degree of product differentiation within the industry, has shown that the potential gains from trade liberalisation are much larger than initially estimated. This line of research represents the application in the context of general equilibrium analysis of recent results in trade theory which have substantially changed the prevalent views on the gains from trade and the explanation of trade flows. These results – associated, in particular with the work of Helpman and Krugman (**1985**) – explain international trade by emphasizing increasing returns to scale and imperfect competition. Starting from the observation that the vast majority of trade flows take place between industrial countries whose endowment of factors of production is quite similar, this

new trade theory states that traditional comparative advantage, based on different factor endowments, is not capable of explaining this type of international trade. Instead, it proposes an explanation based on the existence of significant economies of scale – sometimes external to the firm but internal to the industry – to justify productivity differences, underlying competitive advantage. Furthermore, if the structure of the market corresponds to monopolistic competition, with product differentiation, it is also possible to explain the existence of intra-industry trade – also called cross-hauling. In fact, it is a common fact of international trade that similar goods, produced by the same industry, are simultaneously exported and imported by the same country, which is clearly contrary to the pattern of specialisation predicted by traditional trade theory. Product differentiation – German automobiles are perceived as different from French automobiles by consumers in both countries – combined with some economies of scale, is quite sufficient to explain intra-industry trade.

The integration of these aspects into general equilibrium models is promising. In fact, the gains from trade can be substantial, if trade allows increases in output leading to economies of scale. Moreover, these gains can benefit all factors of production, instead of accruing only to the relatively abundant – to the detriment of the relatively scarce – factors, as predicted by traditional trade theory.

Similarly, in the area of industrial policy, attention has focused on pricing policy in the case of natural monopolies, that is industries where economies of scale are substantial and which therefore tend to have a single producer, nationalised or otherwise regulated. The pricing policy to be imposed on such industries involves very complex second best issues: on the one hand, marginal cost pricing would seem to be desirable, requiring therefore a government subsidy; on the other hand, any government spending is in itself a source of inefficiency, since there is no practical way to raise revenue through taxes without causing some distortion. The trade-off can only be studied in a general equilibrium framework, but it requires that the specific aspects of economies of scale and government intervention be modelled properly. The main difficulty associated with these new developments is the need to base any extension of the general equilibrium approach on a solid theoretical foundation.

IV. OPERATIONAL ASPECTS AND CONSTRAINTS

After reviewing the development of the methodology and its advantages and disadvantages, it may be appropriate to describe some of the constraints associated

with the operational aspects of building a general equilibrium model. These result from the nature of the models, their complexity and their method of solution. They remain important aspects of the assessment of the approach, since they represent significant limitations on the widespread use of general equilibrium models.

First, general equilibrium models are designed to simulate the allocation of resources in a particular economy, under certain policy scenarios. They are not forecasting models, but rather simulation models which answer "what if" questions in a consistent and disaggregated manner. Simulation models do not possess the empirical verifiability of forecasting and econometric models; they do not have the generality of mathematical models based on abstract assumptions. They are only valid – and therefore useful – to the extent that their structure is appropriate to study the problem in question and that their parameter values are an acceptable representation of reality. Thus, to build a general equilibrium model – or to assess the quality of results derived from a model that has already been built – it is necessary to examine in detail the choice of functional forms, the method of parameterization, the data base from which the model is calibrated, the actual parameter estimates used, the choice of aggregation level, etc. Any of these aspects of the model building strategy, if not done properly, can invalidate the results – a consequence of the fact that in general equilibrium everything depends on everything else, and no parts of the model are independent of the rest. Methods exist to detect inconsistencies and specification errors, but the appropriateness of the parameter values and functional forms chosen, as well as the level of disaggregation remain matters of judgement, and their influence on conclusions must be examined carefully. Sensitivity analysis is important to determine the robustness of the results and to identify the key parameter values that dominate the final outcome.

The problem is complicated by the fact that in most cases the choice of structure – functional forms, level of disaggregation, etc. – is specific to the type of issue to be studied. In other words, it is very difficult to develop a model of a country which can then be used to study any question, with only minor changes. Typically, the key aspect determining the consequences of a particular policy is irrelevant in the case of another policy. The multipurpose general equilibrium model is a rare commodity, since it only exists in the cases where the policies to be studied are simple and of a similar nature. The best illustrations of this problem have already been mentioned: to study the gains from trade liberalisation it is very important that specific aspects of market structure be taken into account – such as economies of scale, product differentiation, monopolistic competition, etc. To analyse the impact of a value added tax these aspects are not nearly as important; rather, the model should focus on key aspects such as the determinants of saving or of labour supply,

and include a very detailed description of the tax system. Similarly, technological progress may not be a crucial element in the study of bonds versus new taxes as means of financing the budget deficit; however, it cannot be excluded if the model focuses on energy policy. In summary, a general equilibrium model is usually developed with a particular application in mind, and its structure corresponds to what is relevant in the context of that application; if it is to be applied in a different context, very substantial changes are required.

Another aspect that is crucial to the usefulness and reliability of a policy study based on a general equilibrium model is the extent to which it is possible to integrate the policy decision into the model. Most policy decisions are fairly detailed, include many special provisions and exceptions, and often have qualitative or subjective aspects which are hard to quantify. Inserting a policy decision into a general equilibrium model always involves some simplification and adaptation to the structure of the model. If most of the key aspects of the policy are lost in this process, then the exercise is useless and the policy should be studied in other ways – typically with a less ambitious model, but more detailed and flexible for the purpose in mind. As an example, the general equilibrium framework is probably ideal for studying the implications of a tariff or a quota on textile imports. On the other hand, it may be virtually useless to study the implications of accelerated depreciation schemes for equipment rather than buildings as a means of offsetting the impact of inflation on corporate income tax. In the first case, the policy is simple and can be easily introduced in the model; in the second one, the complexity of the problem is related to the policy itself and not to its economy-wide implications, and therefore a specific model of taxation and inflation will provide more reliable and useful results.

Finally, a word should be added with respect to some practical problems that arise when building and using a general equilibrium model. These are related to data requirements, availability of algorithms, computer resources and general programming expertise.

Any general equilibrium model requires a substantial investment in data gathering, analysis and adjustment. Even in the traditional and simple case of a single data point used to calibrate the model, it is necessary to have reliable data for all aspects of economic activity, which is by no means the case for most countries. Typically, there will be data on the production side, based on input-output tables; there will also be consumption and perhaps saving data from an expenditure survey; there are usually good statistics on foreign trade; and finally there exist also data on taxes and government expenditure, although access is often problematic. It is much more difficult to obtain data on investment, either by sector of origin of the investment goods or by sector of destination of the new capital. And, in the case of

models with various consumer groups, there is seldom good data on income distribution, asset ownership, etc. The major problems, however, are not related to the availability of the data but rather to the compatibility of data from different sources, obtained at different points in time. Very often, production and consumption surveys are not obtained for the same period. Almost always, the classification of goods and services used in production data is different from what is used in consumption or even foreign trade data. And more often than not, the aggregates obtained from one source do not coincide with the aggregates from another source. To build a single data point, corresponding to a general equilibrium, it is necessary to have fully consistent data for all the aspects of the economy represented in the model, for the same period. This being virtually impossible, it becomes necessary to adjust the data using adequate methods⁴, often involving some judgement on which sources are more reliable than others and on how to modify certain data to make it consistent with the rest in the least arbitrary manner possible. This type of work, which is time consuming and which is seldom very scientific, is crucial in determining the quality of the model and of the results.

At present, many different algorithms are available to solve general equilibrium models: methods based on Scarf's initial approach but greatly improved in terms of computer efficiency, methods based on linear approximations or on Newton-type algorithms, simple programs for microcomputers or complex and fast solutions for large mainframes. All allow flexibility in model specification, since they impose very few constraints on the development of the model. Still, some knowledge of the relative efficiency of each type of algorithm is useful: some are more recommended for certain types of applications; others are very efficient if the dimensions of the general equilibrium problem are limited but quickly become unworkable if they grow. In general any algorithm will solve a standard model; but sometimes problems arise which can only be solved if the right kind of algorithm is used. It is therefore important to have some familiarity with these algorithms and their properties.

A related issue is the required computing power and the level of computer expertise necessary to develop, maintain and improve a model. At present some models are solved on microcomputers, using very simple programs in a widely known language. But the most frequent case is the use of a fast mainframe, and the programming of the model in a fairly sophisticated code. The nature of some of the algorithms – in particular the fixed-point type, which does not iterate towards the solution monotonically, but which is guaranteed to converge – requires that the models be solved many hundreds or thousands of times, depending on the complexity and dimensions of the problem. It is therefore important that a fast computer be available, especially if the structure of the model involves many nonlinearities, sometimes requiring iterations within each solution step. It is also

important that inefficiencies be minimised in programs, since otherwise they will slow down considerably the convergence of the algorithm, because they will be repeated many times.

CONCLUSION: ASSESSMENT OF GENERAL EQUILIBRIUM MODELS FOR POLICY ANALYSIS

It may be appropriate to summarise the comments offered above with a discussion of the types of policies which could and should be addressed with a general equilibrium model, as well as policy issues for which these models are not appropriate.

Clearly, the general equilibrium approach is only justified in the case of policies with sufficient impact on the overall economy to warrant the utilisation of such a powerful and costly tool. It is seldom the case that sectoral policies, with limited feedbacks, need a general equilibrium approach. Typically, the approach is used for horizontal policies that cut across many sectors, or perhaps have an impact on producers and consumers simultaneously. Alternatively, these models are fully justified in the case of very substantial policy changes, which, even though confined to a specific sector, will inevitably affect the resource allocation process everywhere else. In this sense the impacts of tax reform, trade policy, global energy or agricultural policy, large projects or the introduction of new technologies are typical issues requiring a general equilibrium approach. On the other hand, policies which are specific to a single sector of small scale relative to the rest of the economy, or which by their complexity cannot be easily integrated in the structure of the model should be studied with other more appropriate tools: examples include the study of a simple subsidy to a particular manufacturing sector, or the implications of privatisation for economic efficiency. Moreover, it should be clear that only policies with a long time horizon should be evaluated with these models. The general equilibrium approach simulates the long run impact on resource allocation and income distribution of certain structural policy decisions after an adjustment process that may be lengthy, and therefore cannot be used to forecast short- or medium-term consequences. The best example of this point is the fact that the models are perhaps ideal to study tax reform in terms of its impact on efficiency and equity, but not in terms of objectives of reflation, or of job creation, which are more short-term concerns, better studied with other tools.

Finally the general equilibrium approach is better suited to study economies where the market mechanism – even if constrained by government intervention – still remains the dominant mode for allocating resources. If in certain countries or in certain sectors, all the major decisions on resource allocation are taken by the government or are not subject to competitive behaviour, then these models should be replaced by standard planning models, more appropriate and more useful in this context. This is particularly the case if the government interferes with the allocation of new capital which is directed to certain industries irrespective of rates of return. If such intervention cannot be easily captured by making explicit some kind of subsidy which justifies the investment by restoring its profitability, one of the major assumptions of the models will be violated and the validity of the analysis becomes questionable.

The recent developments in research, and the new generation of models now becoming widely known will greatly enhance the application of this tool to new areas of policy analysis. Complex issues of market structure, of intertemporal trade-offs, or of second-best policies can be addressed with the newest models, providing results of great practical relevance. The inclusion of financial markets in these models will permit the study of financial policy – another type of horizontal policy, affecting many different sectors and economic agents – which has not so far been analysed using this approach. Similarly, the incorporation of impediments to adjustment specific to certain sectors or certain factors of production will contribute to a more comprehensive analysis of the implications of a policy, by distinguishing between medium- and long-term results. This distinction is of course crucial in many policy cases, when everyone agrees that things will improve in the end, but there is disagreement with respect to effects during the transition period and the adjustment costs to be borne.

The power and potential of general equilibrium models are recognised and well understood today. Their limitations are also clear. Although steady improvements in the models will continue to increase their field of application, some of the disadvantages of the approach will never be removed. In any case, a careful use of the models – with due concern for the adequacy of the approach for the study in question – is the best guarantee that their potential will be realised.

NOTES

1. Walras' law states that all net excess demands add up to zero in value terms; in other words, if in one market demand exceeds supply, in other markets supply must exceed demand, to such an extent that in value terms they cancel out. This result will always be true if all economic agents meet their budget constraints, that is, if they allocate their available resources among the specified markets, not more and not less.
2. However, the recent series of articles on real business cycles explains macroeconomic fluctuations in the context of general equilibrium assumptions. Under certain constraints, generating interesting dynamic properties, a random shock to the technology of production will lead to business cycles which mimic closely the actual observed fluctuations. This line of work, however, has so far been limited to a fairly theoretical approach. See Kydland and Prescott (1982) and Long and Plosser (1983).
3. Goulder, Shoven and Whalley (1983) and Whalley and Yeung (1984) review the options with respect to foreign trade specification in general equilibrium models.
4. Such as the RAS method to update inter-industry transactions data; see Bacharach (1971).

BIBLIOGRAPHY ORDERED BY SUBJECTS

A. GENERAL REFERENCES

- Arrow, Kenneth J., and Debreu, Gerard (1954), "Existence of an equilibrium for a competitive economy", *Econometrica* 22, (June), pp. 265-90.
- Arrow, Kenneth J., and Hahn, Frank (1971), *General Competitive Analysis*, San Francisco, Holden-Day.
- Blitzer, C., Clark, P., and Taylor, L. (1975), *Economy-Wide Models and Development Planning*, London, Oxford University Press.
- Brouwer, L.E.J. (1910), "Über eine eindeutige, stetige Transformationen von Flächen in sich", *Mathematische Annalen* 67, pp. 176-80.
- Debreu, Gerard (1959), *Theory of Value*, New York, John Wiley.
- Ginsburgh, Victor and Waelbroeck, Jean (1981), *Activity Analysis and General Equilibrium Modelling*, Amsterdam, North-Holland.
- Harberger, Arnold C. (1962), "The incidence of the corporation income tax", *Journal of Political Economy* 70, No. 3 (June). pp. 215-40.
- Harberger, Arnold C. (1966). "Efficiency effects of taxes on income from capital", in *Effects of Corporation Income Tax*, M. Krzyzaniak (ed.), Detroit, Wayne State University Press.
- Harberger, Arnold C. (1974), *Taxation and Welfare*, Chicago, University of Chicago Press.
- Johansen, Leif (1975), *A Multi-Sectoral Study of Economic Growth*, second edition, Amsterdam, North-Holland.
- Johnson, Harry G. (1958), *International Trade and Economic Growth: Studies in Pure Theory*, Cambridge, Harvard University Press.
- Johnson, Harry (1954), "Optimum tariffs and retaliation", *Review of Economic Studies*, 21, No. 2, pp. 142-153.
- Jones, Ronald W. (1965), "The structure of simple general equilibrium models", *Journal of Political Economy* 73 (December), pp. 557-72
- Keller, Wouter J. (1980), *Tax Incidence: A General Equilibrium Approach*, North-Holland.
- Kimbell, Larry J. and Harrison, Glenn W. (1983), "On the solution of general equilibrium models", draft manuscript, University of Western Ontario (January).
- McKenzie, Lionel W. (1959), "On the existence of general equilibrium for a competitive market", *Econometrica* 27 (January), pp. 54-71.

- McLure, Charles E. (1975), "General equilibrium incidence analysis: the Harberger model after ten years", *Journal of Public Economics* 4, pp. 125-62.
- McLure, Charles E., and Thirsk, Wayne R. (1975), "A simplified exposition of the Harberger model I: tax incidence", *National Tax Journal* 28 (March), pp. 1-27.
- Meade, James (1955), *The Theory of International Economic Policy*, London, Oxford University Press.
- Powell, A.A. (1983), "The major streams in economy-wide modeling: is rapprochement possible?", *Large-scale Macro Econometric Models Theory and Practice*, (Chapter 9), (J. Krieta and J.B. Ramsey, eds.), Amsterdam, North-Holland.
- Samuelson, Paul A. (1951), "Abstract of a theorem concerning substitutability in open Leontief models", in *Activity Analysis in Production and Allocation*, (Tjalling Koopmans, ed.), New York, John Wiley & Sons.
- Scarf, Herbert E. (1960), "Some examples of global instability of the competitive equilibrium", *International Economic Review* 1.
- Scarf, Herbert E. (1967), "On the computation of equilibrium prices", in *Ten Economics Studies in the Tradition of Irving Fisher*, (W.J. Fellner, ed.), New York, Wiley.
- Scarf, Herbert E., with the collaboration of Terje Hansen (1973), *The Computation of Economic Equilibria*, New Haven, Conn., Yale University Press.
- Scarf, Herbert E. (1981), "The computation of equilibrium prices: an exposition", in *The Handbook of Mathematical Economics*, Vol. 2, (K. J. Arrow, and M.D. Intriligator, eds.), New York, North Holland.
- Scarf, Herbert E. (1983), "Fixed-point theorems and economic analysis", *American Scientist* 71 (May-June), pp. 289-96.
- Scarf, Herbert E. (1984), "The computation of equilibrium prices", in *Applied General Equilibrium Analysis*, (H.E. Scarf and J.B. Shoven, eds.), New York, Cambridge University Press.
- Scarf, Herbert E. and Shoven, John B. (eds.), (1984) *Applied General Equilibrium Analysis*, New York, Cambridge University Press.
- Shoven, John B. and Whalley, John (1977), "Equal yield tax alternatives: general equilibrium computational techniques", *Journal of Public Economics* 8, pp. 211-24.
- Shoven, John B. and Whalley, John (1984), "Applied general equilibrium models of taxation and international trade: introduction and survey", *Journal of Economic Literature* 52 (September), pp. 1007-51

B. COMPUTATION OF EQUILIBRIUM PRICES

- Eaves, B. Curtis (1972), "Homotopies for the computation of fixed points", *Mathematical Programming* 3, pp. 1-22.
- Eaves, B. Curtis (1974), "Properly labeled simplexes", in *Studies in Optimization*, MAA Studies in Mathematics 10, (G.B. Dantzig and B.C. Eaves, eds.)

- Hansen, Terje (1968), *On the Approximation of a Competitive Equilibrium*, unpublished Ph.D. dissertation, Yale University.
- King, A. Thomas (1977), "Computing general equilibrium prices for spacial economies", *Review of Economics and Statistics* 59 (August), pp. 340-50.
- King, A. Thomas (1980), "General equilibrium with externalities: a computational method and urban application", *Journal of Urban Economics* 7 (January), pp. 84-101.
- Kuhn, Harold W. (1968), "Simplicial approximation of fixed points", *Proceedings of the National Academy of Sciences, USA* 61, pp. 1238-42.
- Kuhn, Harold W., "How to compute economic equilibria by pivotal methods" (forthcoming).
- Kuhn, Harold W. and MacKinnon, James G. (1975), "The sandwich method for finding fixed points", *Journal of Optimization Theory and Application* 17, pp. 189-204.
- Lemke, C.E. and Howson, J.T. (1964), "Equilibrium points of bi-matrix games", *SIAM Journal of Applied Mathematics* 12, pp. 413-23.
- Lipton, D., Poterba, James, Sachs, J. and Summers, Lawrence (1962), "Multiple shooting in rational expectations models", *Econometrica* (September).
- Mansur, Ahsan and Whalley, John (1982), "A decomposition algorithm for general equilibrium computation", *Econometrica* (November).
- Merrill, Olin H. (1972). "Applications and extensions of an algorithm that computes fixed points to certain upper semi-continuous point-to-set mappings, unpublished Ph.D. dissertation, Department of Industrial Engineering, University of Michigan.
- Richter, Donald K. (1980), "A computational approach to resource allocation in spacial urban models", *Regional Science and Urban Economics* 70 (March), pp. 17-42.
- Robinson, Stephen M. (1975), "Newton's method for systems of nonlinear equations", in *Analysis and Computation of Equilibrium and Regions of Stability*, (H. Grumm, ed.), IIASA.
- Scarf, Herbert E. (1967), "The approximation of fixed points of a continuous mapping", *SIAM Journal of Applied Mathematics* 15, pp. 1328-43.
- Scarf, Herbert E. (1969), "An example of an algorithm for calculating equilibrium prices", *American Economic Review* 59.
- Todd, Michael J. (1984), "Efficient methods of computing economic equilibria", in *Applied General Equilibrium Analysis*, (Herbert E. Scarf and John B. Shoven, eds.), New York, Cambridge University Press.
- van der Lann, Gerardus and Talman, A.J. (1979), "A restart algorithm for computing fixed points without an extra dimension", *Mathematical Programming* 17, pp. 74-83.
- van der Lann, Gerardus and Talman, A.J. (1979), "A restart algorithm without an artificial level for computing fixed points on unbounded regions", in *Functional Differential Equations and Approximations of Fixed Points* (H. O. Peitgen and H. O. Walther, eds.), Heidelberg-Springer-Verlag.

C. METHODOLOGICAL ADVANCES

- Ballard, Charles L. and Goulder, Lawrence H. (1982), "Expectations in numerical general equilibrium models", *Research paper no. 31*, Stanford Workshop in the *Microeconomics of Factor Markets*, Stanford, CA, Department of Economics, Stanford University.
- Bovenberg, A. Lans (1983), "Capital immobility, capital accumulation, and financial assets: theory in an applied general equilibrium framework", Berkeley, CA, University of California, Department of Economics, mimeo.
- Bovenberg, A. Lans and Keller, Wouter J. (1981), "Dynamics and nonlinearities in applied general equilibrium models", *Central Bureau of Statistics*, the Netherlands, mimeo.
- Feenberg, Daniel R. and Rosen, Harvey S. (1983), "Alternative tax treatment of the family: simulation methodology and results", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.
- Feltenstein, Andrew (1984), "Money and bonds in a disaggregated open economy", in *Applied General Equilibrium Analysis*, (Herbert E. Scarf and John B. Shoven, eds.), New York, Cambridge University Press.
- Fisher, F. (1976), "The stability of general equilibrium: results and problems", in *Essays in Economic Analysis*, (Artis and Nobay, eds.), New York, Cambridge University Press, pp. 3-29.
- Ginsburgh, Victor and Waelbroeck, Jean (1984), "Planning models and general equilibrium activity analysis", in *Applied General Equilibrium Analysis*, (Herbert E. Scarf and John B. Shoven, eds.), New York, Cambridge University Press.
- Harris, Richard (1984). "Applied general equilibrium analysis of small open economies with scale economies and imperfect competition", *American Economic Review* 74, No. 5 (December), pp. 1016-32.
- Harrison, Glenn W. and Kimbell, Larry J. (1983), "How robust is numerical general equilibrium analysis?", University of Western Ontario.
- James, John A. (1984), "The use of general equilibrium analysis in economic history", *Explorations in Economic History* 21, pp. 231-53.
- Jorgenson, Dale W. (1984), "Econometric methods for applied general equilibrium modelling", in *Applied General Equilibrium Analysis*, (H. Scarf and J. Shoven, eds.), New York, Cambridge University Press.
- Jorgensen, Dale W. and Fraumeni, Barbara M. (1981), "Relative prices and technical change", in *Modeling and Measuring Natural Resource Substitution*, (E. Berndt and B. Fields, eds.), Cambridge, MIT Press, pp. 17-47. Reprinted in *Quantitative Studies on Production and Prices*, (W. Eichhorn, R. Henn, K. Neumann, and R. W. Sheppard, eds.), Wurzburg, Physic-Verlag (1983), pp. 241-69.
- Jorgenson, Dale W. and Slesnick, D.T. (1985), "Efficiency versus equity in economic policy evaluation", in *New Developments in Applied General Equilibrium Analysis*, (John Piggot and John Whalley, eds.), New York, Cambridge University Press, forthcoming.
- Joryenson, Dale W., Lau, L. J. and Stocker, T.M. (1980), "Welfare comparison under exact aggregation", *American Economic Review* 70, No. 2 (May), pp. 268-72.

- Kehoe, Timothy (1980), "Index theorems and uniqueness of equilibrium", mimeo.
- Kehoe, Timothy (1980). "An index theorem for general equilibrium models with production", *Econometrica* **48** (July), pp. 1211-32.
- Kehoe, Timothy and Whalley, John (1982), "Uniqueness of equilibrium in a large scale numerical general equilibrium model", London, Ontario, University of Western Ontario, mimeo.
- Mansur, Ahsan and Whalley, John (1984), "Numerical specification of applied general equilibrium models: estimation, calibration and data", in *Applied General Equilibrium Analysis*, (Herbert E. Scarf and John Shoven, eds.), New York, Cambridge University Press.
- Powell, A.A., Cooper, R. and McLaren, K.R. (1983), "Macroeconomic closure in applied general equilibrium modelling: experience from ORANI and agenda for further research", in *New Developments in Applied General Equilibrium Analysis*, (John Piggot and John Whalley, eds.), New York, Cambridge University Press, forthcoming.
- Richter, Donald K. (1975), "Existence of general equilibrium in multi-regional economies with public goods", *International Economic Review*, Vol. **16**, No. **1** (February), p. 201-221.
- Robinson, Sherman and Tyson, Laura (1984), "Modeling structural adjustment: micro and macro elements in a general equilibrium framework", in *Applied General Equilibrium Analysis*, (Herbert Scarf and John B. Shoven, eds.), New York, Cambridge University Press.
- Sullivan, Arthur M. (1983a), "A general equilibrium model with external scale economies in production", *Journal of Urban Economics* **73**, No. **2** (March), pp. 235-55.
- Whalley, John (1977), "A simulation experiment into the numerical properties of general equilibrium models of factor market distortions", *Review of Economics and Statistics* **59** (May), pp. 194-203.
- Whalley, John and Yeung, Bernard (1984), "External sector closing rules in applied general equilibrium models", *Journal of International Economics* **16** (February), pp. 123-38.

D. TAX POLICY

- Arnott, Richard J. and MacKinnon, James G. (1977), "The effects of the property tax: a general equilibrium simulation", *Journal of Urban Economics* **4** (October), pp. 389-407.
- Auerbach, Alan J. and Kotlikoff, Laurence J. (1983), "National savings, economic welfare, and the structure of taxation", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.
- Auerbach, Alan J., Kotlikoff, Laurence J. and Skinner, Jonathan (1983), "The efficiency gains from dynamic tax reform", *International Economic Review* **24** (February), pp. 81-100.
- Ballard, Charles L. (1983), "Evaluation of the consumption tax with dynamic general equilibrium models", Unpublished Ph.D. dissertation, Stanford University.
- Ballard, Charles L. and Goulder, Lawrence H. (1982), "Tax policy and consumer foresight: a general equilibrium simulation study", Harvard Institute of Economic Research Discussion Paper No 940, Harvard University, December.

- Ballard, Charles L. and Goulder, Lawrence H. (1985), "Consumption taxes, consumer foresight, and welfare", in *New Developments in Applied General Equilibrium Analysis*, (John Piggot and John Whalley, eds.), New York, Cambridge University Press, forthcoming.
- Ballard, Charles L., Shoven, John B. and Whalley, John (1982), "The welfare costs of distortions in the U.S. tax system: a general equilibrium approach", *Working Paper No. 1043*, Cambridge, Mass., National Bureau of Economic Research.
- Ballard, Charles L., Fullerton, Don, Shoven, John B. and Whalley, John (1985), *A General Equilibrium Model for Tax Policy Evaluation*, Chicago, University of Chicago Press, forthcoming.
- Becker, Charles M., Mills, Edwin S. and Williamson, Jeffrey G. (1983a), "Public policy, urbanization and development: a computable general equilibrium model of the Indian economy", *Working Paper No. 83-W14*, Department of Economics, Vanderbilt University (July).
- Boadway, Robin and Treddenick, John M. (1978), "A general equilibrium computation of the effects of the Canadian tariff structure", *Canadian Journal of Economics* 11 (August), pp. 424-46.
- Borges, Antonio (1984), "Tax reform in Portugal: a general equilibrium analysis of the introduction of a value added tax", *Working Paper 84-72*, INSEAD.
- Feenberg, Daniel R. and Rosen, Harvey S. (1983), "Alternative tax treatment of the family: simulation methodology and results", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.
- Feldstein, Martin and Feenberg, Daniel R. (1983), "Alternative tax rules and personal saving incentives: microeconomic data and behavioral simulations", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.
- Fullerton, Don (1979), "A general equilibrium taxation model with applications and dynamic extensions", *Proceedings of the NTA-TIA meetings of October 1979*, pp. 249-60.
- Fullerton, Don (1982), "On the possibility of an inverse relationship between tax rates and government revenues", *Journal of Public Economics* 19 (October), pp. 3-22.
- Fullerton, Don (1983), "Transition losses of partially mobile industry-specific capital", *Quarterly Journal of Economics* 98 (February), pp. 107-25.
- Fullerton, Don and Gordon, Roger H. (1983), "A reexamination of tax distortions in general equilibrium models", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, The University of Chicago Press.
- Fullerton, Don, Henderson, Yolanda K. and Shoven, John B. (1984), "A comparison of methodologies in general equilibrium models of taxation", in *Applied General Equilibrium Analysis*, (Herbert E. Scarf and John B. Shoven, eds.), New York, Cambridge University Press.
- Fullerton, Don, Shoven, John B. and Whalley, John (1978), "General equilibrium analysis of U.S. taxation policy", in *1978 Compendium of Tax Research*, Office of Tax Analysis, U.S. Treasury Department, Washington, DC, U.S. Government Printing Office, pp. 23-55.
- Fullerton, Don, Shoven, John B. and Whalley, John (1983), "Replacing the U.S. income tax with a progressive consumption tax: a sequenced general equilibrium approach", *Journal of Public Economics* 20 (February), pp. 3-23.

- Fullerton, Don, King, A. Thomas, Shoven, John B. and Whalley, John (1981), "Corporate tax integration in the United States: a general equilibrium approach", *American Economic Review* 71 (September), pp. 677-91.
- Galper, Harvey and Toder, Eric (1984), "Transfer elements in the taxation of income from capital", in Marilyn Moon (ed.), *Economic Transfers in the United States*, Chicago, University of Chicago Press.
- Goulder, Lawrence H., Shoven, John B. and Whalley, John (1983), "Domestic tax policy and the foreign sector: the importance of alternative foreign sector formulations to results from a general equilibrium tax analysis model", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.
- Goulder, Lawrence (1985), "Tax-financed vs. bond-financed government spending: simulating the efficiency and distributional consequences", mimeo, Harvard University.
- Hausman, Jerry A. (1983), "Stochastic problems in the simulation of labor supply", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.
- James, John A. (1978). "The welfare effects of the antebellum tariff: a general equilibrium analysis", *Explorations in Economic History* 15, pp. 231-56.
- Jorgenson, Dale W. and Yun, Kun-Young (1984), "Tax policy and capital allocation", Harvard University.
- Piggott, John (1979). "A general equilibrium evaluation of Australian tax policy", Ph.D. dissertation, University of London.
- Piggott, John R. and Whalley, John (1977). "General equilibrium investigations of U.K. tax subsidy policy: a progress report", in *Studies in Modern Economic Analysis*, (M. J. Artis and A. R. Nobay, eds.), Oxford, Blackwell.
- Piggott, John R. and Whalley, John (1985), "Applied general equilibrium analysis: an application to U.K. tax policy", New York, Cambridge University Press, forthcoming.
- Piggott, John R. and Whalley, John (1985), "Economic effects of U.K. tax-subsidy policies: a general equilibrium appraisal", in *New Developments in Applied General Equilibrium Analysis*, (John Piggott and John Whalley, eds.), New York, Cambridge University Press, forthcoming.
- Shoven, John B. (1976), "The incidence and efficiency effects of taxes on income from capital", *Journal of Political Economy* 84, No 6 (December), pp. 1261-83.
- Shoven, John B. and Whalley, John (1972), "A general equilibrium calculation of the effects of differential taxation of income from capital in the U.S.", *Journal of Public Economics* 7, pp. 281-322
- Shoven, John B. and Whalley, John (1973), "General equilibrium with taxes: a computation procedure and an existence proof", *Review of Economic Studies* 60 (October), pp. 475-90.
- Slemrod, Joel (1983), "A general equilibrium model of taxation with endogenous financial behavior", in *Behavioral Simulation Methods in Tax Policy Analysis*, (Martin Feldstein, ed.), Chicago, University of Chicago Press.

- Slemrod, Joel (1985), "A general equilibrium model of taxation that uses micro-unit data: with an application to the impact of instituting a flat-rate income tax", *NBER Working Paper No. 1461*, Cambridge, Ma, in *New Developments in Applied General Equilibrium Analysis*, (John Piggot and John Whalley, eds.), New York, Cambridge University Press, forthcoming.
- Stuart, Charles (1984), "Welfare costs per dollar of additional tax revenue in the United States", *American Economic Review* 74 (June), pp. 352-62.
- Summers, Lawrence H. (1983), "The asset price approach to the analysis of capital income taxation", *Discussion Paper No. 1073*, Harvard University.
- Summers, Lawrence H. (1982), "Taxation and the size and composition of the capital stock: An asset price approach", mimeo, Harvard University.
- Whalley, John (1973), "A numerical assessment of the April 1973 taxes changes in the United Kingdom", unpublished Ph.D. dissertation, Yale University.
- Whalley, John (1975), "A General equilibrium assessment of the 1973 United Kingdom tax reform", *Economica* 42, pp. 139-61.

E. INTERNATIONAL TRADE POLICY (including Multi-Country GE Models)

- Carrin, G., Gunning, Jan W. and Waelbroeck, Jean (1983), "A general equilibrium model for the world economy: some preliminary results", in *Global International Economic Models*, (B. G. Hickman, ed.), Amsterdam, North-Holland.
- Chichilnisky, G., Heal, G.M. and McLeod, D. (1983), "Resources, trade and debt", mimeo, Columbia University.
- Clements, Kenneth W. (1980), "A general equilibrium econometric model of an open economy", *International Economic Review* 21 (June), pp. 469-88.
- Deardorff, A.V. and Stern, R.M. (1981), "A disaggregated model of world production and trade: an estimate of the impact of the Tokyo round", *Journal of Policy Modeling* 3, No 2, pp. 127-52.
- Deardorff, Alan and Stern, Robert (1985), *The Michigan model of world production and trade: theory and applications*, Cambridge, Massachusetts, MIT Press.
- Feltenstein, Andrew (1980), "A general equilibrium approach to the analysis of trade restrictions, with an application to Argentina", in *International Monetary Fund Staff Papers* 27, No 4, Washington, DC., pp. 749-84.
- Ginsburgh, Victor and Waelbroeck, Jean (1975), "A general equilibrium model of world trade: Part I and II", *Cowles Foundation Discussion Paper Nos. 472 and 413*, Yale University.
- Manne, Alan S. (1983), "A three-region model of energy, international trade and economic growth", in *Global International Economic Models*, (B. G. Hickman, ed.), Amsterdam, North-Holland.

- Manne, Alan S. and Preckel, Paul V. (1983), "A three-region intertemporal model of energy, international trade and capital flows", mimeo, Department of Operations Research, Stanford University (January).
- Pigott, J. and Whalley, J. (1985), *New Developments in Applied General Equilibrium Analysis*, New York, Cambridge University Press.
- Shoven, John B. and Whalley, John (1974), "On the computation of competitive equilibrium in international markets with tariffs", *Journal of International Economics* 4, pp. 341-54.
- Spencer, John (1985), "The European economic community: general equilibrium computations and the economic implications of membership", in *New Developments in Applied General Equilibrium Analysis*, (J. Pigott and J. Whalley eds.), New York, Cambridge University Press.
- Staelin, C.P. (1976), "A general equilibrium model of tariffs in a noncompetitive economy", *Journal of International Economics* 6(1) (February), pp. 39-63.
- Taylor, L. and Black, S.L. (1974), "Practical general equilibrium estimation of resource pulls under trade liberalization", *Journal of International Economics*, 4(1) (April), pp. 37-58.
- Vincent, David (1982), "A multicountry, multisector general equilibrium model system with endogenous trade", Working Paper No. 174, Kiel Institute of World Economics.
- Whalley, John (1977), "General equilibrium analysis of U.S.-EEC-Japanese trade and trade distorting policies: a model and some preliminary findings", Department of Economics, The University of Western Ontario, Research Report 7713 (November).
- Whalley, John (1979), "Uniform domestic tax rates, trade distortions, and economic integration", *Journal of Public Economics* 11, pp. 213-21.
- Whalley, John (1980), "Discriminatory features of domestic factor tax systems in a goods mobile-factors immobile trade model: an empirical general equilibrium approach", *Journal of Political Economy* 88, No. 6 (December), pp. 1177-1202.
- Whalley, John (1982), "The North-South debate and the terms of trade: an applied general equilibrium approach", University of Western Ontario, Centre for the Study of International Economic Relations, Working Paper No. 8250C.
- Whalley, John (1985). *Trade Liberalisation Among Major World Trading Areas*, Cambridge, Massachusetts, MIT Press.
- Whalley, John, "An evaluation of the recent Tokyo round trade agreement through a general equilibrium model of world trade involving major trading areas", *Journal of Policy Modeling* (forthcoming).

F. ENERGY POLICY

- Borges, Antonio and Goulder, Lawrence H. (1984), "Decomposing the impact of higher energy prices on long-term growth", in *Applied General Equilibrium Analysis*, (H.E. Scarf and J.B. Shoven, eds.), New York, Cambridge University Press.
- Hudson, E.A. and Jorgenson, Dale W. (1978), "Energy policy and U.S. economic growth", *American Economic Review* 68, No. 2 (May), pp. 118-23.