Chapter 2
Economic Policy Using Applied General Equilibrium Models: An Overview

Abstract In the research presented throughout this book, a general equilibrium model serves to assess how the economy as a whole will react to any exogenous change. This chapter reviews general equilibrium theory and its transition to applied general equilibrium models. Specifically, we start by offering an overview of the theory of general equilibrium modelling from its origins and give a taste of how the theory evolved into applied models. We also review the key elements of an applied general equilibrium model, such as modelling production technology, consumers' behaviour, the activity of the public and the foreign sector and input markets. We also introduce the two basic techniques used to determine the numerical values of the model parameters – calibration and econometric estimation – as well as the identification of the benchmark equilibrium. The chapter concludes with a survey of some pioneering applications of general equilibrium models classified by fields and a critical appraisal of the major pros and cons of applied general equilibrium models today.

2.1 Introduction

As discussed in Chap. 1, this book presents a line of research that combines two analytical tools: applied general equilibrium modelling and multicriteria techniques. This chapter focuses on the first of these tools and reviews general equilibrium theory and its transition to applied general equilibrium models. The role of this type of model in our framework is to serve as an analytical description of the main economic driving forces that allows us to have an assessment of how the economy as a whole will react to any exogenous change.

In order to understand the philosophy underlying this modelling approach, in this chapter we look back at the theoretical origins of general equilibrium modelling and the main achievements in their development as fully applicable models. The remainder of the chapter is structured as follows. Section 2.2 gives an overview of the theory of general equilibrium modelling from its origins. Sections 2.3 and 2.4 give a taste of how this general equilibrium theory led to some attempts to translate these conceptual and theoretical ideas into applied models, resulting in so-called

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applied general equilibrium models or computable general equilibrium models. In Sect. 2.5 we review some of the most relevant analytical elements of the construction of an applied general equilibrium model. As we will discuss, building a general equilibrium model requires the specification of several parametric functional forms. Therefore, another important step in the development of these models is to determine the numerical values of the parameters involved in these functions. In Sect. 2.6 we discuss the two main approaches for determining such values: calibration and econometric estimation. Section 2.7 addresses another important step in general equilibrium applications: the determination of the model's so-called benchmark equilibrium. Section 2.8 presents a survey of some applications of computable general equilibrium models classified by fields. Section 2.9 concludes with a critical appraisal of the main current pros and cons of applied general equilibrium models.

2.2 An Overview of General Equilibrium Modelling

The historical origin of general equilibrium theory is to be found in the marginal utility or neoclassical school (school of economics active in the mid- to late nineteenth century). Based on the theory developed by this school, Gossen (1854), Jevons (1871) and Walras (1874) –who used mathematical notations– and Menger (1871) –who did not– took the first steps to develop general equilibrium theory. The most effective and outstanding researcher in this group is L. Walras. Walras can be considered the father of the theory.

General equilibrium's simplest problem lies in the analysis of exchange economies. In this type of economy, the demanders' budget constraint is determined by their initial resource endowment and the price vector. The individual demand function is the optimal response of the individual consumer to the given price system. The market demand function is obtained by aggregating individual functions, and market equilibrium emerges when we find a price for which the addition of net demands equals zero. This idea was already present in classical economic theory expressed as "supply should match demand". Although Cournot (1838), in his discussion of international money flow, and Mill (1848), in his arguments on international trade, had already sensed this point, we owe its expression as a set of mathematical equations to Walras (1874).

Some years later, Pareto (1909) defined a property of market equilibrium. Under the assumptions that goods were perfectly divisible and utility functions were differentiable, if every consumer made an equilibrium allocation of goods, an infinitesimal change in this allocation would not affect the utility levels if it did not affect the budget restriction levels. The so-called Pareto optimum could occur in competitive equilibrium, but it would require more severe conditions. The first theorem for developing this question was set out by Arrow (1951).

The following step in the development of general equilibrium theory was the introduction of production into a static framework. Producers were assumed to minimize production costs given the market prices. Market equilibrium was defined as a situation in which, given a price vector, supply matched demand. Walras considered a productive sector with a single good, and Hicks (1939) generalized this model to include more than just one output.

Earlier on Cassel (1918) had already developed a model with a productive sector, understood as a set of potential linear activities. He applied a simplified Walrasian model that preserved demand functions and production coefficients, but did not deduce the demand functions from the utility functions or preferences. The model was generalized by Von Neumann (1937) to allow for production in a spatial context.

A little later, Koopmans (1951) made a more complete and sophisticated analysis, creating a model explicitly introducing intermediate products. But the general linear model of production was not good enough to deal with the choice of activities as a cost-minimizing process, given the price vector and the quantities. Cost minimization had to be replaced by a condition according to which no activity could provide profits and no activity could suffer any losses in competitive equilibrium. This was exactly the condition used by Walras to initially define production equilibrium in a model with fixed production coefficients. This condition was first used in a general production model by Von Neumann (1937) and was called the Von Neumann law for production activities models.

Meanwhile an alternative productive sector model was being developed. This model emphasized producer organizations or firms rather than activities or technology. The equilibrium condition in the productive sector was that each firm maximized its profits, calculated as the value of the input–output combination over its production potential, given the input and output prices. This vision of production, specified in a partial equilibrium context by Cournot (1938), was implicit in the work of Marshall (1890) and Pareto (1909). It was further specified in a general equilibrium context by Hicks (1939) and especially in the Arrow and Debreu (1954) model.

The Arrow and Debreu's model (1954) is the one we can identify as the "first complete general equilibrium model". It formally demonstrated the existence of equilibrium with a productive sector formed by enterprises. Each enterprise had a set of production possibilities based on the resources it owned. The productive sector reached equilibrium when each enterprise chose the input–output combination of its set of technical possibilities that maximized profits at market prices. This was also the first model to directly include Walras-style preferences through demand-side hypotheses.

More or less simultaneously, McKenzie (1959) built another formal general equilibrium model. It formalized Walras' theory and used a linear production model. McKenzie proved the existence of equilibrium in this model through hypotheses made on demand functions rather than directly on preferences. It considered a linear technology instead of a set of enterprises. It was a generalized form of Wald's model (1951), omitting the structure of production, and the key hypothesis stated that demand functions satisfied the so-called "weak axiom of revealed preference".[1]

[1]For a full exposition of this axiom, see Wald (1951), pp. 370–379.

The spirit of static equilibrium analysis was to choose a time period that was short enough to avoid a big distortion of reality and suppose that all transactions would conclude within that period. This type of analysis had been developed by Walras, Hicks and Arrow–Debreu, although Arrow and Debreu explicitly dealt with inter-temporal planning, of both consumers and producers.

Walras' approach to static equilibrium was absolutely suitable only when everything remained constant: technology, tastes, resources and maybe even capital and population growth rates. Therefore, static comparisons had to be made as comparisons between the different stages.

Hicks (1939) considered the possibility of analysing equilibrium not from a static perspective, but, over time, assuming agents' present price expectations remained unchanged in the future.[2]

A number of authors tried to solve this problem. One was Radner (1972). His solution was to assume perfect forecasting, considering that all the agents had unchanged price expectations. Only a finite number of events could happen each time. From the point of view of the given market, the key events were the sequences of states of nature that could possibly occur over time. For each sequence, the agents correctly anticipated their corresponding price sequence. Rational expectations were implicit in this equilibrium model, where all agents had the same available information.

The trouble with this model, that is, admitting that the agents may behave differently from how they are expected to, has served other authors to demonstrate the non-existence of equilibrium; see, for example, Green (1977) and Kreps (1977).

Hick's model was naturally developed by Grandmont (1977), among others. Grandmont assigned each agent an expectation function that provided a distribution of probabilities on future prices and possibly other relevant variables as well. Therefore, assuming that each consumer had a criterion for choosing the optimum plan according to his or her expectations, the model would determine the excess demand as a function of current prices. Equilibrium would thus be reached if the market were cleared at the given prices.

Theorems on the existence of static equilibrium have been developed and demonstrated for many special cases, particularly for perfectly competitive economies where production is not taken into account and the number of periods is finite. The application of a fixed-point theorem (like the one developed by Brouwer)[3] completes the proof that a price system causes market clearing if every excess demand function equals zero. Despite these achievements, there are also some problems with this theory, as we will now see.

The most remarkable oversights in Walras' static equilibrium theory have been –and probably still are– the analysis of the demand for assets and saving for future consumption. For this reason, one of the main lines of general equilibrium theory development is the introduction of money. Money performs several economic

[2]This type of expectation is called "adaptive expectations" and is usually found in texts by Walras and Hicks.

[3]See, for example, Kehoe (1989), pp. 79–82.

functions, being a means of exchange, an asset or a numeraire. Authors such as Grandmont and Younes (1972) and Grandmont (1977) proved the existence of equilibrium in monetary models.

In order to prove monetary equilibrium, a hypothesis, similar to previous assumptions for the same purpose of limiting price expectations, like Green's conjecture (1973) was needed to prove the existence of a temporal equilibrium in non-monetary economies. The hypothesis was that, on a finite temporal horizon, the expected set of prices that resulted from all possible choices between current prices was assumed to be positive. Then, if all consumers had expectations that satisfied this and the previous model's hypotheses, a temporal equilibrium would also exist in this case.

This review of the main contributions to general equilibrium theory would not be complete without a reference to temporal equilibrium with infinite horizon. Let us remember that the Arrow–Debreu general equilibrium model (1954) had a finite number of periods, events and goods. The main objection to the finite number of goods constraint was that it required a finite horizon and there was no natural way to choose the end of the period.

Two types of models were developed to solve this problem, leading to an infinite number of goods. One model has an infinite number of living consumers. Each consumer could be considered a descendant of a series in an undefined future. This way, consumers living in the present period have an interest in the goods of all periods. This model is called an overlapping generation model. It was first proposed and analyzed by Samuelson (1958). Later on it was rigorously developed by Balasko et al. (1980) and by Wilson (1981).

The second model, introduced by Peleg and Yaari (1970), was a competitive general equilibrium model with a finite number of consumers and an infinite number of goods. Peleg and Yaari presented an exchange model without production. It was Bewley (1972) who produced a competitive general equilibrium model that included production with an infinite number of goods. It represented a generalized form of the existence theorem developed by McKenzie (1959) in the case of many goods, retaining the hypothesis of a finite number of goods.

We can conclude this review by saying that Walras' theory was the most complete and detailed general temporal equilibrium model ever developed. It is really remarkable in that it was also the first formal general equilibrium model. Walras was able to build a model that jointly determined money, production, saving level, capital goods and services prices and the interest rate. Obviously, the further developments summarized here added to and improved the original version.

2.3 From General Equilibrium Theory to Applied General Equilibrium

The step from the theoretical to the applied dimension took place between 1930 and 1940, when there was debate surrounding the feasibility of calculating Pareto optimal resource allocations for a socialist economy that was suitable for use by planners (see

Von Mises 1920; Hayek 1940; Robbins 1934; and Lange 1936). Leontief's *input–output analysis* was the next development (Leontief 1941). This was actually the most decisive step in the attempt to put Walras' theory on track towards an empirical dimension and to definitely align it with economic policy making.

Later on, the linear and non-linear planning models of the 1950s and 1960s, based on works by Kantorovitch (1939), Koopmans (1947) and others, were seen as an improvement of the input–output techniques through the introduction of optimization and as the first attempt to develop an applied general equilibrium.

In the 1950s, attention switched from a derivation of comparative statics to demonstrating the existence of equilibrium. Wald (1951) had already defended Walras' law and had provided the necessary proofs to demonstrate the existence of equilibrium. The use of differential calculus, topological analysis and the theory of convexity allowed authors like Arrow and Debreu (1954) and others to demonstrate the existence of equilibrium in very general models. The main mathematical tool that they used was, as mentioned earlier, Brouwer's fixed-point theorem.

Scarf (1973) developed a computational algorithm to find fixed points that satisfied the conditions of Brouwer's fixed-point theorem. This algorithm could be used to calculate equilibrium in economic models. Many of the first general equilibrium models used this algorithm for problem solving. Some of today's models are still based on that method, although faster variations developed by Merril (1971), Eaves (1974); Kuhn and McKinnon (1975), Van der Laan and Talman (1979) and Broadie (1983) are also used. Of these, Merril's variation is the one most often applied. Newton-type methods or local linearity techniques can be implemented as well. Even though convergence is not guaranteed, these methods can be as quick, if not quicker than Scarf's.

Another approach, implicit in the work of Harberger (1962), was to use a linearized equilibrium system to obtain an approximate equilibrium and, in some cases, to improve the initial estimator through multi-stage procedures so that approximation errors are eliminated. This method was also adopted by Johansen (1960), and improved by Dixon et al. (1982), de Melo and Robinson (1980), among others. It was they that developed the first applied general equilibrium models as such.

2.4 What Is an Applied General Equilibrium Model?

Reproducing the question posed by Shoven and Whalley (1984), we can say that an applied general equilibrium (AGE) or computable general equilibrium (CGE) model is an analytical representation of all the transactions in a given economy in such a way that it is possible to connect each element of the model with some observed empirical data.

The idea is to have an instrument that is capable of describing numerically how the economy behaves and reacts to different external shocks while being consistent with standard economic theory. As we will discuss later on, these models have been traditionally used to analyze the effects of changes in economic policies, such as the imposition of a tariff or quota on imported goods, the granting of export subsidies and income tax changes. They are equally useful for studying the impact of price rises or supply cuts of imported goods like petroleum, the effects of unexpected drops in the supply of goods or a greater regulation of the industrial sector, for example.

The basic elements of an applied general equilibrium model include the modelling of the behaviour of both consumers and producers, plus as many markets as factors, goods and services as are to be considered. Also, they usually account for the public sector, since one of the most common applications of this type of models is to evaluate certain public policies. In the next section we present a brief description of the main elements of a CGE model.

2.5 Main Elements of an Applied General Equilibrium Model

The first indispensable step in the process of clearly defining the problem to be analyzed is to choose the model's type, features and detail level. Analysing the impact of, say, income tax on households has nothing to do with examining the effects of a change in custom duties and tariffs on international trade although both of these events can be addressed in a general equilibrium setting. The first case would require a lot of details about the characteristics of domestic economies, as compared to the second case, where we would probably have to put more emphasis on the different productive sectors trading in foreign markets. Therefore, the type of problem we want to analyze will indicate the necessary degree of disaggregation and the economic sectors whose functions we must specify the most.

No matter what type of problem we set out to analyse, though, we must, in any modelling process, always bear in mind the following specifications:

- The number and type of goods (consumer goods, production goods, primary factors, etc.).
- The number and type of consumers (possibly classified by income, age, qualifications, tastes, etc.).
- The number and type of firms or productive sectors (simple or joint production; type of revenues of the production functions; technological development; etc.).
- The characteristics of the public sector (attitude of the government as demander or producer; fiscal system; budget, etc.).
- The characteristics of the foreign sector (related enterprises and sectors; degree of international integration; established tariffs and custom duties; etc.).
- Concept of equilibrium (with or without unemployment; with or without public and/or foreign deficit, etc.).

The choice of these specifications will output the particularities of the model to be used. On the other hand, the theoretical refinement of the model will also be affected by practical constraints such as information availability. In other words, an

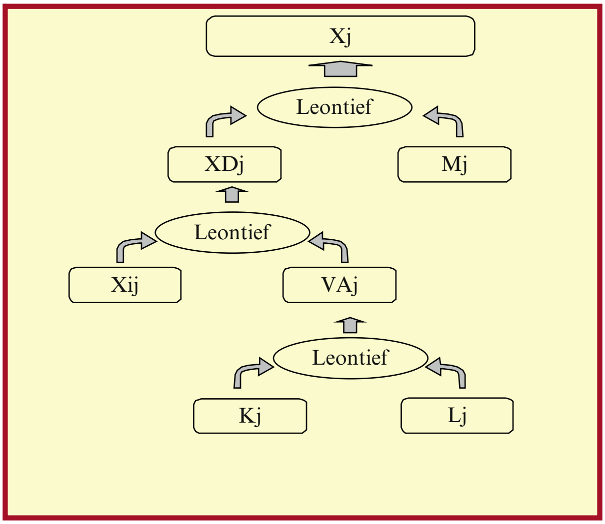

Fig. 2.1 Typical structure of a nested production function (Leontief technology)

applied general equilibrium model involves a trade-off between the researchers' intent to faithfully represent the economy's structure and the *ad hoc* constraints set by the available statistical information.

In the remainder of this section we present a discussion of all these elements.

Production: Production technology is usually represented by a so-called *nested production function*. Figure 2.1 shows a simple example of such a function. In this example, the domestic (or internal) production of sector *j* (denoted as *XDj*) uses production inputs, which typically include intermediate outputs from the other sectors (*Xij*) and primary factors (labour, *L*, and capital, *K*). Primary factors are combined using some production technology to provide the value added by each sector, VA_j. Total production Q_j is the result of combining domestic production Xd_j with imports, M_j, through a specific function usually conforming to Armington's (1969) hypothesis to simplify the analysis. This hypothesis considers that the analyzed country or economy is small enough as not to have an influence on foreign trade. In Fig. 2.1, Leontief-type technology is assumed to be used at all the nesting levels. Even so, this general structure allows for different production functions at each level. Producers are assumed to maximize their profits and this maximization results in supply functions of each good.

Public Sector: If we intend to undertake a study focused on policy making, the model should include some hypothesis about how the government makes such decisions. The government taxes economic transactions, thus collecting tax revenues and influencing the consumer's disposable income. It also makes transfers to the private sector and demands goods and services from different productive sectors *j*. The difference between its revenues and its outlays represents the balance (surplus or deficit) of the public budget *PB* according to the following identity:

$$\text{PB} = \text{Revenues} - \text{Public expenditures}, \tag{2.1}$$

where both income and expenditures are measured in monetary terms. Expenditure is the aggregation of (the nominal value of) public consumption and transfers made to the private sector. In the applications that we present in this book, the government activity (public expenditure and taxation) is perceived by economic agents as exogenous and by the government as decision variables.

Foreign Sector: In the model we will present in Chap. 5, the rest of the world is aggregated in a single foreign sector account. In principle, though, different accounts could be considered, for example, to represent trade with European countries and other foreign countries. Let us denote the foreign sector balance (deficit or surplus) by *ROWD*:

$$\text{ROWD} = \text{Imports} - \text{Exports} - \text{Net Transfers}. \tag{2.2}$$

If we are focusing on domestic issues and the foreign sector is not a key concern of the analysis, a common simplifying assumption (which we will adopt in our general equilibrium model) is to take the level of activity of the foreign sector as fixed. This is consistent with the small country hypothesis in the sense that the rest of the world is not affected by any domestic change introduced in our country.

Consumers: Final demand comes, first, from non-consumer demand sectors, investments and exports and, second, from household consumer goods demand. In general, there are n possible types of goods identified by their productive sectors, and there is usually one or more representative consumers (perhaps grouped by categories according to income source, income level, activity type, etc) who demand consumption goods. Each consumer has initial endowments and a set of preferences. The available consumer income not used for consumption is savings. The representative consumer's purchases are financed mainly by revenues from the sale of the initial factor endowments. The representative consumer's disposable income (*YDISP*) is calculated by adding up all capital and labour earnings, plus transfers received and minus the direct taxes for which his or she is liable:

$$\text{YDISP} = \text{Labour Income} + \text{Capital Income} + \text{Transfers} - \text{Direct Taxes} \tag{2.3}$$

The consumer's objective is to maximize some utility function, U, which depends on consumer goods CD_j and savings SD subject to the budget constraint:

$$\max U(CD_1, \ldots, CD_n, SD)$$

$$s.t. \sum_{j=1}^{n} p_j CD_j + invp \cdot SD = YDISP. \tag{2.4}$$

where n is the number of available goods, p_j denotes the price of consumption good j (j =1, .., n) and *invp* the price of investment goods. Demand functions are derived for each good from (4). Market demands are the result of adding up each consumer's individual demands. Note that market demands are price dependent and, they are also continuous, non-negative, homogeneous of zero degree and satisfy Walras' law.

Savings/Investment: The so-called *savings-driven models* are normally used for investment and savings. These are models on which the closure rule defines the behaviour of investment and that can tally the model's equation system depending on how investment is defined. Usually, investment is taken to be exogenous, savings are determined by the decision of the public sector, the foreign sector and of consumers to maximize their utility and deficits, and public sector and foreign sector investment are left to be determined endogenously according to the following accounting identity:

$$INV = PB + SD \cdot pinv + ROWD, \tag{2.5}$$

where *INV* is the aggregated nominal value of investment.

Input Markets: As for the inputs markets, labour and capital demands are calculated assuming that firms minimize the cost of producing value added. Concerning inputs supply, it is common to assume in the short term that total capital supply is inelastic (as we will do in the model presented in Chap. 5), although more complex specifications could also be used. Labour supply is normally a difficult element to deal with. One problem we face here is that CGE models are built on the assumption that all markets clear in equilibrium. On the other hand, one of the aims of applied work is to reproduce reality as closely as possible. This implies the recognition of unemployment. But such recognition is inconsistent with the equilibrium assumption, since unemployment means an excess supply of labour (and, hence, labour market imbalance). In Chap. 5 we will introduce a simple way to solve this problem.

Once all these elements have been specified, it is time to apply the equilibrium hypothesis. The idea is to assume that markets tend to equilibrium in the sense that supply equals demand in all markets as long as consumers and producers make optimal decisions. Solving the model means finding equilibrium, while allowing relative prices, productive sector activity levels (and perhaps public and foreign deficits) to operate as endogenous variables in equilibrium fitting. From a computational point of view, finding the equilibrium implies solving a system of equations. The complexity of this system is model dependent but must include, at least, the supply functions (one for each output and input), the demand functions, the market clearing conditions and all the relevant accounting identities.

The zero degree homogeneity of the demand functions and the linear homogeneity of profits in relation to the prices mean that only relative prices are significant; the level of absolute prices does not have any impact on the resulting equilibrium. Therefore, equilibrium is characterized by a set of relative prices and by certain production levels in each industry where market demand equals supply for all goods. The assumption that producers maximize their profits means that, in the case of constant scale revenues, no activity offers positive economic profits at market prices.

It is obvious that there is no just one general equilibrium model, but as many models as different combinations of decisions there are to be made (number of sectors, functional forms, etc). The choice of the specific functional forms usually depends on how elasticities are used in the model. The method most often applied is to select the functional form that best accounts for the key parameter values (like price and income elasticities) without damaging the model's feasibility. This is the key reason for perfectly identified functional forms, like Cobb–Douglas, constant elasticity of substitution (CSE), linear expenditure system (LES), Translog, Leontief's generalized and other flexible forms, being used.

2.6 Parameter Specification

Having solved the first problem (model specification), we now face the next obstacle of calculating the values of the parameters involved in the above functional relations, an essential step towards the use of this type of models for simulation purposes. A great deal has been written on the numeric specification procedures needed before calculating the model. We can divide the main ways of specifying these values into two groups: determinist calibration processes and econometric estimates.

2.6.1 Calibration Processes or Numeric Instrumentation

The most often used procedure is the so-called calibration method or numeric instrumentation.[4] We assume that the studied economy, empirically represented by a statistical database, is at an initial equilibrium, usually called "reference equilibrium". The model's parameters are then calculated so that the model reproduces the empirical data as an equilibrium solution for the model.

It is assumed that the reference data represent an equilibrium for the studied economy, and the required parameter values are then calculated using the agents' optimization conditions. If these conditions are not enough to identify the model, some of the parameter values –usually elasticities- are specified exogenously, until the model is identified. These values are normally based on existing databases and, every now and then, on additional estimates.

[4]Work by Mansur and Whalley (1984) perfectly reflects the procedure called calibration. Meade and Stone (1957) researched the disaggregation of national accounts for sectorial surveys. Also St-Hilare and Whalley (1983) designed a database to develop a general equilibrium model.

In practice, the data used for calibration are taken from national accounts or provided by governmental institutions. These data (flows of goods, services and revenues for a specific or reference period) must be gathered and arranged so that they are operational. The most consistent way to do this is through a database known as the social accounting matrix (SAM). A SAM includes the data corresponding to the transactions between firms, consumers' initial endowments and the amounts of goods and consumer goods they demand, the sectorial decomposition of the value added for the different productive sectors, taxes and transfers between the government and private agents, the economy's transactions with the foreign sector, etc. Figure 2.2 shows the standard structure of a SAM.

A SAM database needs to be consistent, which means that it has to be compatible with the different statistical sources. This is not a trivial requirement since there are usually many inconsistencies across databases. For example, the value of gross domestic product (GDP) may not be the same in the national accounts as in the input–output tables; consumer expenditure in the national accounts may be different from the data provided by the input–output tables and the Household Budget Survey, etc. Compatibility of the information sources is achieved through hierarchization. Input–output tables are usually placed at the top of the hierarchy.

This calibration procedure has generated as much interest as criticism. The main pitfall is that it provides no statistical test of the model's specification since the calculation procedure is deterministic. This procedure with calibration processes is quite the opposite to econometric work that usually simplifies model structure to achieve greater richness in statistical terms. The pursuit of economic model perfection may have a negative impact on its statistical properties.

	PRODUCTION	***PRODUCTIVE FACTORS***	***INSTITUTIONAL SECTORS***	***CAPITAL***	***FOREIGN SECTOR***
PRODUCTION	*Intermediate consumption*		*Public sector and households consumption*	*Gross capital formation*	*Exports*
PRODUCTIVE SECTORS	*Value added payments to the factors*				
INSTITUTIONAL SECTORS	*Taxes on activities, goods and services*	*Revenue allocation from the factors to the institutional sectors*	*Current transfers between the institutional sectors*	*Taxes on capital goods*	*Transfers from the rest of the world*
CAPITAL		Consumption of fixed capital	*Savings of the institutional sectors*		*Foreign savings*
FOREIGN SECTOR	*Imports*		*Transfers to the rest of the world*		

Fig. 2.2 Standard structure of a social accounting matrix. *Source*: own elaboration

2.6.2 Econometric Estimates

An alternative way to specify parameter values in a general equilibrium model is through econometric estimation. Although this procedure is probably more common in economics, it is not the procedure generally adopted for applied general equilibrium models, where calibration is typically the norm.[5]

Despite the development of calculation methods to resolve non-linear general equilibrium models, especially in the aftermath of Scarf's research (1973), econometric methods[6] to estimate unknown parameters describing preferences in each model have not evolved at the same rate. Econometric estimations are not typically suitable for large-scale CGE models because this procedure requires a lot of calculations. On the other hand, econometric estimations are perfectly valid for some small-scale general equilibrium models.[7]

We can conclude that, even if the calibration method is less precise, it has the advantage of needing fewer data, observations and calculations. The econometric approach, although more powerful in terms of accuracy, is sometimes unfeasible due to the effort required to estimate all the parameters, each of which demands a great many observations. This is best summarized by Lau's statement:

> ...Thus, it is ideally suited (calibration) in which data are scarce and a quick answer is required. It is a useful shortcut for a modeller in a hurry.[8]

2.7 Benchmark Equilibrium

Once the functional forms of all the economic agents in the model have been defined and calibrated, we have to set the *benchmark equilibrium* or starting point equilibrium. The idea is to replicate the observed economy in such a way that the model reproduces a state of equilibrium where the supply and demand functions of all goods are obtained as the solution to utility and profit maximizing problems – see Fig. 2.3. The outcome will be a vector of goods and factor prices, levels of activity and tax revenues that satisfy the above conditions. Once the model has been calibrated, it can be used to simulate the effects of some proposed change, like a new policy to be implemented. The new equilibrium of the model can be seen as a

[5] Mansur and Whalley (1984). See also Jorgenson (1984).

[6] For a review of the main CGE models developed from stochastic estimates, see Jorgenson (1984).

[7] Mansur and Whalley (1984) discuss the estimates for a classic pure exchange economy, with or without production, and go on to then explain an estimation system for simple general equilibrium models.

[8] Lau (1984), p. 136.

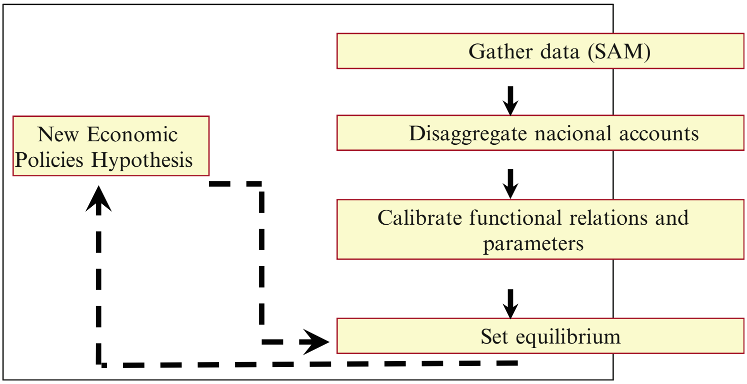

Fig. 2.3 Process of building an applied general equilibrium model. *Source*: own elaboration

prediction of the effect of this change on the most significant economic variables: prices, output levels, government revenues, and the new income distribution among the consumers.

Summing up, a general equilibrium models first establish the behaviour of a typical individual consumer, who, subject to physical and economic restrictions, aims to maximize his or her utility. The demand curves are thus determined for the different goods. Then, once all the individual demands of all goods have been aggregated, a market demand is obtained for each good, service or production factor. Afterwards the individual supplies of all firms are determined, assuming that they maximize their profits subject to technical and market constraints. And, finally, the individual supplies of each good are aggregated. Once the supplies and demands of each good have been obtained, we can investigate and find out if there is one or more prices on each market that equal aggregate supplies and demands. This will determine a price vector that will clear all the markets in the economy. Each agent will have obtained the individual demands and supplies to his or her maximum satisfaction, since the price vector is compatible with the decentralized decisions made by the agents. From this point of equilibrium, we will be ready to simulate and analyse the effects of the different policies applied. This outline of a general equilibrium model assumes, as is traditional, that the economy is modelled under the hypothesis of perfect competition. In Sect. 2.8g) we discuss some developments of related models under imperfect competition.

Standard *software* capable of completely fitting the data, calibration and equilibrium calculation sequence is available. GEMODEL, GEMPACK and, especially, GAMS, with all their different *solvers*, or problem-solving algorithms adapted to the different model necessities (database sizes; multiregional, dynamic or static models, etc.) are the most widespread. The problem nowadays is not so much a matter of resolving equilibrium as, as in other fields of economic theory, but collecting data in order to specify the parameters and finding economists with the skill to actually specify the model.

2.8 Main Applications of Applied General Equilibrium Models

One of the biggest strengths of general equilibrium models is their capacity to explain the consequences of major changes in a particular sector in relation to the economy as a whole. The consequences of a change in an economic policy are frequently analysed assuming that changes are small and using linear approaches based on relevant elasticity estimates. If the number of sectors is small, two-sector models can be used as in international trade theory. However, in a disaggregated model where several changes take place, there is no option but to resort to the construction of numerical general equilibrium models to study the economy.

A survey of the pioneering applications of general equilibrium modelling reveals the main areas where applied general equilibrium models have had a greater impact.

(a) Fiscal Policy Analysis

In the field of taxation, from the early two-sector models by Harberger (1962) and Shoven and Whalley (1977), we have moved on to modelling on a greater scale. (See Piggott and Whalley (1977) for Great Britain; Ballard et al. (1985) for the United States; Kehoe and Serra-Puche (1981) for Mexico; Keller (1980) for Holland and Piggott (1980) for Australia, among others.) This is the area where general equilibrium economic modelling has been more widely adapted and developed.

(b) Trade Policy Analysis

The analysis of general equilibrium applied to the study of trade policies has revolved around the issue of protectionism and its impact on economic efficiency and well-being. Trade models can be divided into two big groups. On the one hand, there are small economy models (closed economies), whose main characteristic is price endogeneity. On the other, there are large-scale economic models (open economies) that incorporate the assumption of price exogeneity in all trade goods.

Noteworthy, among others, are the global general equilibrium models developed by Deardorff and Stern (1986) and Whalley (1985b). They were used to evaluate political options in the GATT negotiation rounds. Dixon et al. (1982) attempted large-scale modelling in Australia. This has been used by governmental bodies to evaluate several commercial options in that country. Also, a group of models developed by the World Bank for different countries (Dervis et al. 1982) has provided information for decision-making processes in borrowing countries, as well as for trade liberalization options for several developing countries.

(c) Migratory Policy Analysis

Applied general equilibrium models are also used to study population movements. They may adopt a purely urban perspective, as King (1977) did, or a regional perspective, as was the case of Kehoe and Noyola's analysis (1991) of the Mexican economy. Kehoe and Noyola (1991) analysed the effects of alternative fiscal policies on emigration from rural to urban areas.

(d) Interregional Policy Analysis

These instruments have also analysed the impact of interregional policies. Take the work by Jones and Whalley (1986), for example. They developed a regional model for Canada that emphasizes issues related to partial labour mobility.

Serra-Puche (1984) developed a similar model for the Mexican economy, and Ginsburgh and Waelbroeck (1981) another for the Indian economy.

(e) Agricultural Policy Analysis

Good examples of general equilibrium models applied to the design of agricultural policies are the works by Keyzer and Wim (1994), who analysed food policies in Indonesia, or Parikh's treatise (1994) on Indian agrarian policies. Parikh (1994) focused on the public distribution system (PDS) according to which the government provides and offers some first necessity goods (rice, sugar, oil, flour and petrol) at below the market prices. Golden and Knudsen (1992) studied the effects of trade liberalization on agriculture.

(f) Stabilization Policy Analysis

The adverse external shocks experienced by most developed countries since the early 1980s, with falling exports, foreign trade losses, high interest rates and debt increments due to US dollar appreciation, led, together with the decrease of trade bank profits, to drastic adjustments. Subsequent adjustment programmes were designed mostly separately by the IMF and the World Bank.

Characteristically, these programmes placed an emphasis on both demand- and supply-side measures. Demand-size measures were to reduce short-term depressions, and supply-size polices provided for greater efficiency through structural adjustments. The two components of the strategy (stabilization and structural adjustment) were not separated, partly due to the dimension of the required adjustments.

Macromodels and standard general equilibrium models proved unsuitable for analysing the problem. The elevated aggregations of macromodels tend to consider the movement of resources between sectors and classes. On the other hand, money is neutral in standard general equilibrium models, and it only affects relative prices. There is no theoretically satisfactory way to study inflation, nominal wage rigidity or nominal exchange rate policies with traditional general equilibrium models. For this reason, some economists have developed so-called "general equilibrium financial models". They try to integrate money and financial assets into the multi-sector and multi-class structure of general equilibrium models. Despite these efforts, there is no consensus yet on the introduction of money and financial assets into general equilibrium theory. Authors like Lewis (1994), who studied the case of Turkey, and Fargeix and Sadoulet (1994) for Ecuador, have contributed to this line of study.

(g) Modelling Under Conditions of Imperfect Competition

The analysis of policies based on classical economic theory is underpinned by the hypothesis of an existing competitive equilibrium. We know that, in reality, competitive equilibrium does not always occur, and, consequently, there are monopolistic markets, oligopolies, monopolistic competitions, externalities, scale economies, etc. –in other words, markets with different degrees of imperfection.

Economists developing general equilibrium models have certainly not overlooked this reality and have tried to include this range of situations in their modelling. Take for example, Negishi's work (1961). Negishi (1961) first suggested that partial equilibrium analysis must be extended to general equilibrium analysis in the theory of monopolistic competition. Radner (1968) developed a general equilibrium model under conditions of uncertainty. Krugman (1979) studied a product differentiation model, trying to bring applied general equilibrium analysis closer to reality. Dixon (1987) analysed the possibility of imperfect competition within the macroeconomic framework of general equilibrium. Bonanno (1990) defended the development of a general equilibrium theory that included imperfect competition. De Melo and Roland-Holst (1994) studied South Korea's multi-sector general equilibrium model and examined if import tariffs and export subsidies in this model could be combined to promote the development of sectors with scale revenues and oligopolistic behaviours. Ginsburgh (1994) developed the model in a monopolistic scenario, and, finally, Brown et al. (1996) researched the existence of general equilibrium models for economies with incomplete assets markets.

(h) Inter-temporal Exchange Modelling

All the above analyses have one aspect in common: they take only the past and present into account for decision making. The resulting models are static. By dealing with exchange decisions inter-temporally, the models to move onto dynamic ground. Examples of such work are the writings by Benjamin (1994) on investment expectations in Bolivia, Cameroun and Indonesia; Blitzer et al. (1994) on the impact of restrictions on coal extraction in Egypt; Mercenier and Sampaïo de Souza (1994) on the structural adjustment of the Brazilian economy; and Berthelémy and Bourguignon (1994) on North–South-OPPP relationships.

(i) To Conclude. Some Recent Related Applications

This brief review of the origins of applied general equilibrium models has revealed one of the most important strengths of this approach. Indeed, AGE models are so versatile that they can be accommodated to a wide array of fields. Moreover, their use has spread to specific areas where there was no previous room for global analyses and where almost no formal works on impact measures had yet been developed. A presentation of the *state of the art* can be found in Kehoe et al. (2005).

One of the fields, particularly closed to our own research, in which CGE models have been successfully applied in recent times is environmental policy. Examples of environmental applications of CGE models include André et al. (2005), O'Ryan et al. (2005), Schafer and Jacoby (2005), Nijkamp et al. (2005), Kremers et al. (2002), Böhringer et al. (2006) or Springer (2003). The main methodological novelty of our work with respect to this literature is the combination of CGE models with multicriteria techniques.

2.9 Conclusions: Advantages and Disadvantages of Applied General Equilibrium Models

Despite the notable development of applied general equilibrium modelling over the last few years, this methodology is not without limitations. These limitations are due to its methodological basis –quite a common occurrence in economics and particularly inherent to any kind of modelling.

The main problem stems from the endemic difficulty of combining theory and reality. Applied general equilibrium models need an empirical basis for their calculation. This basis must reflect reality as faithfully as possible and at the same time be simple enough to be manageable. A list of the main problems with modelling follows[9]:

1. The model: choosing the model's functional forms, elasticity type, tax treatment, etc., is the first obstacle the researcher has to face when modelling a specific economy.
2. Disaggregation: the next problem is to disaggregate the model. Disaggregation and its degree of detail will give strength and credibility to the results of the simulation.
3. Data and parameter values: the model's data and parameters pose the next obstacle. In practice, it is not feasible to use econometric techniques to estimate the parameters that define the different functions in the model because so many estimates are needed. Models have been constructed with more than 20,000 parameters: it is an almost impossible task to estimate all of these parameters econometrically. The construction of a database that is consistent with reality (the so-called SAM) to later on define a general equilibrium that meets the conditions to be met by the model is the most frequently used technique. In some cases, it is complemented with econometrically estimated information. Although it may look like the easiest way to solve the problem, the construction of the SAM is by no means a simple exercise due to the great amount of statistical sources needed for its elaboration.
4. Model verification and validation: another important problem associated with this methodology is the lack of statistical tests to confirm the validity of the model specifications. Most general equilibrium models are calibrated from a database for a specific year. For this reason, except for simple tests to analyse the sensitivity of certain parameters included in the model, econometric procedures cannot be used to test the model's validity.
5. Transmission of the outcome: finally, there is an added problem with applied general equilibrium modelling. This problem has to do with the actual application rather than the construction of the model. The need to make the model as rich as possible contrasts with the simplicity required to explain the model to the people who are to use it for decision making, that is, the policy makers. This is a common obstacle with large-scale econometric models, and the effort to faithfully and easily convey the structure of the model becomes a sometimes unassumable challenge.

Everything that we have said so far leads to the conclusion that applied general equilibrium models are mostly discretionary, where it is the researcher that sets the model constraints and solutions during development. In contrast, their main

[9]See Whalley (1985b).

advantage is that they clearly bridge theoretical economic policy analysis and application. The present developmental lines of applied general equilibrium analysis cover[10]:

1. The reduction of model size by disaggregating precisely those sectors that are interesting for applied analysis. This means smaller and more specific models. Along these lines, the development of regional analyses appears to be one of the most important steps taken in the last few years.
2. The development of econometric general equilibrium models, where models define and estimate the behaviour of consumers or producers in a more complex way. This line of study analyses general equilibrium systems from the point of view of econometrics. Parameters will thus be more appropriately obtained and there will be more feasible chances of validating the models.
3. The definition of models so they can perceive gains or losses in well-being from the distortions generated in the model.

Finally, and apart from actual modelling, there is a line of action being developed that has to do with research group cooperation. The need to have a good command of general equilibrium theory, programming, databases, as well as to be familiar with parameter estimation, to have a sound knowledge of the range of taxation and institutional figures and to be able to interpret the results are forcing research efforts to focus on research groups that can cover all of these areas rather than on single researchers that develop the entire model from start to finish alone.

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[10] See Whalley (1985a).

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