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Applied General-Equilibrium Models of Taxation and International Trade: An Introduction and Survey

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I. *Introduction*

THE BODY OF RESEARCH discussed here is part of a wider series of developments which, in the last few years, has become known as "applied general-equilibrium analysis." The explicit aim of this literature is to convert the Walrasian general-equilibrium structure (formalized in the 1950s by Kenneth Arrow, Gerard Debreu, and others) from an abstract representation of an economy into realistic models of actual economies. The idea is to use these models to evaluate policy options by specifying production and demand parameters and incorporating data reflective of real economies. Most contemporary applied general-equilibrium models are numerical analogs of traditional two-sector general-equilibrium models that James Meade, Harry G. Johnson, Arnold Harberger, and others popularized in the 1950s and 1960s. Earlier analytic work with these models has examined the distortionary effects of taxes, tariffs and other policies, along with functional incidence questions. Recent applied models, surveyed here, provide numerical estimates of efficiency and distributional effects within the same framework.

The Walrasian model provides an ideal framework for appraising the effects of policy changes on resource allocation and for assessing who gains and loses, policy impacts not well covered by empirical macro models. We discuss a number of ways in which these models are already providing fresh insights into long-standing policy controversies. Due to space constraints, we will limit our discussion to recent modeling efforts in the fields of taxation and international trade.

The value of these computational models is that a computer removes the need to work in small dimensions: Much more detail and complexity can be incorporated than in simple analytic models. For instance, tax policy models can simultaneously accommodate several taxes. This is important because taxes compound in effect with other taxes even when evaluating changes in only one tax. Models involving 30 or more sectors and industries are commonly employed, providing substantial detail for policymakers concerned with feedback effects of policy initiatives directed only at specified products or industries.

The models reported here extend Wassily Leontief's work on empirical Walrasian models based on fixed input-output coefficients by incorporating substitution effects in both production and demand, and by including more than one consumer. Earlier work by three economists provides background for much of this activity. One is Leif Johansen (1960) who formulated the first empirically based, multi-sector, price-endogenous model analyzing resource allocation issues. He applied this model to policy questions in Norway. Another is Arnold Harberger (1962), who was the first author to investigate tax policy questions numerically in a two-sector general-equilibrium framework. A final important source of stimulus has been an ingenious computer algorithm for the numerical determination of the equilibrium of a Walrasian system, developed by Herbert Scarf in 1967. Despite subsequent extensions to his original algorithm, and more recently the use of alternative solution techniques, Scarf's work has been instrumental in persuading some of the recent generation of mathematically-trained economists to approach general equilibrium from a computational and, ultimately, a practical perspective.

Applied general-equilibrium tax models have been used to analyze such policy initiatives as integrating personal and corporate taxes, the introduction of value-added taxes, and indexing the tax system. In international trade models the impacts of trade policy changes on resource allocation within countries, custom union issues, international trade negotiations under the GATT, and North-South trade questions have been analyzed.

The plan of this paper is as follows: Section 2 presents a simple numerical example designed to illustrate how applied general-equilibrium models operate; Section 3 discusses how the methods illustrated by the numerical example can be implemented (the choice of parameter values and functional forms, the use of data, solution methods, and how policy conclusions are formulated); Section 4 presents the main features of recent tax models and highlights their most important policy implications; Section 5 similarly discusses trade models; we close with an evaluation of the approach and outline what could be useful directions for further research in this area.

II. *What Is Applied General-Equilibrium Analysis?*

Applied general-equilibrium analysis involves using a numerically specified general-equilibrium model for policy evaluation. However, despite the widespread use of the term "general equilibrium" in modern economics, the precise meaning of the term is often not fully defined. Everyone seems to agree that a general-equilibrium model is one in which all markets clear in equilibrium; there seems to be less agreement as to the essential elements of structure which underlie the equilibrium formulation.

Our use of the term corresponds to the well-known Arrow-Debreu model, elaborated on in Arrow and F. H. Hahn (1971). The number of consumers in the model is specified. Each of them has an initial endowment of the N commodities and a set of preferences, resulting in demand functions for each commodity. Market demands are the sum of each consumer's demands. Commodity market demands depend on all prices, are continuous, nonnegative, homogeneous of degree zero (i.e., no money illusion) and satisfy Walras' Law (i.e., that at any set of prices, the total value of consumer expenditures equals consumer incomes). On the production side, technology is described by either constant returns to scale activities or nonincreasing returns to scale production functions. Producers maximize profits. The zero homogeneity of demand functions and the linear homogeneity of profits in prices (i.e., doubling all prices doubles money profits) implies that only relative prices are of any significance in such a model; the absolute price level has no impact on the equilibrium outcome.

Equilibrium in this model is characterized by a set of prices and levels of production in each industry such that market demand equals supply for all commodities (including disposals if any commodity is a free good). Since producers are assumed to maximize profits, this implies that in the constant-returns-to-scale case no activity (or cost-minimizing techniques for production functions) does any better than break even at the equilibrium prices.

To illustrate how these models work, we present a simplified numerical example representative of those actually used to analyze policy issues. We consider a model with two final goods (manufacturing and nonmanufacturing), two factors of production (capital and labor), and two classes of consumers. Consumers have initial endowments of factors, but have no initial endowments of goods. A "rich" consumer group owns all the capital, while a "poor" group owns all the labor. Production of each good takes place according to a constant-returns-to-scale, constant-elasticity-of-substitution (CES) production function, and each consumer class has commodity demand functions generated by maximizing a CES utility function subject to its budget constraint. There are no consumer demands for factors (i.e., no labor-leisure choice). Even though the two consumer-two producer nature of this example means that it is similar to the Harberger (1962) tax model and could be solved analytically, the solution techniques used here are applicable to larger and more sophisticated models.

The production functions for the example are given by

$$Q_i = \phi_i \left[\delta_i L_i^{\frac{(\sigma_i - 1)}{\sigma_i}} + (1-\delta_i) K_i^{\frac{(\sigma_i - 1)}{\sigma_i}} \right]^{\frac{\sigma_i}{(\sigma_i - 1)}}, \quad i = 1, 2 \tag{1}$$

where Q_i denotes output of the i^{th} industry, ϕ_i is the scale or units parameter, δ_i is the distribution parameter, K_i and L_i are the capital and laborfactor inputs, and σ_i is the elasticity of factor substitution.

The factor demand functions derived from cost minimization for these production functions (1) are:

$$L_i = \phi_i^{-1} Q_i \left[\delta_i + (1-\delta_i) \left[\frac{\delta_i P_K}{(1-\delta_i) P_L} \right]^{(1-\sigma_i)} \right]^{\frac{\sigma_i}{(1-\sigma_i)}} \tag{2}$$

and,

$$K_i = \phi_i^{-1} Q_i \left[\delta_i \left[\frac{(1-\delta_i)P_L}{\delta_i P_K} \right]^{(1-\sigma_i)} + (1-\delta_i) \right]^{\frac{\sigma_i}{(1-\sigma_i)}} \quad (3)$$

where P_K and P_L are the per-unit factor costs for the industry (including factor taxes if applicable).

The CES utility functions are given by

$$U^c = \left[\sum_{i=1}^{2} \alpha_i^{c\,\frac{1}{\sigma_c}} \cdot X_i^{c\,\frac{(\sigma_c - 1)}{\sigma_c}} \right]^{\frac{\sigma_c}{(\sigma_c - 1)}} \quad (4)$$

where X_i^c is the quantity of good i demanded by the c^{th} consumer, α_i^c are share parameters, and σ_c is the substitution elasticity in consumer c's CES utility function. The consumer's budget equation is $P_1X_1^c + P_2X_2^c \leq P_L W_L^c + P_K W_K^c = I^c$, where P_1 and P_2 are the consumer prices for the two output commodities, W_L^c and W_K^c are consumer c's endowment of labor and capital, and I^c is the income of consumer c. If this utility function is maximized, subject to the budget constraint, the demand functions are:

$$X_i^c = \frac{\sigma_i^c I^c}{P_i^{\sigma_c}\left(\alpha_1^c P_1^{(1-\sigma_c)} + \alpha_2^c P_2^{(1-\sigma_c)}\right)} \quad (5)$$

$$i = 1, 2; c = 1, 2.$$

In this simple model, there are ten parameters whose values need to be specified: six production function parameters which affect the supply of the two products (i.e., ϕ_i, δ_i, and σ_i for $i = 1, 2$), and four utility function parameters determining the demand for each of the two products by each of the two consumers (i.e., α_1^1, α_1^2, σ_1, and σ_2). There are four exogenous variables whose values must also be specified: the endowment of labor (W_L) and capital (W_K) for each of the two consumers. The solution to the model is characterized by 12 variables, the four prices P_1, P_2, P_L, P_K, and the eight quantities X_1^1, X_1^2, X_2^1, X_2^2, and K_1, K_2, L_1, L_2 which meet the required conditions for equilibrium.

The equilibrium conditions in this model are that market demand equals market supply for all inputs and outputs, and that profits are zero in each industry. These can be written out more fully as:

(a) *Demands equal supply for factors*

$$K_1(P_L, P_K, Q_1) + K_2(P_L, P_K, Q_2) = \bar{K} \quad (6)$$

$$L_1(P_L, P_K, Q_1) + L_2(P_L, P_K, Q_2) = \bar{L} \quad (7)$$

where $K_1(P_L, P_K, Q_1)$, $K_2(P_L, P_K, Q_2)$, $L_1(P_L, P_K, Q_1)$ and $L_2(P_L, P_K, Q_2)$ are given by (2) and (3).

(b) *Demands equal supply for goods*

$$X_1^1(P_1, P_2, P_L, P_K) + X_1^2(P_1, P_2, P_L, P_K) = Q_1 \quad (8)$$

$$X_2^1(P_1, P_2, P_L, P_K) + X_2^2(P_1, P_2, P_L, P_K) = Q_2 \quad (9)$$

where X_1^1, X_2^1, X_1^2, and X_2^2, are given by maximizing (4), subject to consumer budget constraints, and Q_1 and Q_2 are given by (1). Finally, we have:

(c) *Zero profit conditions hold in both industries*

$$P_K K_1(P_L, P_K, Q_1) + P_L L_1(P_L, P_K, Q_1) = P_1 Q_1 \quad (10)$$

$$P_K K_2(P_L, P_K, Q_2) + P_L L_2(P_L, P_K, Q_2) = P_2 Q_2. \quad (11)$$

Given the four commodity and factor prices, one can evaluate the demands for commodities by all consumers because factor prices determine consumer incomes (which give the position of each consumer's budget constraint), and commodity prices give the slope of the budget constraint. The factor requirements to meet commodity demands are given by (2) and (3). An equilibrium is therefore characterized by four prices, P_L, P_K, P_1, P_2, such that equations (6)–(11) hold.

Once the parameters of these production and demand functions are specified and the factor endowments are known, a complete general-equilibrium model is available. Tax and other policy variables can then be added as desired.

By way of example, in Table 1 we list sample numerical values for all the parameters and the exogenous variables in this model. We have then solved this example using Olin Merrill's (1972) fixed-point algorithm, a refinement of the Scarf algorithm. This algorithm finds a set of market clearing prices for goods and factors, providing a solution to the simultaneous nonlinear equations above, (6)–(11).

The equilibrium solution for this example (the values of the endogenous variables) is shown in Table 2. At the computed set of equilibrium prices, total demand for each output exactly matches the amount produced, and producer revenues equal consumer expenditures. Labor and capital endowments are fully employed, and consumer factor incomes equal producer factor costs. Because of our assumption of constant returns to scale, the per-unit cost in each industry equals the selling price, meaning that economic profits are zero. The expenditures of each household exhaust its income. Since only relative prices affect behavior in general-equilibrium models such as this, we have chosen labor as numeraire.

To illustrate how a general-equilibrium model can be adapted for policy evaluation work, we consider the same numerical example as above, but with a tax policy regime added using the approach as in Shoven and Whalley (1973). The fundamental difficulty in modifying the model to incorporate taxes is the interdependence of demands and supplies, and tax revenues. For a given tax program (that is, for a specified tax rate imposed on a particular commodity or factor) tax revenues will be determined once demands, production levels, and factor employments are known. Demands also depend on tax proceeds since these provide income to one or more of the agents in the economy. The solution suggested by Shoven and Whalley is to solve not only for equilibrium prices as in the example above, but also for equilibrium tax revenues. In the simple case where all government revenues are redistributed to consumers (i.e., no provision of public goods and services), this means that in equilibrium the transfer payments made by government to consumers equal taxes collected by government. This is another condition that the equilibrium must satisfy.

We assume the same values of the parameters and exogenous variables as given in Table 1, along with an exogenously specified tax rate of 50 percent on each unit of capital income generated in the manufacturing sector. In the disburse-

TABLE 1

SPECIFICATION OF PRODUCTION PARAMETERS, DEMAND PARAMETERS, AND ENDOWMENTS FOR A SIMPLE GENERAL-EQUILIBRIUM MODEL

Sector	Production Parameters		
	Φ_i	δ_i	σ_i
Manufacturing	1.5	.6	2.0
Nonmanufacturing	2.0	.7	.5

Demand Parameters

Rich Consumers			Poor Consumers		
α_1^c	α_2^c	σ^c	α_1^c	α_2^c	σ^c
0.5	0.5	1.5	0.3	0.7	0.75

Endowments

	K	L
Rich Households	25	0
Poor Households	0	60

TABLE 2

EQUILIBRIUM SOLUTION FOR ILLUSTRATIVE SIMPLE NO TAX GENERAL-EQUILIBRIUM MODEL (PARAMETER VALUES SPECIFIED IN TABLE 1)

Equilibrium Prices				
Manufacturing Output		1.399		
Nonmanufacturing Output		1.093		
Capital		1.373		
Labor		1.000		
Production				
	Quantity	Revenue	Capital	Capital Cost
Manufacturing	24.942	34.898	6.212	8.532
Nonmanufacturing	54.378	59.439	18.788	25.805
Total		94.337	25.000	34.337
	Labor	Labor Cost	Total Cost	Cost Per Unit Output
Manufacturing	26.366	26.366	34.898	1.399
Nonmanufacturing	33.634	33.634	59.439	1.093
Total	60.000	60.000	94.337	
Demands				
	Manufacturing	Nonmanufacturing		Expenditure
Rich Households	11.514	16.674		34.337
Poor Households	13.428	37.704		60.000
Total	24.942	54.378		94.337
	Labor Income	Capital Income		Total Income
Rich Households	0	34.337		34.337
Poor Households	60.000	0		60.000
Total	60.000	34.337		94.337

ment of tax revenues, we assume that rich households receive 40 percent, with the remaining 60 percent going to poor households. The new equilibrium solution is shown in Table 3.

It is useful to illustrate how a general-equilibrium calculation differs from other less satisfactory methods. One purpose of such an equilibrium calculation might be to calculate the tax revenues that accrue to government from the taxes. A naive revenue estimate might use the equilibrium values in Table 2 as the base for the tax. In the no-tax regime the price of capital is 1.373 and the employment of capital in manufacturing is 6.212. A 50 percent tax rate on capital income in manufacturing might therefore be expected to raise 4.265 units of revenue (i.e., 50 percent of 1.373 x 6.212). In fact, this would be a seriously misleading estimate of tax revenues. When all the general-equilibrium responses are allowed for, the new revenue is only 2.278. Compared with the no-

TABLE 3

EQUILIBRIUM SOLUTION FOR ILLUSTRATIVE SIMPLE GENERAL-EQUILIBRIUM MODEL WITH 50% TAX ON MANUFACTURING CAPITAL

Equilibrium Prices				
Manufacturing Output			1.467	
Nonmanufacturing Output			1.006	
Capital			1.128	
Labor			1.000	
Production				
	Quantity	Revenue	Capital	Capital Cost (including tax)
Manufacturing	22.387	32.830	4.039	6.832
Nonmanufacturing	57.307	57.639	20.961	23.637
Total		90.469	25.000	30.469
	Labor	Labor Cost	Total Cost	Cost Per Unit Output
Manufacturing	25.999	25.999	32.831	1.467
Nonmanufacturing	34.001	34.001	57.638	1.006
Total	60.000	60.000	90.469	
Demands				
	Manufacturing	Nonmanufacturing		Expenditure
Rich Households	8.989	15.827		29.102
Poor Households	13.398	41.480		61.367
Total	22.387	57.307		90.469
	Labor Income	Capital Income	Transfers	Total Income
Rich Households	0	28.191	.911	29.102
Poor Households	60.000	0	1.367	61.367
Total	60.000	28.191	2.278	90.469

tax equilibrium, the relative price of manufacturing to nonmanufacturing output rises, while the net-of-tax price of capital falls. However, the tax-inclusive cost of capital in manufacturing increases, leading to a less capital-intensive method of production in manufacturing. Less manufacturing and more nonmanufacturing output is produced because of the tax. Expenditures of "poor" (labor-owning) households increase, while those of "rich" (capital-owning) households fall. General-equilibrium effects, therefore, need to be taken into account in revenue estimation, or in any other policy issue arising from such a tax.

A question frequently addressed by these models is whether any particular policy change is welfare-improving. In this instance, policy appraisal using these techniques usually relies upon a comparison between an existing equilibrium (i.e., with unchanged tax policies), and a counterfactual equilibrium computed with modified policies. Because the underlying theoretical structure of these models is so firmly rooted in traditional microtheory, a common procedure is to construct numerical welfare measures of the gain or loss.

The measures most widely employed are Hicksian compensating and equivalent variations associated with the equilibrium comparison. The compensating variation (CV) takes the new equilibrium incomes and prices, and asks how much income must be taken away or added in order to return households to their prechange utility level. The equivalent variation (EV) takes the old equilibrium incomes and prices and computes the change needed to achieve new equilibrium utilities. For a welfare-improving change, the CV is negative and the EV is positive, although it is quite common to employ a sign convention so that a positive value for either measure indicates a welfare improvement. For the economy as a whole, the welfare costs of the taxes are measured by aggregating the CVs or EVs across individuals.[1]

Because the utility function (4) in our numerical example is linear homogeneous, these welfare measures are especially easy to compute. Adopting the sign convention that for a welfare-improving change both the CV and EV are positive, yields

$$CV = \frac{(U^N - U^O)}{U^N} I^N \qquad (12)$$

$$EV = \frac{(U^N - U^O)}{U^O} I^O \qquad (13)$$

[1] As noted by John Kay (1980), the sum of EVs is a more easily interpreted measure if repeated pairwise comparisons are being performed. This is because old incomes and prices are used and are typically the same in the sequence of pairwise comparisons. Further, aggregation difficulties may arise in using an arithmetic sum of EVs or CVs as a welfare criterion, even though they are widely used elsewhere, including cost-benefit analysis. Some of these difficulties are discussed in Robin Boadway (1974).

TABLE 4

WELFARE MEASURES OF THE IMPACT OF A 50% TAX ON CAPITAL ON MANUFACTURING IN TABLE 1

	Hicksian Equivalent Variations	Hicksian Compensating Variations
Rich Households	−4.55	−4.45
Poor Households	+3.99	+3.83
Total	−0.56	−0.62
Welfare Loss as a Percent of National Income	0.62%	0.66%
Welfare Loss as a Percent of Tax Revenues	24.59%	27.23%
Decline in Welfare as a Percent of Marginal Dollar of Revenues Raised and Returned through Transfers	79.3%	79.3%

where U^N, U^O and I^N, I^O denote the new and old levels of utility and income, respectively.

In Table 4 we report the Hicksian compensating and equivalent variations associated with the 50 percent tax on capital income in manufacturing considered in Table 3. Here, we compare a no-tax (Pareto optimal) equilibrium to an equilibrium after the imposition of taxes. The fact that these taxes are distorting is indicated by the aggregate welfare loss. However, the redistribution caused by the factor price change means that poor households gain and rich households lose. The aggregate welfare cost of the tax is around 0.6 percent of national income, a number similar to Harberger's (1966) estimate of the cost of the corporate tax in the U.S. where the tax discriminant was not so different from that used in this example. Although 0.6 percent of GNP may not seem to be a large number, when measured against tax revenues the welfare cost appears much larger. The deadweight loss is around one-fourth of tax revenues, suggesting that this distortionary tax is an inefficient mechanism for raising revenues. Also, as stressed by Edgar Browning (1976), Dan Usher (1982), Charles Stuart (forthcoming), and Charles Ballard, Shoven and Whalley (1982), the marginal costs of raising an extra dollar in revenues will significantly exceed these average cost estimates; in this case, we find the marginal deadweight loss to be 79 cents for each extra dollar raised.

Later in the paper we describe models constructed to analyze alternative tax and trade policies in a number of countries. The differences between these models and the numerical example above lie in their dimensionality (i.e., in the number of sectors modeled), their parameter specification procedures which are based on empirical estimates, and their inclusion of more complex policy regimes than a simple tax on one factor in one sector. The tax models vary in the degree to which they model the whole tax system; some attempt to incorporate the entire tax structure, while others include only those portions of the tax system relevant to the issues being directly examined. In the trade models, a key difference is between those models that are multicountry or global in orientation, and those that examine how trade with the rest of the world affects individual countries.

Applied general-equilibrium analyses, then, are attempts to assemble and use models for policy evaluation. In the tax models, for instance, a proposal may be for the corporate tax to be abolished and replaced by a value-added tax. In trade models, multilateral tariff cuts proposed in a set of international negotiations could be the issue. Using applied general-equilibrium techniques, it is possible to compute alternative equilibria for different policy regimes and to assess impacts of the change.

One point frequently made is that this approach would not be particularly instructive if the equilibrium solution in any of these models were not unique for any particular tax or tariff policy. Uniqueness, or the lack of it, has been a long-standing interest of general-equilibrium theorists (Timothy Kehoe 1980). There is, however, no theoretical argument that guarantees uniqueness in the applied models described later. With some of the models, researchers have conducted ad hoc numerical experimentation (approaching equilibria from different directions and at different speeds), but have yet to find a case of nonuniqueness. In the case of the tax model of the U.S. due to Ballard, Don Fullerton, Shoven and Whalley (forthcoming), uniqueness has been numerically demonstrated by Kehoe and Whalley (1982). The current working hypothesis adopted by most modelers seems to be that uniqueness can be presumed for all of the models discussed here until a clear case of nonuniqueness is found.

Many other problems beyond the possibility of nonuniqueness are also encountered in designing and using these models. What type of model is to be used? Should it, for instance, be a traditional fixed-factor static model, or should it have dynamic features? Once the model form is determined, how are functions and parameter values to be chosen? How are foreign trade, investment, government expenditures, and a range of other complicating features to be treated? How is the model to be solved? And, finally, even after the model has been solved, how are equilibria to be compared; that is, which summary statistics are to be used in evaluating the policy change? These questions apply equally to all applied general-equilibrium modeling efforts whether or not they are directed towards tax and trade-policy evaluation. We therefore now turn to a discussion of how these issues are dealt with in the design of applied models.

III. *Implementing Applied General-Equilibrium Analysis*

A. *Choosing the Model*

Although the appropriate general-equilibrium model for tax or trade policy analysis depends partly on the focus of the model, most models currently in use have a similar form. They are variants of static, two-factor models that have long been employed in public finance and international trade, and are associated with the work of Eli Heckscher, Bertil Ohlin, Paul Samuelson, James Meade, Harry Johnson, and Arnold Harberger. Most computational models involve more than two goods, while aggregating the factors of production into two broad types, capital and labor. In some models, these composite factors are disaggregated into subgroups (e.g., labor, distinguished by skilled and nonskilled). Intermediate transactions are also usually incorporated, either through fixed or flexible coefficient input-output matrices.

Perhaps a natural question is: Why have most models evolved in this way, when it is possible to use more general specifications, possibly involving joint production[2] and more alternative inputs than capital and labor composite factors? Although it is possible that in future work these features will gradually appear, at the present three reasons seem to account for the popularity of basic two-factor structure in applied work.

First, many policy issues have already been analyzed theoretically using this framework. If the major contribution of numerical work is to advance from qualitative to quantitative analysis, it is clearly natural to retain the same basic theoretical structures. This way researchers can use the intuition gleaned from theoretical work to guide numerical investigations of policy alternatives.

Second, most data on which the numerical specifications are based come in a form consistent with two-factor models. For instance, national accounts data identify wages and salaries and operating surpluses as major cost components. This suggests a model with capital and labor as inputs. Input-output data provide intermediate transaction data, with value added broken down in a similar way.

Finally, the partition between goods and factors can be used in applied models so as to simplify computation and sharply reduce the costs of repeated solution. This is done by using factor prices to generate cost-covering goods prices, calculating consumer demands and evaluating the derived demands for factors (i.e., those amounts needed to meet consumer demands). In this way, even a model with large numbers of goods can be solved by working with a system of excess factor demands only. This simplification not only reduces execution costs for solution of models, but also makes feasible the incorporation of more detail in the treatment of households and goods.

In some cases, static equilibrium models have been sequenced through time to reflect changes in an economy's capital stock due to net saving. These models have been used to analyze intertemporal issues in tax policy, such as whether a move from an income tax to a consumption tax (under which saving is less heavily taxed) is desirable. Under this approach, a series of single-period equilibria are linked through saving decisions that change the capital stock of the economy through time. Saving depends on the expected future return to assets acquired in the current period, with myopic expectations (i.e., expected future returns on assets equal current returns)

[2] The ORANI model (Peter Dixon, Brian Parmenter, John Sutton and D. Vincent 1982) incorporates joint production with empirically estimated transformation frontiers.

frequently assumed to simplify computations. At any point in time the economy has a stock of capital and a labor endowment; saving today augments the capital stock in all future periods. In each period a general equilibrium is computed in which all markets clear, including that for newly-produced capital goods. The economy thus passes through a sequence of single-period equilibria that change through time as the capital stock grows. A tax policy that encourages higher saving will also cause lowered consumption in the initial years, with an eventual higher consumption level due to the larger capital stock.

A further issue in choosing one's model concerns the treatment of external sector transactions. In the multicountry trade models, a common approach is to use the so-called "Armington" formulation, which treats similar products produced in different countries as different goods. This differs from theoretical Heckscher-Ohlin models in which it is assumed that products are homogeneous across countries. Among other reasons, the Armington formulation is usually adopted in order to accommodate the phenomenon of countries both importing and exporting the same good (cross hauling). The external sector specification is also important in the tax models, since the effects of tax policies on an economy which is a taker of rental rates on world capital markets will be significantly different from those for a closed economy. Although international capital mobility is usually ignored, Lawrence Goulder, Shoven and Whalley (1983) have shown how its incorporation can change the analysis of tax policy options quite substantially compared to a model with immobile capital.

Other issues in model design include the treatment of investment and government expenditures. Investment usually reflects household-saving decisions (broadly defined to include corporate retentions), which are based either on constant expenditure shares in static models or on intertemporal utility maximization in dynamic formulations. Government expenditures are usually broken down into transfers and real expenditures. The latter are frequently determined from utility-maximizing behavior for government: i.e., the government is treated as a separate consuming agent that buys public goods and services. In a few cases, models have been used with public goods in household utility functions, although this complicates the tax models.

B. *Choosing Functional Forms*

The major constraints on the selection of demand and production functions in all the applied models is that they be both consistent with the theoretical approach and analytically tractable. The first constraint involves choosing functions that satisfy the restrictions listed in the presentation of general-equilibrium models, above, such as Walras' Law for demand functions. The second requires that the demand and supply responses of the economy be reasonably easy to evaluate for any price vector considered as a candidate equilibrium solution for the economy. This largely explains why the functional forms used are so often restricted to the family of "convenient" forms (Cobb-Douglas, Constant Elasticity of Substitution (CES), Linear Expenditure System (LES), Constant Ratios of Elasticities of Substitution, Homothetic, (CRESH) Translog, and others).

The choice of a specific functional form typically depends on how elasticities are to be used in the model. This point is best illustrated by considering the demand side of these models. Demands derived from Cobb-Douglas utility functions are easy to work with, but have the restrictions of unitary income and uncompensated own-price elasticities, and zero cross-price elasticities. These restrictions are typically implausible, given empirical estimates of elasticities applicable to any particular model, but can only be relaxed by using more general functional forms. With CES functions, unitary own-price elasticities no longer apply. However, if all expenditure shares are small, the compensated own-price elasticities equal the elasticity of substitution in the preferences, and it may be unacceptable to model all commodities as having essentially the same compensated own-price elasticities. A response to this difficulty is to use hierarchical or nested CES functions, adding further complexity in structure. The unitary income elasticity feature of the Cobb-Douglas functions can also be relaxed. One way is to use LES functions with a displaced origin, but then the origin displacements need to be specified. The general approach seems to be one of selecting the functional form that best allows key parameter values (e.g., income and price elasticities) to be incorporated, while retaining tractability.

On the production side, CES value-added functions are usually used to allow for substitution between primary factors. If more than two factors are used, hierarchical CES functions are again used. The intermediate production functions are sometimes modeled as fixed coefficients; on other occasions, some intermediate substitutability is allowed. In the international trade model one specification used is to have fixed coefficients in terms of composite goods, but with substitution possible among the components of the composite. By way of example, a fixed steel requirement per car may be specified, but with substitution between imported and domestic steel represented by CES functions. This may be necessary because of the large amount of trade in intermediate products and the unrealistically low import price elasticities that fixed coefficient intermediate production would imply if the Armington treatment of differentiating products by country is used.

C. *Selecting Parameter Values*

Parameter values for the functional forms are frequently crucial in determining results of policy simulations generated by the applied models. The procedure most commonly used to select parameter values has come to be labeled "calibration" (Ahsan Mansur and Whalley 1984). This procedure is outlined in Figure 1. The economy under consideration is assumed to be in equilibrium, a so-called "benchmark" equilibrium. The parameters of the model are chosen such that the model can reproduce this data set as an equilibrium solution.[3] If CES or LES functions are used in the model, exogenously specified elasticity values (usually based on literature estimates) are also required in this procedure because the benchmark data only give price and quantity observations associated with a single equilibrium. On the demand side, for instance, only the slope of the budget constraints at the equilibrium consumption quantities is given by the benchmark data. The parameter values thus generated can then be used to solve for the alternative equilibrium associated with any changed policy regime. These are usually termed "counterfactual" or "policy replacement" equilibria.

In practice, benchmark equilibria are constructed from national accounts and other government data sources. In general, the information will be inconsistent (e.g., payments to labor from firms will not equal labor income received by house-

[3] An additional important feature of this procedure is that once calibration is complete, it should be possible to reproduce the benchmark equilibrium data set as an equilibrium solution of the model. This is the replication check referred to in Figure 1, which serves as an important accuracy test of a computer code. If the replication check fails, then a programming error has been discovered and the coding must be investigated further.

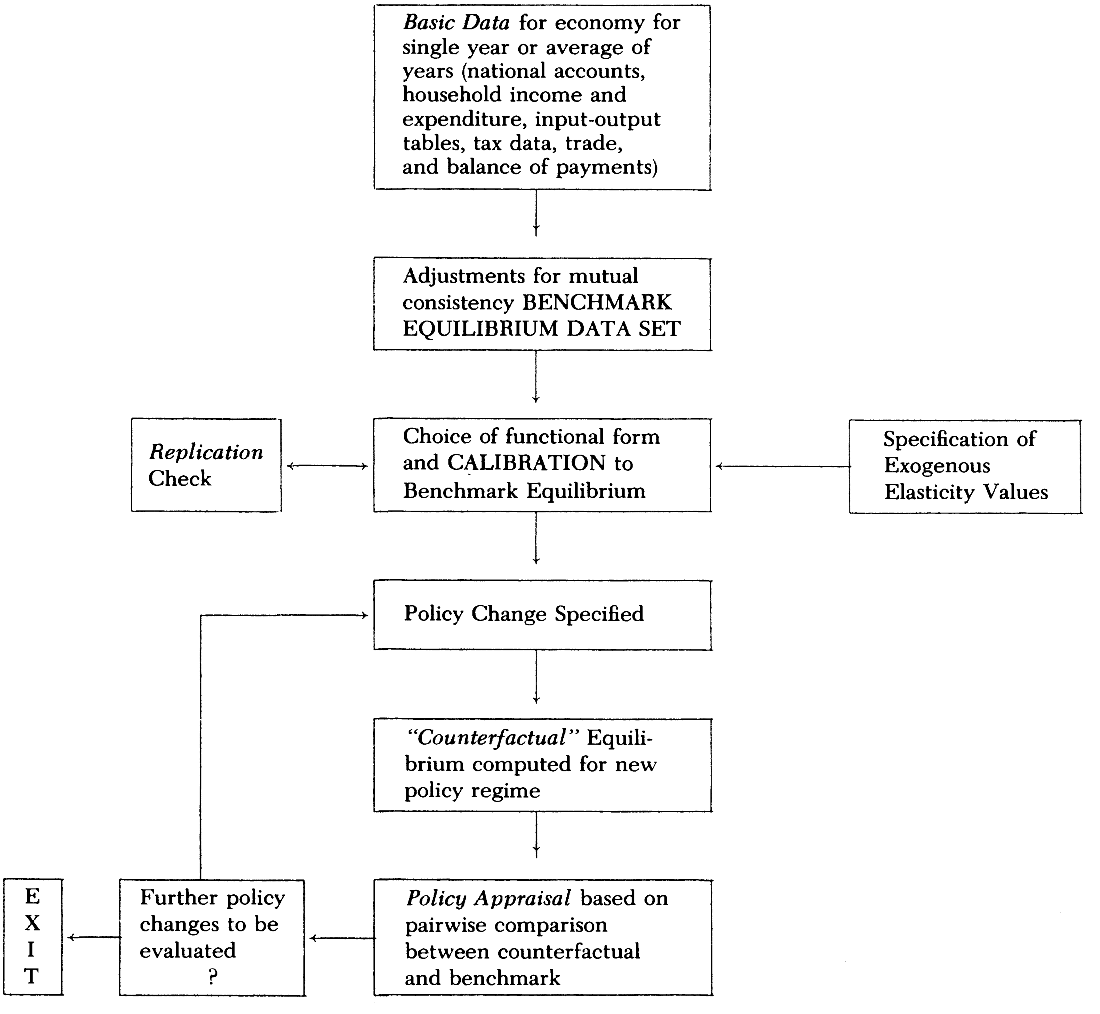

Figure 1. Flow chart outlining calibration procedures and model use in typical applied general-equilibrium model

holds), and a number of adjustments are required to the basic data to ensure that equilibrium conditions hold. Some data are taken as correct and others are adjusted to be consistent in the process of generating a benchmark data set. The construction of data sets of this type is described in Kemal Dervis, Jaime de Melo and Sherman Robinson (1982), France St. Hilaire and Whalley (1983), John Piggott and Whalley (forthcoming), and Ballard, Fullerton, Shoven and Whalley (forthcoming). Because the benchmark data are usually produced in value terms, units must be chosen for goods and factors so that separate price and quantity observations are obtained. A commonly used units convention, originally adopted by Harberger, is to choose units for both goods and factors so that they have a price of unity in the benchmark equilibrium.

Typically, calibration involves only one year's data, or a single observation represented as an average over a number of years. A crucial point in using calibration is that because of the reliance on a single observation, the benchmark data typically do not identify a unique set of values for the parameters in any model. Particular values for the relevant elasticities are usually specified on the basis of other research, and these serve to identify uniquely the other parameters of the model along with the equilibrium observation. This typically places a lot of reliance on literature surveys of elasticities and, as many of the modelers have observed in discussing their own work, it is surprising how sparse (and sometimes contradictory) the literature is on some elasticity values. Also, although this procedure might sound straightforward, it is often exceedingly difficult because each study is different from every other and recognizing and taking account of these differences is necessary.

The specification of elasticities is most easily thought of as determining the curvature of isoquants and indifference surfaces, with their position given by the benchmark equilibrium data. For Cobb-Douglas demand or production functions, a single price and quantity observation is sufficient to determine the parameters of the function uniquely. For CES functions, extraneous values of substitution elasticities are required, because the curvature of indifference curves and isoquants (given by the single elasticity parameter) cannot be inferred from the benchmark data. Similarly, for LES demand functions, income elasticities are determined once the origin coordinates for utility measurement are known.

A further feature of calibration is that no statistical test of the model specification which has been chosen is applied, because a deterministic procedure of calculating parameter values from the equilibrium observation is employed. The procedure thus uses the key assumption that the benchmark data represent an equilibrium for the economy under investigation. In contrast to recent econometric work that often simplifies the structure of the economic model to allow for substantial richness in statistical specification, here the procedure is quite the opposite. The richness of the economic structure only allows for a much cruder statistical model which, in the case of calibration to a single year's data, becomes deterministic.

Once the calibration procedure is completed, a fully specified numerical model is available that can be used for policy analysis. As indicated in Figure 1, any policy change can be considered and a counterfactual equilibrium computed for the new policy regime. Policy appraisal then proceeds on the basis of pairwise comparisons of counterfactual and benchmark equilibria. If further policy changes are to be evaluated, the new policy is incorporated, and the resulting counterfactual equilibrium is also compared to the benchmark.

Because the use of deterministic calibration rather than stochastic estimation in these models is often troubling to econometricians, it is perhaps worthwhile to outline some reasons why this calibration approach is so widely used. First, in some models many thousands of parameters are involved, and to estimate simultaneously all of the model parameters using time series methods would require either unrealistically large numbers of observations or overly severe identifying restrictions. Although partitioning models into submodels (such as a demand and production system) may reduce or overcome this problem, partitioning does not fully incorporate all the equilibrium restrictions that are emphasized in calibration. Second, as mentioned, benchmark data sets are in value terms, and the decomposition into separate price and quantity observations makes it difficult to sequence equilibrium observations with consistent units through time as would be required for time series estimation.

Thus far, these problems have largely excluded complete econometric estimation of general-equilibrium systems, although some progress in this direction has been made in work by Kenneth Clements (1980), Mansur (1980), and Dale Jorgenson (1984). Mansur, for instance, notes the difficulties in formulating a maximum likelihood procedure incorporating equilibrium restrictions. Michael Allingham (1973) has also worked on estimation of general-equilibrium systems but for a linear system of demand and supply functions rather than preferences and production functions. Jorgenson provides estimates for an economy-wide system of cost functions.

D. *Solving Models for Counterfactual Equilibria*

Early applied models either used Herbert Scarf's algorithm (1967, 1973) for solution or approximated an equilibrium using Johansen's (1960) procedure. Some recent models continue to rely on Scarf-type methods, but use faster variants of his algorithm due to Merrill (1972), Harold Kuhn and James MacKinnon (1975), B. Curtis Eaves (1974), and G. van der Laan and A. J. Talman (1979). Merrill's refinement seems the most widely used. As work has developed on applied models, however, it has become apparent that a Newton-type method or other local linearization techniques can also be used. These often work as quickly if not more quickly than the Scarf-type methods listed above, although these methods do not guarantee convergence. Victor Ginsburgh and Jean Waelbroeck (1981), for instance, have successfully used a *tâtonnement* procedure in their model work. Also, Glenn Harrison and Lawrence Kimbell (1983; also Kimbell and Harrison 1983) have developed an iterative procedure based on a Walrasian factor price revision rule with which they have experienced rapid convergence. This corresponds to a method for analytic solution of models in which all substitution elasticities are identical.

Another device, originating in Johansen's work, is to use a linearized equilibrium system to solve for an approximation to an equilibrium.[4] This procedure has been refined by Dixon, Parmenter, Sutton and Vincent (1982) who use a multi-step procedure so that approximation errors are eliminated. A similar approach of removing linear approximation errors in a Johansen system by iterated linearization is used by Lans Bovenberg and Wouter Keller (1983b).

Execution costs for existing models using all these techniques currently seem manageable, even on a production run basis. No standard off-the-shelf computer routine has yet emerged for the complete sequence of data adjustment, calibration, and equilibrium computation due to the complexities involved in each application of these models. However, what seems clear from recent literature is that it is no longer the solution methods that constrain model applications, but the availability of data and the ability of modelers to specify key parameters.

E. *How Are Policy Conclusions Reached?*

As has already been noted in discussing the numerical example above, the theoretical welfare economics literature is usually followed in making comparisons between equilibria in order to arrive at policy conclusions from the tax and trade models. For welfare impacts, the most commonly used summary measures are the Hicksian compensating (CV) and equivalent variations (EV) discussed above. Welfare measures for the economy as a whole are computed by simply aggregating the CVs or EVs over the different consumer groups. While this is consistent

[4] The Johansen system, however, does not allow for multiple consuming agents and in its application it appears to break the income-expenditure link central to Walras' Law.

with what is done in cost-benefit studies, theoretical shortcomings of the sum of CVs or EVs as a social welfare function are well known. However, because these models provide a detailed evaluation of who gains, who loses, and by how much, as a result of a policy change, no single summary measure need be chosen if the policy analyst using the results is interested in the detailed impacts of a policy change. In some models, equilibria are computed under the constraint that government revenues must remain unaltered which, in the tax models, usually implies replacing one set of taxes with another. In other models, government revenues are allowed to change. Where this occurs, however, the welfare impact from changes in the level of provision of public goods and services needs to be added to the economy-wide welfare measures.

In addition to welfare impacts, other differences between equilibria can also be evaluated. Income distribution effects can be examined using the Lorenz curve or the Gini coefficient or some other measure. Distributional effects using alternative income concepts (e.g., gross of tax, or net of tax) can be examined. Changes in relative prices can also be examined, and in the international trade models, changes computed in each country's terms of trade. Changes in the use of factors of production across industries, and changes in the product composition of consumer demands are important in some policy evaluations, and can also be extracted from the equilibrium computations.

However, the main focus of many (but not all) of the applied models is on the welfare impacts of policy changes, with particular emphasis on aggregate efficiency impacts. Although distributional effects may be considered, the bottom line in most policy evaluations is whether any given policy change raises or reduces aggregate welfare. In trade models, the difference between national and global welfare can be important. A tariff, for instance, may improve the national terms of trade and raise national welfare, even though a greater global loss may be involved. As a result, global and national welfare considerations can lead to quite different policy conclusions.

IV. *Applied General-Equilibrium Tax Models*

In this section we summarize the main features of some recent applied general-equilibrium tax models, highlighting their common features as well as the differences among them. We emphasize the role played by key parameters, discuss the strengths and weaknesses of the models, and outline the main policy implications to be drawn from results obtained thus far. Because these models are complex, we present much of this information in a series of tables. Table 5 outlines structural characteristics; Table 6, the data used; Table 7, some of the more significant results.

A. *Common Features*

The applied general-equilibrium tax models all derive in one way or another from Harberger's (1959, 1962, 1966) earlier work on United States corporate and capital income taxes. Their common features reflect this heritage. In Harberger's model, two sectors of production are identified: the corporate and the noncorporate sector. The corporate tax is assumed to be an *ad valorem* partial factor tax, a tax on capital income generated in the corporate sector. Revenues are redistributed to consumers in lump-sum form, and the government budget is balanced.

Using linearization and approximation techniques, Harberger (1962) generates an algebraic expression for the change in the net rental price of capital due to the introduction of a corporate income tax.

He assumes particular values for the substitution elasticities in production functions and for the consumer-demand elasticities, and he uses United States data for the mid-1950s on factor and expenditure shares. His main conclusion is that the reduction in the net return to capital is approximately equal to the tax revenues raised and, therefore, capital bears fully the burden of the corporate tax.

In this paper, Harberger implicitly outlines the calibration procedure mentioned above. He chooses units for factors of production as those amounts that sell for one dollar in the presence of the tax (i.e., in a benchmark equilibrium). His counterfactual experiment involves removing the corporate tax and replacing it by a nondistorting alternative, the differential tax incidence approach of Richard Musgrave (1959).

Harberger's basic structure has been preserved, with embellishments, in most subsequent work. Taxes are modeled as *ad valorem* and the government budget is balanced in equilibrium. The tax instruments that make up a typical modern tax system (income, corporate, property, sales, excise, and social security taxes) are all incorporated in model equivalent form. For instance, corporate and property taxes are usually treated as part of a larger system of taxes on capital income with rates varying across industries. The Musgrave and Harberger emphasis on the twin issues of efficiency and distributional impacts of taxes appears in most of the work.

Shoven and Whalley (1972, 1973) are the first to analyze taxes using a full general-equilibrium computational procedure. In their 1972 paper an artificial commodity is used to incorporate the tax distortions, which effectively limits the applicability of the analysis to one tax at a time. In 1973 they developed a procedure to deal with several simultaneous tax distortions without using artificial commodities. Scarf's algorithm enables the existence of a tax equilibrium to be shown, and also provides a method through which such equilibria can be computed.

This method of simultaneously incorporating several tax distortions was used by Whalley (1975) to examine the impact of 1973 tax changes in the United Kingdom, and this work was further developed by Piggott and Whalley (1977, and forthcoming) into a 33-product and 100-household-type model which has been used to evaluate structural characteristics of the United Kingdom's tax/subsidy system. They produce estimates of the welfare gains and losses for household groups classified by income, occupation, and family size for a series of hypothetical tax changes. Shoven (1976) reexamines the Harberger calculations of the efficiency costs of distortionary capital income taxes, using more disaggregated data than Harberger, showing how the level of aggregation affects results.

Two models closely related to the Shoven-Whalley work are those by Piggott (1980) on Australia and Jaime Serra-Puche (1984) on Mexico. Piggott's model differs from the other tax models in using two-stage CES production functions with differing types of capital and labor. At one stage, different types of labor "produce" the aggregate labor input and, correspondingly, different types of capital services "produce" the aggregate capital input. At the second stage, aggregate labor and capital combine to produce value added. Serra-Puche analyzes tax incidence in Mexico in a model with three factors. Subsequent work by Kehoe and Serra-Puche (1983) has used a similar approach to analyze the 1980 fiscal reform in Mexico, incorporating unemployment generated by an exogenously-specified, downward-rigid real wage.

Keller's (1980) tax model of Holland also uses a Harberger structure, but differs from the Shoven-Whalley work in using

TABLE 5: SUMMARY OF CHARACTERISTICS OF

Model	Country(ies)	Demand: Demand Functions
Ballard, Fullerton, Shoven, Whalley (forthcoming)	U.S.	Derived from nested CES/Cobb-Douglas utility functions
Ballentine, Thirsk (1979)	Canada	Differential equations giving quantity changes in terms of elasticities
Keller (1980)	The Netherlands	Derived from nested CES utility functions
Piggott (1980)	Australia	Derived from nested CES utility functions
Piggott, Whalley (forthcoming)	U.K.	Derived from nested CES utility functions
Serra-Puche (1984)	Mexico	Derived from Cobb-Douglas utility functions
Shoven, Whalley (1972)	U.S.	Derived from Cobb-Douglas utility functions
Slemrod (1983)	U.S.	Derived from Cobb-Douglas utility functions
Whalley (1975)	U.K.	Derived from CES utility functions

APPLIED GENERAL-EQUILIBRIUM TAX MODELS

Side	Production Side	
Disaggregation	Production Functions	Disaggregation
12 consumer income groups	CES or Cobb-Douglas production functions, fixed coefficient use of intermediate inputs	19 industries 16 final demand categories
12 income classes	Differential equations giving quantity changes in terms of elasticities	12 production sectors 7 final production categories
4 demand sectors: skilled and unskilled labor, public, foreign	Nested CES production functions	4 industries
12 socio-economic household groups, plus government, foreign and corporate sectors	CES value-added production functions with intermediate production structure allowing substitutability between domestic and foreign inputs	18 domestic and 14 foreign industries
100 socio-economic household groups, plus public, investment and external sectors	CES value-added production functions, fixed coefficient use of intermediate goods	33 industries
10 rural/urban income groups, plus government, plus the rest of the world	Cobb-Douglas production functions	14 industries producing 15 final consumption goods
2 income groups	CES production functions	2 industries: corporate and noncorporate
9 income groups	Cobb-Douglas production functions	4 industries, 6 income-generating assets
7 income groups	CES production functions	9 industries

TABLE 6: SOURCES FOR

Model	Base Year for Data	Extraneous Use of Elasticities
Ballard, Fullerton, Shoven, Whalley (forthcoming)	1973	Labor supply, savings (literature search) production elasticities of substitution between capital and labor (literature search)
Ballentine, Thirsk (1979)	1969	Factor substitution, price and income demand elasticities (literature search)
Keller (1980)	1973	Income elasticities of demand (from survey data) elasticities of substitution in production and consumption (best guess)
Piggott (1980)	1972–1973	Elasticities of substitution in production (literature search) elasticities of substitution in demand (literature search and best guess)
Piggott, Whalley (forthcoming)	1973	Elasticities of substitution in demand and production (literature search)
Serra-Puche (1984)	1977	Unitary substitution elasticities in demand and production
Shoven, Whalley (1972)	1953–1959 (average)	Elasticities of substitution in production (various specifications)
Slemrod (1983)	1977	Unitary substitution elasticities in demand and production
Whalley (1975)	1968–1970 (average)	Elasticities of substitution in production and demand (best guess and literature search)

Data and Elasticities in Tax Models

Production Data	Demand Data	Taxes Incorporated in the Model
National Accounts, Input-output tables	Consumer Expenditure survey, taxation statistics	All existing U.S. taxes including corporate, income, social security, sales and property taxes
Input-output tables, plus National Accounts data	Budget share	Corporate, property and income taxes
National Accounts, Input-output tables	National Accounts, Personal Income Distribution Survey, Budget Survey, Savings Survey	Taxes on consumer goods and services, on capital goods, imports, labor, capital and corporate income; lump-sum taxes
National Income and Expenditure Accounts, Input-output tables	National Income and Expenditure Accounts, Household Expenditure Survey	All existing Australian taxes and subsidies including income and sales taxes, production taxes and subsidies, factor taxes and subsidies
National Accounts, Input-output tables	National Accounts, Family Expenditure Survey	All major U.K. taxes and subsidies including income, corporate, property, excises, social security and value-added taxes, housing and agricultural subsidies
Input-output tables	Survey of Family Income and Expenditure	All existing Mexican taxes, including turnover taxes, special taxes, income taxes, tariffs and export taxes
Literature source	Literature source	Taxes on income from capital
Extraneously specified Cobb-Douglas exponents	Survey of financial characteristics of consumers, income and expenditure data	Corporate and property taxes
National Accounts	National Accounts	Major U.K. taxes including purchase and excise taxes, income taxes, corporation taxes, rates (property tax) and national insurance (social security)

TABLE 7: SUMMARY OF MAJOR

Model	Policy Interventions Incorporated	Policy Data Used	Policy Conclusions
Ballard, Fullerton, Shoven, Whalley (forthcoming)	Integration analysis: four alternative plans for corporate and personal income tax integrations. Consumption tax alternatives: change in the tax treatment of savings	U.S. personal and corporate income taxes	Total integration of personal and corporate income taxes yields gains whose discounted present value is $500 bil. or 1% of national income. Total integration with scaling to preserve tax yields leads to a progressive change income distribution even though every class is better off. Consumption tax alternatives yield gains of $650 bil. in present value terms.
Ballentine, Thirsk (1979)	Changes in local government expenditures, corporate and property income taxes, federal income taxes, and housing subsidies	Tax and expenditure data	Personal income taxes markedly progressive while property and corporate income taxes have a more mixed incidence pattern. Incidence effects of different expenditure programs small.
Keller (1980)	Changes in marginal tax rates in various production and consumption sectors	Major taxes in the Netherlands (value-added, corporate, social security and income)	Efficiency effects of taxes generally small (excepting corporate income tax); only small amounts of tax shifting.
Piggott (1980)	Total and sectoral abolition of taxes and subsidies under various model parameter specifications	Existing Australian sectoral taxes and subsidies	Replacing all taxes and subsidies with an equal-yield replacement tax leads to decrease in total domestic final demand: demand for imports rises modestly and world demand for Australian exports rises dramatically. Replacing all taxes and subsidies with an equal-yield export tax leads to total welfare gain of 3.5% of Australian NDP.
Piggott, Whalley (forthcoming)	Variations in U.K. taxes and subsidies	Existing U.K. taxes and subsidies	Existing U.K. tax system yields distorting losses of 6–9% of NNP per

a local linearization procedure to solve for the tax change equilibria. Four groups of agents on the demand side are incorporated. Government and the foreign sector are separately identified, along with low income/unskilled labor and high income/skilled labor groups. His incidence analysis concentrates on distributional effects between these two latter groups.

Greg Ballentine and Wayne Thirsk (1979) also use a local linearization approach along Harberger lines in their general-equilibrium tax work on Canada. Their main concern is incidence analysis of changes in financing arrangements (including intergovernmental transfers) for local government expenditures, such as increases in federal, personal or corporate taxes to finance increased municipal expenditures. No explicit functional forms

POLICY FINDINGS OF TAX MODELS

Model	Policy Interventions Incorporated	Policy Data Used	Policy Conclusions
			year. Subsidies to local authority housing area are a significant source of welfare loss. Significant redistributive effects of taxes.
Serra-Puche (1984)	Replacement of indirect turnover taxes with consumption value-added tax (as instituted in Mexico in 1981)	Existing Mexican turnover taxes, specific goods taxes, income taxes, tariffs and export taxes	Resource allocation moved in favor of the government target sectors (agriculture and foodstuffs); income distribution improved, reducing differentials between urban and rural households.
Shoven, Whalley (1972)	Imposition and removal of existing taxes on income from capital under various model parameter specifications	Existing U.S. capital income taxes (corporate, property and personal income, including capital gains)	In 6 of the 12 cases examined, capital bears more than the full burden of the surtax, while in the remaining 6 cases, labor shares in the burden.
Slemrod (1983)	Complete indexation of U.S. tax system for inflation	Existing U.S. corporate and property taxes	Indexing the U.S. tax system leads to aggregate efficiency gains with the lowest income groups experiencing slight losses and the highest income groups receiving substantial gains.
Whalley (1975)	1973 U.K. tax reform	1973 U.K. taxation changes represented in model-equivalent form	Welfare gain from 1973 U.K. tax changes found to be small and in some cases may be negative. Replacement of purchase tax and SET by VAT appears to yield welfare losses, while changes made to income tax systems may yield gains.

for demand and production are used, but are implied by the configuration of elasticities adopted. On the demand side, for instance, they are careful to ensure that Engel and Slutsky aggregation conditions are satisfied by the elasticities chosen. Total differentials through the equilibrium conditions yield approximate estimates of changes between equilibria. An especially interesting departure in this model is the attempt to incorporate a degree of factor mobility both domestically among regions and internationally.

B. *Differences Among Models*

The main departures from the basic Harberger structure in models appears in more recent work where two issues not discussed by Harberger, the modeling of time and the treatment of financial assets, are now beginning to be addressed. The model of the United States (Ballard, Fullerton, Shoven, Whalley: BFSW, forthcoming) incorporates all major distorting taxes as in earlier work, but differs from other models through the incorporation of time through dynamic sequencing of single period Harberger-type equilibria. In the BFSW model, a number of commodities and industries appear as in the static models, but saving decisions in any period are made by households based on myopic expectations regarding the future rate of return to capital. Household saving determines the demand for capital goods produced in the period. This treatment allows each period's equilibrium to be computed without requiring information on future periods' prices.

Saving results in an increase in the capital stock, and affects intertemporal behavior through changed consumption possibilities in future periods. Calibration is made to an assumed growth path in the presence of existing tax policies, rather than to a single benchmark equilibrium. A change in policy displaces the economy from the balanced growth path. After a transition period,[5] the economy settles on a new growth path with an alternative capital/labor ratio. The pairwise comparison between equilibria in static models is replaced by a pairwise comparison between the equilibrium sequences under the alternative policy regimes. The restrictive assumption of myopic expectations can be replaced by a perfect foresight approach (or a limited foresight specification), as shown by Ballard and Goulder (1982), although significantly more computation costs are involved. Bovenberg and Keller (1983a) have also extended Keller's model by adding dynamic features similar to those introduced by BFSW in order to analyze tax incidence over time.

The treatment of financial assets has been addressed in Joel Slemrod's (1983) model of the United States, which differs from earlier models in incorporating endogenous financial behavior, of both households and firms, into the general-equilibrium approach. His work is motivated by the extensive literature in recent years that stresses corporate tax as a tax on equity returns only, rather than a tax on all capital income originating in the corporate sector. The rate of tax on capital income depends not only on the sector of origin but also on the financial arrangements that accompany the flow of income. Slemrod introduces uncertainty into his model through stochastic production-function parameters. A risk-aversion parameter is introduced into the preference functions, which are defined over both expected consumption and the variance of income. Both risky and riskless assets yield capital income, resulting in a portfolio allocation problem for households in addition to the usual budget problem generating consumption demands. Household commodity and asset demands are based on maximization of a two-stage preference function, the first stage incorporating the risk-aversion parameter. Market clearing for all goods and assets is incorporated with a supply response in financial assets based on an extraneous elasticity which determines the response of firm debt-equity ratios with respect to relative tax costs of debt and equity. The model is parameterized to represent a "stylized" economy rather than calibrated to an exact benchmark equilibrium, as in the other models.

C. *Key Parameters*

In spite of the extensive detail incorporated into these models, most modelers emphasize the important role played by a few key parameter values in determining results from their policy analyses. These are typically elasticity values and the *ad valorem* tax rates. The procedure generally employed is to choose a central

[5] The economy does not instantaneously jump to the new balanced-growth path because changes in the capital stock cannot exceed domestic saving in the model. As long as saving causes the capital stock to grow at a rate different from the labor growth rate, factor prices will be changing along the transitional path.

case specification, around which sensitivity analysis can be performed.

As far as elasticities are concerned, the key parameters tend to be labor supply, saving, and commodity-demand elasticities. In all of these areas, modelers typically encounter difficulties in selecting "appropriate" values due to conflicting literature estimates, and frequent changes in what seems to be the consensus among empiricists in the relevant area. With labor supply, for instance, the view for many years seemed to be that wage elasticities for prime-age males are small and could even be negative but values are larger and positive for secondary workers. However, some recent work seems to be challenging this view. The elasticity of saving with respect to the rate of interest was also thought, for many years, to be small (close to zero), but recent work by Michael Boskin (1978), and Lawrence Summers (1981) has challenged this view. Commodity-demand elasticities, on the other hand, have typically not accumulated a consensus view on a product-by-product basis, but significant variations exist among the literature estimates available. As users of elasticity estimates, all of this makes the tax modelers' task more difficult in that they often have to select among competing estimates, and follow changing literature opinions as to likely ranges for best-guess values.

On the tax-rate front, the modelers' task is equally difficult. They must first decide on the appropriate treatment of each tax to be modeled, often adjudicating literature disagreements. For instance, is the corporate tax to be modeled as a Harberger partial-factor tax, a lump-sum tax (as suggested by Joseph Stiglitz 1973), or as a tax on the return to equity capital in each industry? Is the property tax a tax on factor incomes or an excise tax? Is the social security tax a tax on labor or a benefit-related financing system for transfers to the elderly?

Having settled on the tax treatment to be employed, modelers must then select values for tax rates to be used in the model-equivalent representation of the tax. Following Harberger, the most commonly used procedure is to calculate an average effective tax rate by dividing taxes paid (as recorded in the benchmark data) by the model tax base. However, as Fullerton and Roger Gordon (1983) have emphasized, for several taxes there is no a priori reason to expect average and marginal tax rates to be the same, and the marginal rather than the average rate should be used in a model which evaluates resource allocation effects of taxes. Also, several alternative marginal rates can be calculated which depend on more characteristics than can adequately be captured by the models. For example, the marginal tax rates that savers face depend not only on the savers' income tax rate but also on the asset acquired and the financing and intermediation vehicles used. Faced with these problems, some modelers are averaging across marginal rates calculated for a range of circumstances, and incorporating these into their analysis. Strictly speaking, however, even this is inappropriate because distortions at the appropriate margins are not fully represented.

D. *Policy Implications of Results*

Although the ability to apply general-equilibrium techniques to tax policy questions may strike some readers as an accomplishment worth noting in itself, ultimately the most important contributions of the applied models lie in their results, and the new insights these offer into policy issues.

For several years following the original Harberger work on the resource allocation effects of taxes in the United States, public finance economists argued that deadweight losses from taxes were small (perhaps one percent of GNP per year).

When combined with the results of incidence studies, such as Joseph Pechman's and Benjamin Okner's (1974) suggesting little redistribution from the tax system, this often led to a policy stance in favor of redistributive tax changes with only limited attention focused on changes designed to improve allocative efficiency. A striking feature of the results from the general-equilibrium tax models is their suggestion of considerably larger deadweight losses from tax distortions, especially at the margin. In addition, while distributional results suffer from some of the same problems as in incidence studies (such as Pechman and Okner), they do seem to indicate that tax policies may have more redistributive power when their general-equilibrium effects are taken into account. For example, Harvey Galper and Eric Toder (1982) find for the United States tax system that the combination of a graduated schedule of marginal tax rates and the existence of a variety of preferences on assets held by households results in a more progressive tax system than might initially appear, because the general-equilibrium solution yields reduced before-tax returns of the preferred assets, relative to fully taxed assets, thereby lowering the after-tax returns available to high-income households.

A further example of these themes in results is provided by Piggott and Whalley (forthcoming) in their analysis of the United Kingdom's taxes and subsidies. They estimate that the 1973 United Kingdom tax/subsidy system yields distorting losses of between six to nine percent of net national product per year, with subsidies to local authority housing identified as a significant source of welfare loss. The costs of distortions from the tax subsidy system appear to be heavily concentrated in three areas: capital taxes, public-sector housing subsidies, and excise taxes. Distortionary costs for the most part are shown to be additive, with the notable exceptions of corporate and property taxes. They suggest that around one-quarter of net revenues raised by government each year are foregone through the deadweight loss associated with the tax subsidy system. Sharp distributional gains and losses occur through replacing the existing tax system by a yield-preserving neutral sales tax. The welfare gain to the top ten percent of households is around 25 percent of disposable income; the loss to the bottom ten percent is around 20 percent of disposable income. This, of course, differs from the traditional view that tax systems have only small distributional impacts. The tax system is shown to penalize manufacturing, but substantially to protect and promote housing. Additional welfare costs are calculated from saving and labor-supply distortions and are shown to be small or modest, although small elasticities are used.

Not all models fully endorse these implications. Slemrod's (1983) results, from fully indexing the United States tax system for inflation, suggest only small welfare gains, while Ballard, Shoven, and Whalley (1982) stress the significance of welfare costs of taxes at the margin. They estimate that welfare losses per extra dollar of revenues raised from existing United States distorting taxes may approach a dollar. That is, the private cost of a government dollar is almost two dollars.

There seems little doubt that these tax models are now being successfully applied to a range of policy issues and are yielding important insights. Results are helping to frame positions on policy issues, especially in suggesting which effects of taxes may be large and which small. In providing initial null hypotheses until better data and model estimates become available, this process clearly advances policy debate especially if modelers' conclusions are scrutinized carefully to see which are believable new insights, and which are quirks of unrealistic parameter values or model specifications.

E. *Weaknesses of the Models*

Even though they have a strong claim to policy applicability, the tax models suffer from a number of deficiencies which reflect problems both endemic to all applied general-equilibrium models and specific to the tax area. In the former are the difficulties of choosing appropriate elasticity and other parameter values, and the inevitable feature that a tractable model abstracts from important details in producing policy recommendations. In the latter are the inability, as yet, of models to incorporate fully detailed microdata available to public finance economists, the relatively unsatisfactory distributional modeling, and the average/marginal tax rate issue alluded to earlier.

Our current state of knowledge of elasticity values inevitably means that the degree of confidence that both modelers and policy analysts have in results is weakened. Although the spirit of "doing the best possible" until better elasticity values arrive has much to commend it, the dilemma for modelers is how much confidence to have in such elasticity-dependent estimates of impacts. This partly explains why modelers seem content to emphasize the broad themes of results rather than precise point estimates.

The level of detail, which ideally should be taken into account in evaluating any particular tax issue, frequently clashes with the limitations imposed by tractability. A good example is provided by attempts to analyze the impact of taxes on saving. Typically, a single-saving asset is identified, but as is emphasized in more institutional treatments of this issue, the range of tax treatments for different saving vehicles means that, ideally, all the margins need to be separately identified. For example, saving in the form of housing is lightly taxed; some saving is sheltered through pensions and IRAs; the tax treatment among financial assets differs depending upon financing, whether dividends are paid; and human capital formation is treated differently from other saving. Inevitably, the applied models have to aggregate over some of these margins, raising more concerns regarding the results.

A clear weakness of the applied models, compared to other empirical work in public finance, is their incomplete integration of the information contained in detailed microdata sets. Although this is an inevitable result of an emphasis on tractability, the differences can be quite striking. Pechman and Okner (1974), for instance, use data on 87,000 households in their tax incidence work; the most detailed of the tax models covers only 100 households. However, a start in this direction has been provided by Slemrod's (forthcoming) important paper.

Another, and in some ways related, issue is the restrictive nature of the distributional analysis presently possible with the tax models. The impacts of taxes on the personal distribution of income is usually calculated through the changes in factor incomes, transfers, and direct taxes. Little work has been done on life-cycle tax incidence, although recent work by Ballard (1983) is moving in this direction.

Despite these problems, the contribution to policy debate on tax issues that these models have made seems firmly established, and more contributions seem likely in the years ahead. Models are now being used or contemplated in a number of government agencies in various countries, evidence of the potential contribution that policymakers see. As these models move from the academic development stage closer to the heart of the policy process, added realism, more detail, and better data are likely to appear.

V. *Applied General-Equilibrium Trade Models*

Applied trade models differ from tax models in being based on a more varied heritage, and in having a more diffuse focus. Some are multicountry models designed to analyze global issues. Other single-country models investigate how developments abroad affect individual economies. Some are oriented exclusively to trade policy questions. Others are general-purpose modeling efforts, one part being the capability to analyze trade questions. Some are models of developed economies, while others analyze developing economies where trade policy issues are often quite different.

In synthesizing experience with these models, we have chosen to follow a similar route to that adopted for the tax models, namely to display details of models in tabular form and then comment in the text. Accordingly, Tables 8 and 9 summarize the main characteristics of the models, along with sources for data and elasticity values. Table 10 presents summaries of the major policy implications of results obtained thus far. To aid presentation in the tables we divided the models into separate multicountry and single-country groups.

A. *Types of Models*

In analyzing the impacts of trade policies, the applied models base themselves on the traditional framework emphasized in pure trade theory. Countries export commodities in which they have a comparative advantage. The differences among models reflect the way in which comparative advantage is incorporated, as well as the modeling of the policy regimes.

The most prevalent approach in modern trade theory is that associated with Heckscher and Ohlin. Within this framework, each country involved in trade has production functions and demand functions; in "strong" versions, identical production and demand parameters are assumed across countries. Trade is determined by the relative factor intensity of production, and the relative factor abundance among countries.

By contrast, the multicountry models listed in Tables 9 and 10 are not assumed to have identical production and demand parameters. Thus trade is determined on the basis of more than just differences in relative factor endowments. A further characteristic common to most of the multicountry and single-country models is the use of the so-called Armington assumption, discussed earlier. This treats products produced in different regions as qualitatively different (i.e., heterogeneous rather than homogeneous) across countries as in a traditional Heckscher-Ohlin model.

The reasons for this treatment are multifold, revealing the compromises that empirical modelers often have to make. In addition to the problems created by the presence of "cross hauling" in trade data, some of the early trade models encountered the difficulty that unrealistically strong specialization effects were produced when a change in trade policy occurred. This reflected the use of homogeneous products and production possibility frontiers that were close to linear, so that a small change in trade policy results in large moves toward specialization. The Armington treatment avoids these difficulties.

Also, the key empirical parameters to which many of the models are calibrated are import- and export-demand elasticities; in a model with homogeneous products, there is no simple import-demand elasticity unless the economy is completely specialized. Unless the Armington assumption is used, calibration becomes difficult because there is only a demand for the imported commodity (some of which is also domestically produced).

A major difference between the multicountry and single-country models is the way in which the determinants of trade are modeled. In the multicountry models, there is a specification of production and demand for all of the countries participating in trade. In the single-country models, this is not the case because the focus of the model is on the implications of trade policy for a single country, and a cruder modeling is adopted for the rest of the world. Usually a closing rule is adopted (i.e., a simple specification of the import supply and export demand functions) which countries face in their trade with the rest of the world, along with the specification of capital flows and other external sector characteristics. The use of these external sector closing rules in these models can be quite important, as has been emphasized by Whalley and Bernard Yeung (1984). Another major difference between the multicountry and single-country models is the capability of the multicountry models to analyze multilateral trade policy issues such as are involved with customs unions, trade liberalization under the GATT, or any other trade policy change simultaneously involving a number of countries. Single-country models are typically inappropriate for analyzing this class of policy issues.

The models also use different approaches in their treatments of trade protection policies. Most models incorporate tariffs, but different attempts have been made to incorporate the nontariff barriers. A simple way to incorporate nontariff barriers is through *ad valorem* tariff equivalents, but this can be inappropriate in a number of cases. For example, the effect of a quantity constraint is such that the *ad valorem* tariff equivalent would not remain unchanged as prices change in a model. In turn, nontariff barriers in developed and developing countries are quite different. Developing countries typically have import licensing, usually accompanied by foreign exchange rationing, and, as is evident from the Dervis-de Melo-Robinson work on Turkey and other countries, a careful modeling of these policies is crucial to an understanding of the policy issues involved.

A further issue, emerging in more recent work, concerns modeling the production side. Although not summarized in the tables, recent work by Richard Harris (forthcoming) has emphasized how both scale economies and industrial organization features, stressed in some of the recent international trade theory literature, can have important implications for numerical results of the impacts of trade policy changes. Harris emphasizes that if scale economies are large enough and the trade policy issues involve countries of different size, as is true in the United States-Canadian case, then incorporating scale economies can substantially change estimates of the impact of trade policies. A similar theme appears in earlier work by Dixon (1978).

B. *Exchange Rates and Capital Flows*

Another issue in the trade models concerns the role of exchange rates and the related issue of international capital flows since the traditional pure theory of international trade produces no real effects from exchange-rate changes. If a monetized extension of a classical general equilibrium model were to be used to analyze trade policy changes, and a money-demand function by region appeared along with specified levels of national money stocks, neutrality would prevail in the sense that the real and financial behavior of the system would be entirely independent. Once real side behavior is known, specifying national money stocks in each of the regions simply serves to determine domestic price levels and exchange rates. Alternatively, should a fixed exchange-rate regime be analyzed, one can calculate the national money stocks that are neces-

TABLE 8

SUMMARY OF MODEL CHARACTERISTICS OF TRADE MODELS

		Demand Side		Production Side	
Model	Country(ies)	Demand Functions	Disaggregation	Production Functions	Disaggregation
Multicountry Models					
Jan W. Gunning, G. Carrin, Jean Waelbroeck (with J. M. Burniaux and J. Mercenier) (1982)	11 groups of less developed countries and the rest of the world	Demand for CES import-export composite goods modeled as Extended Linear Expenditure System (ELES) for each consumer group	2 consumer groups (rural, urban) for each region, plus a rudimentary rest of the world	CES value-added functions plus fixed coefficient intermediate use of composite goods in the urban sectors; linear production functions in the rural sectors	6 production sectors (2 rural, 4 urban) in each regional model
Alan V. Deardorff, Robert M. Stern (1981)	18 major industrialized countries, 16 major developing countries, and the rest of the world	Cobb-Douglas utility functions; CES between home and imported goods in the same industry	34 countries plus the rest of the world	CES value-added functions; fixed coefficient intermediate use of CES composites of home and imported goods[a]	22 tradable and 7 nontradable industries for each of the 34 countries plus a residual rest of the world
Manne, Preckel (1983)	3 regions: industrialized countries, oil-exporting developing countries, oil importing developing countries	Demand for energy and nonenergy imports derived from CES production functions	3 regions: industrialized countries, oil-exporting developing countries, oil-importing developing countries	Nested CES	Energy and aggregated nonenergy commodities for each region
Marcus H. Miller, John E. Spencer (1977)	4 "countries": U.K., (6 member) EEC, Australia and New Zealand, rest of the world	Derived from two-stage CES utility functions	4 "countries": U.K., (6 member) EEC, Australia and New Zealand, rest of the world	Cobb-Douglas	2 commodities per country (agriculture and nonagriculture)
Whalley (1982)	EEC, U.S., Japan, rest of the world	Derived from nested CES utility functions	41 consuming groups comprising households, government, investment (stratified by income in U.S. and Japan and by region in EEC)	CES value-added functions; fixed coefficient intermediate use of CES domestic-import composites	33 commodities in each of 4 regions

Whalley (forthcoming)	7 trade blocs; U.S., EEC, Japan, Other Developed Countries, OPEC, Newly Industrialized Countries, Less Developed Countries	Derived from nested CES-LES utility functions	7 trade blocs	Nested CES value-added functions; fixed coefficient intermediate use of composite inputs	6 commodities in each of 7 trade blocs
Single-Country Models					
Boadway, Treddenick, (1978)	Canada	Domestic final demand for each CES composite good is unit price and income elastic; import supply and export demand own price-dependent only (constant elasticity)	Domestic demand for final goods, world demand for domestic exports	3 alternate specifications: fixed intermediate coefficients with Cobb-Douglas functions for labor and capital, fixed intermediate coefficients with CES functions for labor and capital, and variable coefficients Cobb-Douglas functions	2 alternate aggregations of industries 1. 16 groups 2. 56 groups
Dervis, de Melo, Robinson (1982)	Turkey	Constant expenditure proportions for import-export composite goods	One aggregate household[b]	2-level CES production functions; fixed coefficient use of intermediate goods	19 industries, 3 labor types
Dixon, Parmenter, Sutton, Vincent (1982)	Australia	Derived from Klein-Rubin utility functions with CES aggregration of comparable imported and domestic goods	Effectively one household	4-level input functions 1-Leontief between inputs of composite products 2-CES between imported and domestic products 3-CRESH between primary factors 4-CRESH between labor inputs CRESH output functions	114 commodities (112 industries)

[a] Alternative assumptions are also used in other versions of this model.
[b] In Ch. 13 of this reference, the model is disaggregated to include 7 socioeconomic household groups in order to study income distribution effects.

TABLE 9

SOURCES OF DATA AND ELASTICITIES IN THE TRADE MODELS

Model	Year	Base Year Data	Extraneous Use of Elasticities	Production Data	Demand Data	Trade Data
Multicountry Models						
Gunning, Carrin, Waelbroeck (with Burniaux and Mercenier) (1982)	1978	From World Bank data for 1978	Elasticity of substitution between domestic goods and imports, export demand elasticity, elasticity of substitution between capital and labor in urban sectors	World Bank data	World Bank data	World Bank data
Deardorff, Stern (1981)	1976	Data derived from various sources	Import demand, production function elasticities, elasticity of substitution between home and imported goods (literature search)	UN industrial data, OECD labor force statistics and National Accounts data	OECD National Accounts data	UN trade data
Manne, Preckel (1983)	1980 (with projection to 1990 and 2000)	Based on 1980 World Bank data	Elasticities of substitution between domestic and imported commodities (various specifications)	World Bank regional data on GNP, energy production, Royal Dutch/Shell supply forecasts	World Bank regional data on GNP, energy consumption	World Bank data
Miller, Spencer (1977)	1960 (Production) 1968 (Demand)	Based on data from various sources	Production elasticities (literature search) Elasticities of substitution between domestic and imported goods and between goods from each production sector	Derived principally from Denison (1967)	Derived principally from OECD Foreign Trade Statistics	OECD Foreign Trade Statistics
Whalley (1982)	1973	Constructed international benchmark data set	Elasticities of substitution between home and imported goods and within product categories (best guess) elasticity of substitution in production (literature search)	Input-output plus value-added data (capital and labor return) for each region	Household expenditure data disaggregated across traded goods using foreign trade data	From OECD Trade Statistics Balance of Payments Accounts

Whalley (forthcoming)	1977	Constructed benchmark data set	Production elasticities of substitution, demand elasticities of substitution within good categories, between categories, between imported and domestic goods (literature search, central case, and various specifications)	UN National Accounts data	Calculated as a residual	From UN, UNCTAD and OECD Trade Statistics
Single-Country Models						
Boadway, Treddenick (1978)	1966	1966 Input-output table	Production elasticities of substitution (literature search) world elasticities of supply of imports and demand for exports, domestic elasticities of substitution between domestic and imported goods (various specifications)	Input-output table	Input-output table	Input-output table
Dervis, de Melo, Robinson (1982)	1973	Constructed benchmark data set with some parameters adjusted to fit dynamic (1973–1976) trends	Elasticities of substitution in production, elasticities of substitution between domestic and imported goods, export demand elasticities (various specifications)	Input-output table, Census of Manufacturing Industries data	Input-output table, population census data	Input-output table
Dixon, Parmenter, Sutton, Vincent (1982)	1968–1969	Constructed 1968–1969 Input-output data base from government and agricultural statistics	Extensive elasticities file (literature search and best guess)	Constructed Input-output table	Constructed Input-output table	Constructed Input-output table

[a] Denison (1967).

TABLE 10

SYNTHESIS OF MAJOR POLICY FINDINGS OF TRADE MODELS

Model	Policy Interventions Incorporated	Policy Data Used	Policy Conclusions
Multicountry Models			
Gunning, Carrin, Waelbroeck (with Burniaux and Mercenier) (1982)	8 simulation experiments to evaluate the impact on LCDs of changes in 1. ROW growth, 2. capital flows to LDCs, 3. oil prices, 4. ROW's income elasticity of imports	Simulation experiments, no data required	Impact on LDCs of exogenous changes is limited: Suggests that LDC growth is less sensitive to ROW growth rate than earlier fix-price models would indicate.
Deardorff, Stern (1981)	Tokyo Round changes in tariff and nontariff barriers (agricultural quota concessions, government procurement liberalization)	Post-Kennedy Round base rate tariffs, Tokyo Round offer rate tariffs, quantification of non-tariff barriers	Economic welfare will increase in all industrialized countries except Australia, New Zealand and the Netherlands. Welfare will decrease in most of the developing countries.
Manne, Preckel (1983)	Alternative scenarios incorporating: 2 assumptions on energy supply; 2 assumptions on energy demand; 2 assumptions on capital flows	Alternative energy supply and demand scenarios	Increases in world oil prices have very little effect on GDP growth in industrialized countries, but could have a major (negative) impact on the terms of trade of oil importing developing countries, inducing GDP growth substantially.
Miller, Spencer (1977)	Removal of U.K.-EEC tariffs and U.K.-Commonwealth preferences	U.K.-EEC and U.K.-Commonwealth tariffs and transfers	U.K. entry into EEC increases U.K. imports of EEC manufactured goods by 50%, but increases U.K. income by only 1/6 of 1%; with transfer to EEC of 1.5 % of income, U.K. net loss is 1.8% of national income.
Whalley (1982)	Changes in tariffs, nontariff barriers and taxes in the EEC, U.S. and Japan	Tokyo Round tariff formulae and *ad valorem* equivalent of nontariff barriers; domestic taxes	World welfare gain from tariff cuts no greater than .1% of world GNP; EEC and Japan gain proportionally more than U.S. or rest of the world, but this could be offset by proposed changes in nontariff barriers.

Whalley (forthcoming)	Abolition of tariff and nontariff barriers in the North, the South, and in both regions simultaneously	All tariff and nontariff barriers (represented in *ad valorem* form) in each of the seven blocs	Abolition of tariff and nontariff barriers in: 1. the North results in annual welfare gains of \$21 billion, the majority of which accrues to the LDCs and NICs; 2. the South leads to annual gains of \$17 billion, but with a \$65 billion gain to the North and a \$48 billion loss to the South; 3. both North and South give world welfare gain of \$30 billion, with gains accruing to the North and losses to the South.
Single-Country Models			
Boadway, Treddenick (1978)	Elimination of tariffs, elimination of tariffs along with taxes (commodity and capital income)	Canadian tariff and taxation rates	Similar results for all cases studied (excepting variations in export demand elasticity): when tariffs are removed, the welfare index falls by 1.16% (when export demand elasticity = 1) and rises by .06% when export demand elasticity = 25; when taxes and tariffs are removed, the welfare index falls by 2.63% with unit export demand elasticity and rises by .27% with export demand elasticity of 25.
Dervis, de Melo, Robinson (1982)	Setting a 50% tariff on imports; giving a 50% subsidy to exports; examining 1977 Turkish foreign exchange crisis	Simulation experiments and actual events; no data required	Imposing a 50% tariff in one sector at a time produces small short-run allocational effects with no sector experiencing more than a 5% change in output. A 50% export subsidy has greater effect on domestic output than does the 50% tariff: the home country is more sensitive to export-side than import-side disturbances. Causes of the 1977 foreign exchange crisis in Turkey were principally differential domestic inflation and increases in oil prices.
Dixon, Parmenter, Sutton, Vincent (1982)	A 25% across-the-board increase in Australian import tariffs	Simulation experiment; no data required	A 25% increase in all protection rates leads to a .21% fall in total employment, an increased deficit in the balance of trade, and increases in consumer and capital goods prices.

sary to support the equilibrium and achieve the desired exchange rates.

The models summarized in Tables 7 and 8 do not all follow this classical approach to neutrality. This is especially the case with the single-country models where, in a number of instances, exchange rates appear in the formulation. In some cases, these exchange change-rate terms refer to the real exchange rate between traded and nontraded goods but, in a number of the models, results are reported for changes in exchange rates with the appearance that they have real effects. This can make the interpretation of results difficult from a theoretical point of view.

On the capital-flow side, the approach in most of the models is to exclude international capital flows. Where capital-flows are present, an important difference between models occurs because countries are typically modeled as takers of rental rates on world capital markets and, therefore, face perfectly elastic capital-supply functions. This issue has been analyzed for the tax models by Goulder, Shoven and Whalley (1983) who have shown how the treatment of international capital flows can significantly affect results. The intuition from this would be that a similar conclusion could apply for trade policy analysis.

C. *Key Parameters*

Two sets of key parameters appear in trade models: international trade elasticities, and the trade policy parameters. With the widespread use of the Armington assumption, a common procedure is to relate the elasticities of substitution between the Armington commodities back to empirical estimates of import- and export-demand elasticities that countries face. This, in turn, involves the use of literature estimates of trade elasticities. A widely-used source is a compendium of estimates, due to Robert Stern, Jonathan Francis and B. Schumacher (1976). This study summarizes a number of estimates of trade elasticities, producing best-guess estimates by product and by region. Many of the elasticity estimates are relatively low (in the neighborhood of one), and there has been substantial literature over the years as to how reasonable these are. More recently, Chris Alaouze (1977) has worked explicitly on Armington trade elasticities.

These elasticity values are important because low-trade elasticities tend to produce strong terms-of-trade effects. The work from the 1950s, by Harry Johnson (1954) and William Gorman (1957–1958) on the optimal tariff emphasizes that a country's optimal tariff is equal to one over the import price elasticity of the trading partner minus one. Import price elasticities in the neighborhood of one, therefore, produce very high optimal tariffs, and associated with these are strong terms-of-trade effects. As long ago as 1950, Guy Orcutt raised the whole question of specification bias in trade-elasticity estimates, and further contributions to this issue have subsequently been made by Murray Kemp (1962), Nanak Kakwani (1972), and Mansur (1982). In spite of disagreements as to the appropriate way to estimate these elasticities, literature values continue to be widely used, but with a fair amount of skepticism because of their low values.

Trade policy parameters break down into tariffs and nontariff barriers, with nontariff barriers representing the major problem. Information on nontariff barriers is scarce, and there is not even widespread agreement as to exactly what the appropriate list of nontariff measures should include. Also, estimates which have been made of nontariff barriers are not particularly satisfactory. While there are estimates obtained by the residual method of taking the differences between world and domestic prices and subtracting transportation and tariff cost margins, there are conceptual difficulties with this approach. There is a substantial amount of dissatisfaction, among the trade modelers at present, that the impact of nontariff barriers has been adequately captured. Until more data and information are available, this sense of discomfort will almost certainly remain.

D. *Major Themes of Results*

Policy results obtained thus far yield a number of strong implications for trade policy. One striking conclusion from all the models is that the welfare effects of changes in trade policy are relatively small compared to the effects of other kinds of policies, such as taxes. As long ago as the 1950s, Tibor Scitovsky concluded that welfare gains from the formation of the European Economic Community were very small, around 1/20 of one percent of GNP per year, and small numbers were also produced by Johnson (1958) in his calculations of the gain to Britain by joining the EEC. This theme shows through strongly in the results summarized in Table 10. The intuition is: distortions that affect a relatively small portion of total activity, where the distortions themselves are often relatively mild, can be expected to have small distorting effects.

This conclusion, however, has been sharply queried in recent work by Harris (forthcoming) who also cites earlier studies of United States–Canadian free trade by Ronald J. Wonnacott and Paul Wonnacott (1967), suggesting that the gains to Canada from free trade with the United States are significant. The essential difference in the Harris work from that summarized in the tables is the role of scale economies, and the ability of small economies to realize large gains when much larger trading partners reduce their trade barriers. Undoubtedly, Harris' results will prompt further work along these lines in future model developments, although it seems fair to say that Harris' results reflect both the presence of scale economies and asymmetries in the size of the regions in his model. Most of the gains from United States–Canadian free trade go to Canada, the smaller country; global gains remain small.

Another strong policy implication from the models is that terms-of-trade effects associated with changes in trade policies can be significant. Robin Boadway and John Treddenick, for instance, show that Canada would be made worse off from a tariff reduction due to a terms-of-trade deterioration. This is contrary to the usual perception in Canada of a small, open, price-taking economy, which would suggest it could make itself better off by eliminating tariffs. This strength in terms-of-trade effects, in turn, suggests that the threat of a retaliatory trade war (were cooperative arrangements in the GATT to break down) could be serious, resulting in high optimal tariffs on a global basis.

Another interesting set of policy implications refers to geographically discriminatory trade arrangements of the customs union type. In their work on British entry into the EEC, Marcus Miller and John Spencer show that the welfare effects are relatively small and tend to be dominated by the direct budget transfers accompanying the expansion. Their results suggest that the United Kingdom was made significantly worse off by joining the EEC.

Some of these models have been used to look at issues other than trade liberalization. Alan Manne and Paul Preckel produce the interesting result that the impacts of the energy shock of the 1970s were relatively small, perhaps less severe than had been thought to be the case at the time. Future work will also undoubtedly cover wider dimensions of trade policy than have been taken up thus far, one of these being the regional impacts of trade policy stressed in work by Dixon, Parmenter, Sutton, and Vincent on Australia.

E. *Weaknesses of the Models*

As with the tax models, the same two general weaknesses apply: the problems of the elasticity specification, and the inability to incorporate completely all detail relevant to any particular policy issue. More specific problems relate to the modeling of production and alternative policy regimes. The work of Harris has already been mentioned as highlighting the importance of scale economies and imperfect competition. Recent theoretical work in international trade has concentrated heavily on these issues, especially the imperfect competition issue, with models being developed to explain cross hauling in a way quite different from the manner in which it is accommodated in the present applied models through the Armington treatment. To some extent, the applied trade models have lagged recent theoretical developments, and undoubtedly more work will need to be done in respecifying models.

Another major weakness is the modeling of nontariff barriers. Issues such as the operation of voluntary export restraints where the implicit value of the rent is transferred to the exporting country have not been satisfactorily analyzed through these models. In current trade policy issues between the United States and Japan, this is a crucial question, as a significant amount of United States–Japanese trade is covered by voluntary restraints. A feature neglected in the models of developing countries is the role of rent seeking, accompanying trade restrictions. This has been stressed in theoretical work, but not fully incorporated in the empirical models.

Despite all these problems and difficulties, however, the applied trade models have already made contributions both to trade policy debates, and to the evaluation of possible changes in the international trading mechanism. Undoubtedly, refinements will occur in future years, and some of the extensions mentioned above will be incorporated as these models develop.

VI. *Further Issues with the Tax and Trade Models*

While the applied general-equilibrium models described in this paper can reasonably claim to have advanced from the simple numerical examples of ten to fifteen years ago to a stage where quasi-realistic, larger-dimensional models are yielding new insights into policy debates, it should be obvious to readers that there is a range of difficulties beyond those mentioned, which arise with the approach. Our view is, these in no way invalidate the approach but it is important that policymakers using results be aware of these problems so as to form their own judgments to reasonable policy implications.

A. *Robustness of Results*

One key issue with the models is how robust the results are to alternative parameter values. Because the calibration procedure was used to select parameter values, meaningful statistical tests of any model specification are usually not possible. Users of model results are often left with a sense of discomfort that any given results could disappear, or even change sign, if alternative parameter values were chosen.

There seems to be widespread agreement among modelers that once policy parameters are specified, the elasticity values are the single most important set of parameter values in determining results. Because of the reliance on empirical estimates, one response to the robustness issue is to say that model results are only as robust as elasticity estimates appearing in the literature. The problem, however, is more severe than this for two reasons. First, elasticity values combine in both offsetting and compounding ways in these models, and the robustness of any single elasticity value in the literature may mean little when used in conjunction with other elasticities in a large model. Second, the robustness issue cannot be discussed independently of the particular features of results one has in mind. Some may be very sensitive, while others hardly change. Varying trade elasticities, for instance, may make a big difference to projected changes in trade flows from a policy change, while leaving welfare impacts largely unaffected.

The response thus far in the applied models has been to take alternative elasticity values to those used in a "central-case" specification, displacing the key values by what seem to the particular modeler as "large" changes. Most modelers appear to claim a reasonable degree of robustness for their results, while admitting the limited nature of the sensitivity tests performed. Usually elasticities are varied only singly and not in combination, for the understandable reason that the volume of results generated is difficult to digest. Perhaps the best hope for further insight into this issue is the systematic sensitivity analyses being carried out by Glenn Harrison and Lawrence Kimbell (1983) who have computed over a million solutions to their model in exploring robustness. The main difficulty in their work appears to be synthesizing the results so that a clear judgment on robustness can be made. Some things are little affected, others more so. Also, how these results translate to other models is unclear.

B. *Model Preselection*

A further difficulty with the applied models is the set of issues raised by preselection (i.e., the necessity to decide on a particular model structure before the policy analysis proceeds). A good way of illustrating this problem is to consider the classic Harberger analysis of the impacts of corporate tax. Using the standard assumption in static models of a closed economy with a fixed amount of capital, Harberger concludes that capital bears the burden of the corporate tax. Clearly, if the economy in question is viewed as a participant in an international capital market and is a taker of rental rates on world capital markets, the policy conclusions would change. In this case, it is impossible for capital to bear the burden of a capital tax, because the effect of the tax would simply be to cause capital to leave the country until the net-of-tax return is equal to that prevailing on the world markets. Model preselection can thus powerfully affect the conclusions that are reached.

The fundamental difficulty is that there are many alternative models in the literature, each applicable to the policy question at hand and each yielding different policy implications. Applied general-equilibrium analysis does not provide a way of discriminating between alternative models because no form of hypothesis testing is involved. Thus, a broadly-based single-rate income tax, which is nondistorting in a static fixed-factor model, becomes distorting in a dynamic model due to the double taxation of saving. The effects of a tariff are different in models with or without international factor mobility, or with or without a downward rigid real wage. Conflicting economic theories are not resolved merely by putting numerical values on parameters in specified functional forms, and some degree of summary judgment by modelers in selecting the particular theoretical structure to be used seems inevitable in work in this area.

A related difficulty, common to all modelers, is that in choosing their model structure, they have found there is no single all-purpose, general-equilibrium model that can be used. In order to work on a particular policy issue in a particular country, modelers have had to find some simple way of closing the model with respect to time (savings and investment), space (foreign trade and factor mobility), and other issues such as government expenditures, taxes, and regulatory activity. Models differ in their methods of closure and this makes a comparison among models difficult. It also presents challenges to theorists to work out the implications of some of these closure rules, which have not always been fully thought through.

C. *"Theoretical" Pedigree*

Another issue with applied models derives from the attempt to develop models that are consistent with the theoretical general-equilibrium literature developed in the 1950s and 1960s, and thus allow for welfare statements on policy issues. Because of the difficulties in accommodating a wide range of empirical phenomena in model building, there is often a tendency to depart from the essential structure and graft on ad hoc portions of the model not rooted in traditional theory. These include instances where the price level affects resource allocation, exchange rates appear to have real effects, and unemployment is present. Unfortunately, the problem is, the models that make major departures from known theoretical structures can become difficult to interpret. The conflict between modelers' desires to build realistic models which seek to capture real features of the policy issue at hand, and to stay within the realm of developed economic theory is something that seems to be increasingly apparent in some of the more recent models.

D. *Issue-Specific versus General-Purpose Models*

Another issue, raised increasingly by the modelers themselves, is the design question of large-scale, multipurpose models versus smaller-scale, issue-specific models. Models developed in the early 1970s have, over time, become larger in scale and now provide a multipurpose capability. However, in analyzing any one issue, a significant portion of the model is often unimportant. With smaller-scale models, it is clearly much easier to identify key parameters that affect results, to work with those parameter values and subsequently to trace through the main effects of the policy change being evaluated. However, it seems counterproductive to reformulate models repeatedly for each policy application. Also, excessive use of small-scale models naturally raises the issue of whether or not the crude level of aggregation in the models results in systematic biases. Shoven's (1976) work indicates that disaggregating from 2 to 12 sectors in his analysis of the impacts of distortionary capital income taxes in the United States increases welfare loss estimates by around 30 percent, but a systematic investigation of the aggregation issue in the models has not yet been done.

Perhaps the main point to be kept in mind relates not so much to the use of existing models but rather the strategy to be followed in developing new models. Existing models represent sunk costs, and even if they are overly elaborate for the particular issue at hand, it still seems worthwhile to see what the model has to say. For new models, experience gained so far does suggest that it is well worthwhile to consider with care exactly what the model will be used for and how much detail makes sense before embarking on model construction.

Despite these problems, models are making contributions to policy debate by providing more refined calculations of efficiency costs and distributional impacts than previously available. The point to be emphasized is not that these models are either right or wrong, but that policy decisions have to be made and that these models are capable of providing fresh insights on policy options not available from any other source. Sometimes results will be dismissed as unconvincing; on other occasions policymakers may stop and think, and occasions may arise when a policymaker's prior position will actually be changed. We would never advocate slavish mechanistic use of any of these models in policymaking, but our view clearly is that their potential contribution seems to be large.[6]

VII. *Directions for Future Research*

The directions that seem fruitful for future research partially reflect our comments in preceding sections, and partially our experience thus far with our own models. While computing equilibria is no longer the technical difficulty it seemed fifteen years ago, specifying the model for which the equilibrium is to be computed remains a challenge. Better data, and especially more and better elasticity estimates seem to be crucial to advancement of the field. In the past, one of us has gone so far as to argue for the establishment of an "elasticity bank" in which elasticity estimates would be archived, evaluated by groups of "experts" (even with a quality rating produced) and an on-file compendium of these values maintained. While this may be overly ambitious, the general direction is one that is sorely needed.

Equally, the robustness and estimation issues are both worthy of considerably more attention. Years ago in the debate on central planning in the 1930s, Lionel Robbins referred to the difficulty of solving the millions of equations characterizing a Pareto optimal allocation. In this debate the prior question (How do you know how to write the equations even before you worry about solution?) was not fully discussed. The robustness and estimation issues are precisely these questions: What is the most reasonable numerical specification of a general-equilibrium model suitable for analyzing the policy issue under discussion, and how reliable are results from this model? The debate in the 1930s was in many ways the inspiration for the work in the 1960s on general-equilibrium computation. The experiences of modelers in the 1970s and 1980s may prove to be the impetus for a new genre of work on specification of general-equilibrium systems.

Other questions arise from the experience of modelers with model design. One of the most common problems encountered by modelers is the necessity to be simultaneously a "jack of all trades." Modelers must know general-equilibrium theory so that their models have a sound theoretical basis; they must know how to solve their models; they need to be able to program (or at least communicate with programmers); they must understand the policy issues on which they work; they have to know about data sources and all their associated problems; and they have to be conversant with relevant literature, especially that on elasticities. Not surprisingly, modelers can at times feel a sense of inadequacy when faced with colleagues specializing in just one of these topics. This need to do several things well can also inhibit graduate students from doing thesis work in the area. Perhaps a future direction is teams of modelers, each with different skills, run on the lines of research groups in natural sciences. While a "Manhattan Project" for general-equilibrium modeling may be going too far, a team built on complementary modeling, computing, and data skills would almost certainly be able to make outstanding contributions to the field.

A further fruitful direction, as yet unexplored, is to develop more fully the implications of the applied work of the last decade for theoretical work. Joseph Schumpeter once labeled Walrasian general equilibrium as the "Magna Carta" of

[6] A useful survey of the way in which large-scale energy models have been used in the Energy Modelling Forum at Stanford (in ways that are not dissimilar to what we have in mind) is contained in "Modelling for Insights, Not Numbers" by H. G. Huntington, J. P. Weyant and J. L. Sweeney (1982).

economics, and others subsequently argued that general-equilibrium analysis has no operational content. The theorists might want to make a judgment as to whether the experience with applied models supports or denies this claim and how they might redirect their work. The experience of modelers in finding they need closing rules, simplified treatment of various features and the like, seems to indicate a need to be more specific rather than more general in approaching equilibrium modeling. What are the properties of these simplified treatments, and how do they affect results?

Finally, it is worth raising the issue of data organization and their use in applied equilibrium models. Since the work of Simon Kuznets and the early Keynesian macromodels, our national accounting procedures have been heavily oriented toward calculating macroaggregates rather than subaggregate microeconomic detail. As a result, full Walrasian accounts do not appear in the publications of statistical agencies. One cannot, for instance, open a statistical publication and identify separate demand and supply accounts. In constructing their benchmark equilibria to which they calibrate their models, this is implicitly what the new generation of applied general-equilibrium modelers is doing. Perhaps the next ten years might see further progress in this direction, possibly through an expansion of the social accounting matrix approach developed by Richard Stone and others.

VIII. *Conclusion*

In this paper we have surveyed some recent, applied general-equilibrium modeling efforts in the areas of taxation and international trade. These are most easily understood as attempts to quantify the impacts of alternative tax and trade policies within the traditional general-equilibrium framework. Although the basic structure of production and preference functions in these models is the same as in their theoretical counterparts, use of the computer permits the quantitative analysis of large-dimensional models. Qualitative analysis of an issue in a general-equilibrium framework can often only identify potentially offsetting effects, and this new quantification offers a way to determine the size of the net effect. Also, qualitative analysis is frequently unsatisfactory for policymakers who want quantitative orders of magnitude to tell them which policy changes are significant and worth pursuing. The applied general-equilibrium models in these fields seek to help out in both these directions.

A number of policy findings have thus far been generated by these models. In the tax models, a general theme seems to be that efficiency costs (deadweight losses) of taxes may be more severe than had previously been supposed. This is especially the case with marginal deadweight losses from taxes. A further finding suggests that tax systems may be progressive in their distributional impact, rather than proportional as often supposed. In the trade models, the role of terms-of-trade effects and the difference between national and global interests is an important theme.

As with all such modeling efforts, policy statements generated by these models have to be treated with an appropriate degree of caution. However, our view is that these models have already contributed to policy debate, and if used sensibly can make further important contributions. This is especially so with estimates of combined efficiency and distributional effects of policies where, prior to these models, no wholly satisfactory way of simultaneously quantifying these effects existed.

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