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General Equilibrium Analysis of U.S. Agriculture: What Does It Contribute?

Thomas W. Hertel

Applied general equilibrium analysis as we know it today has intellectual origins in the debate over the feasibility of the centralized computation of a Pareto optimal allocation of resources within an economy (Whalley, pp 30-34)¹ During the first half of the century, economists were preoccupied with the question of whether or not it was computationally feasible to solve the associated system of behavioral equations. Recent developments in operations research have proven optimists correct. It is indeed possible to solve very large models representing national economies, either in the form of centralized planning problems or, more commonly, as decentralized equilibrium problems. While this has not brought an end to the debate over the operational relevance of general equilibrium theory, the increasing use of computable general equilibrium (CGE) models in policy analysis has served to sharpen the debate. It now focuses heavily on questions such as model specification, parameter choice, disaggregation, and the appropriate representation of policies (Whalley). CGE analysis now has a great deal in common with partial equilibrium modeling, a theme I will develop in this essay.

Leif Johansen implemented the first operational CGE model in the late 1950's. Variants of this model are still used for planning purposes in Norway (Shreiner and Larsen). These models have also been popular in the development economics literature (Robinson, 1988, 1989). CGE analysis in North America has tended to emphasize tax and trade issues (Shoven and Whalley). One consequence is that the U.S. Department of Treasury and the Canadian Department of Finance both have employed variants of these models for a number of years. However, nowhere has CGE analysis been as successfully institutionalized as in the Australian Industries Assistance Commission (Powell and Lawson, Vincent), where it has been used for 15 years to analyze the economywide effects of changing relative rates of protection.

In light of this history, the relatively recent appearance of CGE analysis in U.S. agricultural economics may be viewed as a belated arrival. But,

Hertel is associate professor in the Department of Agricultural Economics, Purdue University, West Lafayette, IN. Otto Doering, Garth Holloway, Everett Peterson, Marinos Tsigas, and Wally Tyner provided helpful comments on an earlier draft. Earlier versions have been presented in seminars at Purdue University, USDA's Economic Research Service, and the University of Missouri. The research discussed here was conducted under a project jointly funded by the Economic Research Service and the Agricultural Experiment Station, Purdue University.

¹Sources cited in the text are listed in the References section at the end of this essay.

perhaps, there is good reason for this. A general equilibrium model is only as strong as its partial equilibrium components, and, until recently, most CGE models had fairly simple representations of producer and consumer behavior. Thus, further acceptance of CGE models applied to U.S. agriculture hinges on better communication between the modelers and other agricultural economists aimed at strengthening critical components of the models. Unfortunately, partial equilibrium analysts who do not understand CGE models cannot improve them.

This essay attempts to bridge the gap between partial and general equilibrium analysts, thus promoting greater dialogue between practitioners of CGE analysis and others in the profession. Along the way, I hope to dispel several misperceptions of CGE analysis. For example, CGE analyses are often viewed as abstract, theoretical exercises, with little resemblance to partial equilibrium modeling, much less to the real world. While some CGE applications may fall prey to this criticism, there is no inherent reason why this must be the case. To show the similarities between the partial and general equilibrium approaches, I will begin by comparing partial and general equilibrium analyses of a subsidy on farm output. Similarities and differences as well as strengths and weaknesses of the two methodologies will be identified.

Partial Equilibrium Analysis of a Farm Subsidy

Partial equilibrium models may be thought of as collections of supply and demand equations, representing a summary of economic behavior in various markets of interest. Since agricultural economists are often concerned with farm commodity markets, the supply equations in many models describe the supply of products from the farm sector, while the demand equations describe the market conditions facing producers beyond the farmgate. Depending on the particular biases of the researchers, these supply and demand equations may or may not be derived from explicit assumptions about producer and consumer behavior. Let's leave that issue aside for the moment and turn to the implications of this framework for analyzing a farm subsidy.

I will simplify by assuming that the intervention in question may be expressed as an *ad valorem* output subsidy. (More complex policies do not shed any light on the distinction between partial and general equilibrium analyses.) In this case, the relationship between the farm price of output (p_F) and the market price (p_H)

is simply $p_F = s * p_H$, where $s > 1$ denotes the presence of a subsidy. The partial equilibrium solution to this problem, written in terms of the supply and demand elasticities, becomes

$$\hat{p}_H = (\eta_F - \eta_H)^{-1} \eta_F (-\hat{s}), \quad (1)$$

where “ $\hat{\cdot}$ ” denotes proportional change. In the case of a single commodity, η_F and η_H are the relevant supply and demand elasticities, so that we may verify the familiar special cases whereby (a) either perfectly elastic demand ($\eta_H = -\infty$) or inelastic supply ($\eta_F = 0$) results in the subsidy benefits going entirely to farmers, while (b) either perfectly elastic supply ($\eta_F = \infty$) or inelastic demand ($\eta_H = 0$) results in all of the subsidy benefits being passed on to consumers. In the multiple-commodity case, s is a vector of interventions, and η_F and η_H are elasticity matrices, with as many dimensions as there are markets in the model.

This multicommodity, partial equilibrium framework is adequate for many, if not most, applications. However, there are some important gaps to keep in mind. A first limitation of expression 1 is its failure to acknowledge the finite resource base in the economy. To the extent that the farm subsidy encourages resources to move into agriculture (or perhaps it discourages them from moving out), the rest of the economy has less land, labor, and capital to work with. There is an opportunity cost associated with this factor movement that is only superficially acknowledged by the introduction of upward sloping factor supply schedules into a partial equilibrium model of the farm sector.²

A second limitation of the partial equilibrium model is its failure to address the question: Who foots the bill for the added subsidies? The opportunity cost of raising 1 dollar of additional revenue via the current system of Federal income taxes has been shown to be considerably more than a dollar, due to the marginal excess burden associated with further distortions in consumer and producer choices (Ballard, Shoven and Whalley). By contrast, this phenomenon may be explicitly dealt with in a CGE model. Even if an economywide model does not flesh out the tax system, it is possible at least to keep track of the transfers implicit in a given subsidy.

The third weakness of the partial equilibrium model is the absence of an explicit budget constraint for the household(s) in question. There is no link between the sources and the uses of income. Changes in factor returns are not reflected in altered consumer expenditures. This limitation is most severe when the policy shocks considered are very large, and when they

result in income transfers between households with very different consumption patterns.

A final limitation of the partial equilibrium approach is the absence of any definitive check on the conceptual and computational consistency of this model. The larger and more complex the model, the greater the probability of inconsistencies. This leads to skepticism on the part of model users and potential “consumers” of model results. By contrast, as will be pointed out below, Walras’ Law offers a powerful check on the consistency of a well-defined general equilibrium model. In fact, this alone may be reason enough to justify the CGE approach in some cases.

General Equilibrium Analyses of a Subsidy

To illustrate how the general equilibrium approach addresses these limitations, it is necessary to lay out the structure of a very simple CGE model. Because the model is only complex enough to illustrate my basic point, it can be completely described by one picture (fig. 1).

A Simple Model

I have assumed a closed economy, with one aggregate household which consumes two goods: food (good #1) and nonfood (good #2). This household also owns all primary factors of production in the economy, which are held in fixed supply (\bar{q}_{H0} and \bar{q}_{H3}). Again, for the sake of simplicity, I distinguish between only two primary factors: farmland (good #0), which is specific to the farm and food sector, and a capital/labor aggregate (good #3), which is mobile between the two sectors. Household income ($y = p_{H0}\bar{q}_{H0} + p_{H3}\bar{q}_{H3}$) is derived from these primary factors. Given the initial household budget shares, $c_{H1}y$ is spent on good #1 and $c_{H2}y$ is spent on good #2.

There are no intermediate inputs in this economy, and constant returns to scale in production are assumed. The nonfood commodity is produced using only the capital/labor input, while the farm and food commodity is produced by combining the capital/labor input with farmland. (In a sense, this is what distinguishes the farm economy from other sectors.) In initial equilibrium, the cost shares of each of the two inputs are given by c_{F0}^1 and c_{F3}^1 . The land and nonland inputs are substitutable in food production, with the ease of substitution determined by the non-negative elasticity σ_F . This substitutability, in fact, underpins the food sector’s partial equilibrium supply response in this model, which may be expressed as

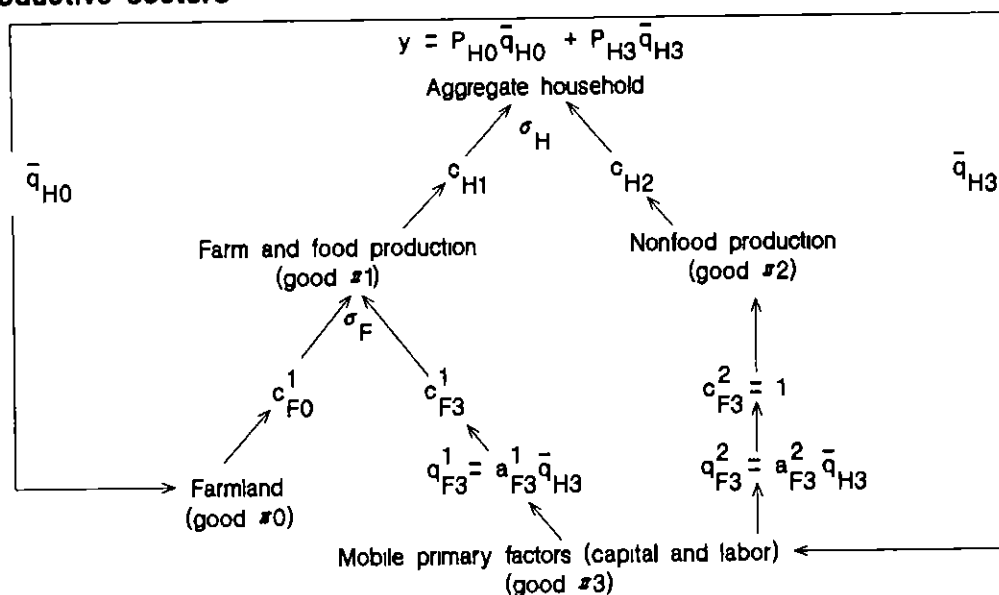
$$\eta_F = \sigma_F (c_{F3}^1 / c_{F0}^1) \quad (2)$$

Note that supply response increases with increased substitutability for the fixed land input, and with an increased share of variable inputs in total costs (c_{F3}^1).

²See Floyd for an early illustration of this type of partial equilibrium model.

Figure 1

An illustrative general equilibrium model with four goods, one household, and two productive sectors^{1,2}



1/ Subscripts H and F refer to the household and firms, respectively. Each of these entities may face different prices for the four goods, which are indexed by using subscripts 0 to 4. Superscripts 1 and 2 refer to (1) the farm and food sector and (2) the nonfood sector. \bar{q}_{H0} and \bar{q}_{H3} represent the fixed supplies of land and nonland inputs which earn returns of P_{H0} and P_{H3} . c_{F0}^1 denotes the cost share of good #0 (land) in sector 1, with similar definitions for c_{F3}^1 , c_{F3}^2 , c_{H1} and c_{H2} . $a_{F3}^1 = q_{F3}^1 / \bar{q}_{H3}$ which is the quantity share of this input in sector 1.

2/ Each arrow corresponds to an equation in the model. A complete set of equations, along with their manipulation and solution, is available from the author.

The importance of comparing supply elasticities across models is rarely lost on partial equilibrium analysts, however, general equilibrium modelers are less diligent in this matter. This is probably because η_i does not enter directly as a parameter in the model, but must instead be calculated as in equation 2.³ Based on my own experience, differing assumptions about partial equilibrium behavior go a long way toward explaining empirical discrepancies between partial and general equilibrium models. Many differences between such analyses are falsely attributed to "general equilibrium" effects. Consequently, I encourage partial equilibrium modelers and other consumers of CGE results to demand this type of summary information from CGE modelers.

A final point regarding figure 1 stems from the fact that we need a convenient method of summarizing the two sectors' relative claims on the mobile factor of production. This may be done by defining $a_{F3}^1 = q_{F3}^1 / q_{H3}$, that is, the quantity share of the capital/labor aggregate which is used in agricultural production. Similarly, $a_{F3}^2 = q_{F3}^2 / q_{H3}$.

³See Hertel (1989) for a general discussion of how to compute partial equilibrium supply elasticities under alternative assumptions about technology and factor mobility.

Introducing a Farm Subsidy

Having laid out the basic notation for this model, we are in a position to solve it. This involves collapsing the equations implicit in figure 1 into as many dimensions as there are commodities. In this sense, finding a solution is no different than in the partial equilibrium case, with one important distinction. Since the general equilibrium model is exhaustive in its treatment of economic activity, one of the market-clearing conditions is redundant. This is Walras' Law, which has two important practical implications for CGE analysis. First, since we are left with only three equations, we can solve only for the changes in relative prices among the four commodities. Here, I will choose land as the numeraire good and will omit the supply = demand equation for land, which will produce the following outcome after introduction of a farm subsidy.

$$\hat{p}_H^* = \begin{bmatrix} P_{H1}/P_{H0} \\ P_{H2}/P_{H0} \\ P_{H3}/P_{H0} \end{bmatrix} = \begin{bmatrix} 1 + (c_{F3}^1 x) \\ c_{F3}^2 x \\ x \end{bmatrix} (-\hat{s}), \quad (3)$$

$$\text{where } x = \frac{(a_{F3}^1 c_{H2} - a_{F3}^2 c_{H1}) \sigma_H}{-a_{F3}^1 c_{F0}^1 \sigma_F - (a_{F3}^1 c_{H2} - a_{F3}^2 c_{H1}) (c_{F3}^1 - c_{F3}^2) \sigma_H}$$

The second practical implication of Walras' Law is that if we evaluate changes in supply and demand in the omitted land market, using the equilibrium relative price changes, they must be equal, that is, $\hat{q}_{H0}(\hat{p}_H^*) = \hat{q}_{F0}(\hat{p}_H^*)$. Since this property is an implication of the entire model's structure, its verification offers a global check on the conceptual and computational consistency of this model. This can be extremely valuable. By way of example, consider what might happen in a large nonlinear model with hundreds of markets when a new wrinkle such as imperfect competition is introduced. What if the modeler forgets to distribute to households the excess profits generated in the new equilibrium? How could we possibly know that this has been omitted? There is no general method of checking for such overlooked inconsistencies in a partial equilibrium model. However, in a general equilibrium model, such a leakage would result in insufficient commodity demand, and hence, insufficient derived demand for land. Consequently, Walras' Law would be violated.

Now return to expression 3. Note that each of the relative price changes depends on the common parameter "x". This parameter is actually quite similar in structure to the ratio of elasticities premultiplying the farm subsidy in expression 1. To see this, note that (given c_{Fj} and c_{Hj}) σ_F determines η_F and σ_H determines η_H . Thus, the value of x, and the subsequent degree to which this subsidy is shifted among markets, depends fundamentally on the supply and demand elasticities embedded in this model. When $\sigma_H = 0$, such that demands are not responsive to price, or $\sigma_F = \infty$, such that the partial equilibrium farm supply curve is perfectly elastic, $x = 0$ and all benefits from the subsidy are passed forward to consumers. This is the same result we encountered in the partial equilibrium case. By contrast, if nonland inputs cannot be substituted for the sector-specific land input ($\sigma_F = 0$), then farm supply will be completely unresponsive to price, and x may be shown to collapse to $x = (c_{F0}^1)^{-1}$, which means that all of the subsidy benefits are passed back to landowners.⁴ This confirms our partial equilibrium intuition.

We can also see how, in the more general case, all the parameters in the model have a bearing on the general equilibrium outcome.⁵ Note, however, what happens

⁴The magnification factor, $(c_{F0}^1)^{-1} > 1$ serves to load a given amount of subsidies onto the smaller land expenditure base.

⁵The reader might wonder why income elasticities of demand do not appear in expression 3. Since the economy in figure 1 is closed (that is, there is no international trade), and with fixed factor supplies the only way disposable income can change is through a change in the efficiency with which the fixed resource base is employed. Such changes are commonly referred to as changes in "excess burden." In this context, I have assumed the economy in figure 1 to be initially in an undistorted state, where firms and households face the same prices ($p_{Hn} = p_{Fn}^1 = p_{Fn}^2$ for all n) prior to introduction of the subsidy. This means that, to a first order approximation, marginal changes in the farm subsidy will not have excess burden effects. Since there is no change in excess burden, then there will be no change in household income. This is why income elasticities of demand do not appear in the solution.

when the farm sector becomes "small" relative to the rest of the economy. The value of a_{F3}^1 approaches zero, and we can obtain approximate relative price changes for the farm sector without reference to the nonfarm economy.

$$(p_{H1}/p_{H0}) \cong [1 + (c_{F3}^1/c_{F0}^1)](-\hat{s}), \text{ and}$$

$$(p_{H3}/p_{H0}) \cong [1/c_{F0}^1](-\hat{s}) \quad (4)$$

This is a formal demonstration of why we do not need a general equilibrium model to assess accurately the farm sector impact of most farm policy changes in the case of a highly industrialized economy such as the United States. This point likely comes as little surprise to many economists. Since just 2-3 percent of the U.S. labor force is involved in farming, why model the entire economy to say something about the agricultural impact of a grain subsidy?

Three Common Myths Dispelled

At this point, I hope that I have clarified several popular misconceptions about CGE modeling. The first myth is that general equilibrium analysis is an abstract, theoretical exercise. However, applied work in this area boils down to a problem of constructing a sound data set and choosing (or estimating) appropriate elasticities. This is hardly a theoretical exercise, and it is really no different from partial equilibrium modeling.

A second myth is that CGE models are complex and difficult to solve. In fact, the solution of CGE models is not necessarily any more complex than the solution of large, nonlinear partial equilibrium models. Matrix inversion is sufficient to solve a locally linearized CGE model. And the solution of well-specified nonlinear CGE models can generally be accomplished by choosing from a variety of software alternatives. For large models, the CGE approach has the great advantage of having a global consistency check, namely Walras' Law.

The third myth relates to the value of indiscriminate applications of CGE analysis to issues facing U.S. agriculture. For example, if we can conduct CGE analyses of mandatory supply control, then why not look at more specific issues like the tobacco program? Again, if one is interested only in how a farm policy intervention influences the farm sector itself, then partial equilibrium analysis is probably good enough. Rather than investing scarce time and money in developing (or modifying) a CGE model, it may be much wiser to devote research resources to the improvement of partial equilibrium analyses.

I imagine the reader is now wondering: What's the big deal? Why all of the fuss about CGE analysis of the farm and food economy? Keep reading—the next section discusses why such efforts are warranted.

Benefits From Using CGE Analysis

Five good reasons exist for applying the CGE framework in selected analyses of U S agriculture ⁶

Accounting consistency

The treatment of interindustry effects

Theoretical consistency

CGE analysis as a vehicle for "putting things in perspective"

Welfare analysis

Those who have worked with such models quickly recognize that the accounting identities in a CGE model are as important as the behavioral equations. The fact that (a) households cannot spend more than they earn, (b) the same unit of labor cannot be simultaneously employed in two different places, and (c) the economy as a whole must balance its payments with the rest of the world, serves to circumscribe the range of possible general equilibrium outcomes. CGE models are built upon a social accounting matrix (SAM) which details all the basic identities for a given economy (Pyatt and Round, Hanson and Robinson). Thus, the first advantage of CGE analysis revolves around the explicit incorporation of these accounting identities into the behavior model.

A second advantage of CGE analysis arises from tracing and measuring interindustry linkages between the farm and nonfarm sectors. When conducting a partial equilibrium analysis, it is often very difficult to know where to "draw the line," because the farm sector purchases inputs from the manufacturing, mining, and service sectors, and farm output is sold to both food and nonfood sectors. Having an exhaustive model for analyzing such issues is valuable ⁷.

Theoretical consistency is particularly important in large economic models, which too often become black boxes, unintelligible, even to other modelers. Unless individual components are built upon received economic theory, other researchers have great difficulty interpreting model results. If the model structure adheres strictly to standard neoclassical theory, as do well-specified CGE models, the model user can draw upon experience to understand and explain what is going on when a given policy is changed. A final advantage of theoretical consistency, which has already been mentioned, is that Walras' Law may be used as a global consistency check.

Another advantage of CGE analysis is that it helps to

put things in perspective. Microeconomic theory emphasizes the importance of relative, as opposed to absolute, levels of economic variables. How taxation or technological change affects the farm sector is largely irrelevant unless we know how the levels of these variables compare with those in the nonfarm sector. For example, taxation of the farm and food sector reduces farm output when viewed in isolation. However, a general equilibrium analysis of U S tax policy reveals that low relative rates of taxation have conferred an implicit subsidy on agriculture which at times has rivaled direct farm payments in overall importance (Hertel and Tsigas) ⁸.

Finally, one of the things I like best about CGE models is the fact that they force us to focus more clearly on households, and, ultimately, on people. Changes in welfare are measured by examining the change in household utility, or the implied changes in real income (adjusted for all price changes). The latter is much more concrete, in my opinion, than the concepts of producer and consumer surplus, and emphasizes, for example, that farmers are consumers and taxpayers as well as owners of agricultural assets.

Conclusions

In an attempt to catch up with three decades of applied general equilibrium analysis, U S agricultural economists have recently risked overdoing CGE modeling. We may have oversold the benefits of CGE modeling, while failing to acknowledge many of limitations.

Yet, there remain areas of use for CGE models in agricultural economics which have not been pursued with sufficient vigor. One of these is integrating diverse research results and bringing them to bear on specific policy problems. Where else can the work of a production economist be integrated with that of someone estimating complete consumer demand systems? ⁹ Many research results in international trade, industrial organization, and marketing may also be integrated into a CGE framework. This makes it possible to distinguish between (a) parameters that we either already know a lot about or which are unimportant for current policy issues, and (b) parameters about which we know relatively little but which are key to the accurate assessment of important policies. The implications of such model-sensitivity analyses for directing future policy-oriented research should not be overlooked.

CGE analysis has also received far too little attention in the training of graduate students. Too many Ph D agricultural economists graduate without acquiring an economywide perspective on agricultural problems.

⁶See Hertel (1990) for a survey of CGE applications relating to agriculture.

⁷Input-output analysis has been the preferred vehicle for assessing interindustry linkages. CGE analysis simply permits us to relax the customary assumptions of fixed I-O coefficients, perfectly elastic factor supplies, and exogenous final demand. In this sense, I-O analysis is a special case of CGE analysis.

⁸See also Boyd, and Boyd and Newman for further analysis of tax policy and U S agriculture within an economywide setting.

⁹See Hertel, Ball, Huang, and Tsigas for an illustration of this point.

They often lack the ability to see how then specialized knowledge of production, consumption, marketing, and trade fits together and how these diverse pieces interact in determining the incidence of shocks to the farm and food system ¹⁰

In summary, CGE analysis is a valuable addition to the agricultural economist's analytical tool kit. However, a CGE model is only as good as its individual components. Robert Solow made this same point in his critique of Jay Forrester's global modeling efforts in the early 1970's. Forrester asserted that rather than "go to the bottom of a particular problem what we want to look at are the problems caused by interactions." To this, Solow (p. 157) responds

I don't know what you call people who believe they can be wrong about everything in particular, but expect to be lucky enough to get it right on the interactions. They may be descendants of the famous merchant Lapidus who said he lost money on every item he sold, but made it up on the volume.

Future improvements in the CGE analysis of U.S. agriculture depend on developments in the partial equilibrium specification of farm sector models. Thus, a great need for dialogue exists between those who are primarily involved in CGE modeling and those who conduct other sorts of farm sector analyses. However, such a dialogue can be fruitful only if CGE models are "demystified." It is my hope that this essay will help to further such debate within the agricultural economics profession.

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¹⁰A copy of a syllabus for such a course at Purdue is available from the author. Write to: Thomas W. Hertel, Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907.

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