APPLIED GENERAL EQUILIBRIUM ANALYSIS OF AGRICULTURAL AND RESOURCE POLICIES*

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Thomas W. Hertel

Staff Paper 99-2

March 1999

Dept. of Agricultural Economics

Purdue University

* The author thanks Philip Abbott, Kym Anderson, Bruce Gardner, Glenn Harrison, Garth Holloway, Brad McDonald, Everett Peterson, Matt Rendleman, Gordon Rausser, Sherman Robinson, Gerald Schluter, Serdar Sayan, Yves Surry, Marinos Tsigas, and Randy Wigle for their comments on earlier drafts of this chapter.

**Professor and Director, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University, W. Lafayette, IN 47907-1145, phone: 765-494-4199, email: hertel@agecon.purdue.edu.

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Thomas W. Hertel
Department of Agricultural Economics, Purdue University
West Lafayette, Indiana 47907-1145
hertel@agecon.purdue.edu

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Abstract

This paper reviews the literature on applied general equilibrium analysis of agricultural and resource policies. It begins with an historical overview, followed by an assessment of the benefits of this methodology for examining sectoral policies. The chapter then turns to questions of disaggregation of commodities, households, regions and factors of production. Parameter specification and model closure are discussed, as well as problems of modeling policies which affect agriculture. There are also special sections on agriculture and the environment, product differentiation and imperfect competition and model validation. The paper closes with a discussion of future challenges to the field.

Chapter Outline

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Introduction

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, 1986, pp. 30-34).[1] During the first half of this century, quantitative economists were preoccupied with the question of whether or not it was computationally feasible to solve the associated system of behavioral equations. Since that time, rapid developments in operations research have proven the optimists correct. It became possible to solve very large models representing national economies and indeed, the global economy. Initially these were solved as centralized planning problems, intended to deduce the optimal allocation of resources in the economy. With the demise of central planning, decentralized "computable" general equilibrium models have become dominant. While this has not brought an end to the debate over the operational relevance of general equilibrium theory, the increasing use of such models in policy analysis has served to sharpen the debate. It now focuses heavily on questions of model specification, parameter choice, and the appropriate representation of policies (Whalley, 1986). In this sense, many of the issues raised in this survey are no different from those which arise in other areas of applied economics. This is why I prefer to use the term "applied" general equilibrium (AGE), in place of the popular "computable" general equilibrium (CGE) label.

Leif Johansen (1960) developed the first operational AGE model in the late 1950's. Variants of this model are still used in Norway (Shreiner and Larsen). Since Johansen's pathbreaking contribution, AGE models have been applied to a very wide range of topics. John Shoven and John Whalley and their students spearheaded work in the analysis of tax issues (Shoven and Whalley, 1992) and Whalley (1985) led the way with multiregion AGE modeling of trade policy questions. The Australian school of AGE modeling, led by Peter Dixon, has been analyzing issues of protection in the Australian economy for more than twenty years (e.g., DPSV, 1982). Applied GE models have also been popular in the development economics literature (Dervis, de Melo and Robinson, 1982; Robinson, 1988).

This survey focuses on AGE modeling issues and applications related to agricultural policy analysis. In order to keep this task manageable, I have elected to limit the bulk of the discussion to issues arising in comparative static, AGE analysis of agricultural policies in national market economies, as well as globally. As noted above, there are a number of surveys of AGE analysis focusing specifically on developing economies. To this we might add the work of Sadoulet and de Janvry (1995), which has a strong developing economy orientation. While many of the issues are common, regardless of the level of economic development, there are some salient differences having to do with underdeveloped markets and other rigidities. I will not have much to say about these "structural" issues here, as they tend to be locationally and institutionally specific. Additionally, I

[1] Sections I and II draw heavily on material in Hertel (1990).

will not attempt to cover the specialized topics relating to AGE analysis under uncertainty or dynamics. Appropriate treatment of these topics would take me well beyond the page limits for this chapter.[2]

Another area of modeling which I will omit in this survey has to do with the incorporation of financial variables in the model. This work, aimed at a synthesis of micro- and macro-economics, is quite challenging. In his 1991 review of this subject, Sherman Robinson highlights the theoretical tension between the neoclassical paradigm and AGE models with financial behavior. "We are still far from a theoretical reconciliation between Walras and Keynes and empirical models cannot help but reflect the theoretical gap." (p. 1522). Nevertheless, the need for this type of synthesis remains. In their recent survey of issues arising in this area, Bevan and Adams (1997) point out that many of the structural adjustment packages presented to developing countries and economies in transition ignore the real sector consequences of their macroeconomic prescriptions. Analysis of monetary variables in an AGE model could help to fill this gap, and this clearly represents an important topic for research (see, for example, McKibbin and Sachs, 1991). However, as the Bevan and Adams survey indicates, no clear consensus exists and many difficult issues remain to be resolved. Consequently, all of the work reviewed below will relate only to *real* models, in which monetary variables, such as the money supply, price levels and nominal exchange rates have no role to play.

Why AGE Analysis of Agriculture?

Benefits of AGE Analysis

An important question to be raised at the outset of this survey bears on the relevance of AGE analysis for agriculture. With food and agriculture representing an ever shrinking share of GDP and consumer expenditure, why should we go to the trouble of constructing an economywide model to analyze policies in these sectors? There are several important advantages offered by this approach to policy analysis.

Household focus: Traditional agricultural economic analysis has tended to focus on commodities, and associated factor returns. In contrast, AGE models begin with households as the primitive concept. Households supply factors of production and consume goods and services. Welfare in the model is computed directly in terms of household utility and not some abstract summation of producer, consumer and taxpayer surplus. After all, most households embody a combination of all three of these attributes, namely, income generation, consumer expenditure and the payment of taxes or the receipt of subsidies. The focus also on people, services, resources and

[2] For a recent AGE application with uncertainty, which focuses on agriculture, see Boussard and Christensen (1997). Readers interested in intertemporal models are referred to Keuschnigg and Kohler (1997), McKibbin and Wang (1998), and Wilcoxen (1989). Recursive-dynamic applications are quite common in agriculture (Fisher *et al.*, 1988; Burniaux and van der Mensbrugghe, 1991; Wang, 1997), and Diao, Roe and Yeldan (1998) have an application drawing on endogenous growth theory.

the environment, instead of just commodities is increasingly important, as the share of farm household income generated outside of agriculture increases.[3]

Finite resources and accounting consistency: AGE models rely on social accounting matrices (SAMs) for their empirical structure (Pyatt and Round, 1979; Hanson and Robinson, 1988). These SAMs detail all the basic accounting identities which must hold for the economy to be in equilibrium. Those who work with AGE models quickly recognize that these identities are as important as the behavioral assumptions. The fact that households cannot spend more than they earn, or that the same unit of labor, land or capital cannot be simultaneously employed in two different places, serves to tightly circumscribe the range of possible GE outcomes.

A related issue has to do with the fiscal integrity of the analysis. Historically, agricultural economists have rarely posed the question: Who pays for farm subsidies? (Alston and Hurd, 1990). Yet it has been shown, using AGE methods, that the marginal excess burden of raising revenue in the United States is often very high (e.g., Ballard, *et al.*, 1985b). By incorporating an explicit budget constraint for the government, AGE models can capture the cost of higher levels of agricultural subsidies — or alternatively, the fiscal benefits of reducing expenditures on farm programs. Chambers (1995) takes the distortionary effect of taxation into account in his general equilibrium analysis of alternative forms of agricultural subsidies. He shows that traditional, partial equilibrium calculations of farm subsidy incidence misrepresent social losses and systematically overestimate the benefits agricultural producers derive from farm programs by ignoring the impact on government revenue requirements.

A final benefit resulting from the exhaustive accounting in AGE analysis derives from the applicability of Walras' Law. This "law" states that if: (a) all households are on their budget constraint (subject to explicitly defined inter-household transfers or borrowing), (b) all firms exhaust their revenues on factor payments, taxes, and transfers of excess profits to households, and (c) all markets are in equilibrium (i.e. supply = demand), then one of the equilibrium relationships in the model will be redundant and may be dropped. This provides an extremely powerful check on the consistency of the AGE model, since the redundant equilibrium condition may be checked — after the fact— to verify that there were no errors in data base management, model coding, or possibly in the theoretical structure. Indeed, most AGE modelers will admit to having discovered many errors via the use of this check.[4] Given the complexity of implementing a large-scale empirical model, this can be a very powerful tool indeed.

Second-best analysis: One of the distinguishing features of agricultural policy analysis is the high degree of public intervention in the farm and food sector. This includes programs which: (a) subsidize inputs such as credit, water, and fertilizer, (b) restrict acreage planted to certain crops, (c) intervene in output markets with subsidies or production quotas, (d) subsidize (or tax less) the

[3] The latest information from the U.S. indicates that 88% of farm household income is derived from nonfarm sources (USDA, 1995).

[4] For example, if one decided to introduce imperfect competition in an existing AGE model, but forgot to distribute the excess profits to owners of the enterprise, Walras' Law would reveal this in the form of insufficient demand in the omitted market.

consumption of food relative to other goods and services, and (e) intervene at the border with export subsidies, import tariffs and quotas, etc. This complex web of policy interventions makes it very difficult to anticipate the efficiency consequences of a marginal perturbation in, or reform of, farm and food policies (Clarete and Roumasset, 1990). Chambers (1995) derives conditions under which, *at the margin*, land retirement may dominate decoupled transfers to producers due to their impact on the government budget and hence existing levels of distortionary taxation.

In an AGE application focusing on US agriculture in the mid-1980's, Hertel and Tsigas (1991) show that, *at the margin*, tradeable output quotas could have been welfare-enhancing. This stemmed from the fact that existing agricultural, food, and tax policies had retained excessive resources in agriculture and the quotas would provide a mechanism for moving some of these inputs out of the farm sector. However, those authors also show that the supply control approach which was preferred at the time, namely acreage restrictions, would have reduced efficiency in the economy. Finally, they demonstrate that the first-best alternative of removing all of the distortions would generate welfare gains an order of magnitude larger than the tradable quotas. In summary, AGE models provide an excellent vehicle for conducting welfare analysis in a second-best setting, and this makes them particularly well-suited for use in agricultural policy analysis.

Interindustry linkages: Often when one is conducting policy analysis in the farm sector, it is difficult to know where to draw the line between the commodities and sectors affected by a given policy and the rest of the economy. More generally, distinguishing agriculture from non-agriculture in the modern, industrialized economies has become quite difficult. Increasingly, large, commercial farms contract out some of their operations. The firms providing these services — ranging from pesticide applications to financial services — may not be exclusively tied to agriculture. Sayan and Demir (1998) assess the degree of interdependence between agriculture and non-agriculture industries in Turkey using techniques from input-output analysis. They find that when backward linkages from agriculture to non-agriculture are ignored, the agricultural multipliers are understated by about 20%. Linkages from the agriculture to non-farm sectors producing energy, fiber and other nonfood items are also important. When backward linkages from non-agriculture to agriculture are omitted from Sayan and Demir’s analysis, the non-farm multipliers for Turkey are about 8% too low. A final, important reason for capturing the non-farm linkages has to do with the diversification of farm households’ earnings. They often have significant financial or wage earning interests in other sectors, so that their welfare depends on much more than the changes in agricultural activity.

Economywide Perspective: AGE analysis also provides a valuable tool for putting things in an economywide perspective. Microeconomic theory emphasizes the importance of relative, as opposed to absolute, levels of economic variables. For example in the case of technological progress, it is not the absolute rate of TFP growth that matters for agricultural production and prices, but rather the rate of TFP growth *relative to* the non-farm sector (Simon, 1947; Gruen, 1961). Similarly, a tax reform which raises tax rates for agriculture, may not discourage farming activity if the non-agricultural tax rates rise by more. In an AGE analysis of the US tax system, Hertel and Tsigas (1988a) find that relatively low tax rates on capital, labor and output in agriculture, as well as relatively lower consumption taxes on food, have all conferred an implicit subsidy on the farm and food sector. Nowhere is the importance of relative vs. absolute comparisons more evident than in international trade. It is very common for agricultural economists to compare production costs in different regions, and, when they are lower in one country than another, to conclude that country is more competitive. However, this ignores the most fundamental proposition of international trade, namely that countries will export the product in which they have a *comparative advantage*. Where do they go wrong? Any partial equilibrium comparison of costs invariably must make an assumption about the terms of trade. Yet, the terms of trade are fundamentally endogenous. They adjust to ensure external balance. In equilibrium, a given economy may be the most efficient producer of both agriculture and manufactures. But if its comparative advantage is in manufactures, it will import agricultural products.

In order to better understand where partial equilibrium analysis of competitiveness can lead one astray, it is useful to think about a specific example. Consider the case whereby the US embarks on an effort to become more competitive by investing in the skill-base of its workforce. *A priori* we might think that this should result in an increase in agricultural output, since a more highly skilled workforce will result in more productive farmers. However, once we take into account general equilibrium constraints, we will find that the opposite conclusion is more likely correct. The reasoning is as follows. First of all, more productive labor will tend to boost output across the board. Consequently, at constant prices, exports will increase and imports will be displaced by domestic production in all sectors. Furthermore, foreign investment is also likely to increase in response to the higher level of labor productivity. This leads to a violation of the general equilibrium condition for external balance:

(1) $S - I = X + R - M$

where S = national savings, I = investment, X = exports, R = international transfers, and M = imports.

Without any GE adjustment, the left hand side of (1) becomes more negative ($I\uparrow$) and the right hand side becomes more positive ($X\uparrow$, $M\downarrow$). Something clearly must adjust to ensure that (1) will hold. In general equilibrium, this is the real exchange rate. Goods produced in the US must become more expensive abroad, and imports must become relatively cheaper. As the system re-equilibrates, what will happen to farm output? Since agriculture is relatively more intensive in land, the availability of which is unchanged, and relatively less intensive in skilled labor, the supply of which has increased, we expect agricultural outputs (and exports) to *fall* in this instance. (This is the well-known Rybcyznski theorem.) In summary, here we have a case where the economywide constraints are strong enough to actually reverse partial equilibrium intuition.

Hidden Challenges to AGE Analysis

Having made the argument that general equilibrium analysis is called for in some circumstances, the next question is: What type of AGE model is appropriate? In a paper titled "Hidden Challenges in Recent Applied General Equilibrium Exercises," John Whalley (1986) emphasizes the need to move from general to special-purpose models if AGE analysis is to become more policy relevant. He notes that the AGE models of the 1960s, 1970s and early 1980's were developed partially in order to "demonstrate the feasibility of constructing applied general equilibrium models ... showing they could handle much larger dimensions than theoretical models" (p. 37). Application of such models to particular policy issues often involved redesigning the basic model, while carrying along considerable excess baggage. With model construction and computational cost now less burdensome, Whalley suggests that future efforts be directed at developing special purpose models, tailored to address specific issues. He notes that particular attention should be paid to parameter specification and the manner in which policies are modeled. The remainder of this survey may be viewed as an overview of recent attempts to meet some of these "hidden challenges", which have often limited the impact which general purpose AGE models have had on agricultural policy issues.

Most of the early AGE models of developed market economics (DMEs) treated agriculture (possibly along with forestry and fisheries) as a single, aggregate sector, producing one homogeneous product (e.g., Ballard, *et al.,* 1985a). This type of aggregation was essential in order to permit complete commodity coverage at a relatively uniform level of aggregation. Also, this is often the level of aggregation provided in published input-output tables. However, when it comes to analyzing farm policies, more detail is required. This is because intervention varies widely across farm commodities, with some receiving a great deal of support (1985 U.S. sugar prices were five hundred percent of the world price), while others (such as the U.S. poultry industry) are virtually free of intervention. By lumping all of these products into one single aggregate, little can be said that would carry any weight with agricultural policy makers. The question of appropriate disaggregation of AGE models for agricultural policy analysis will be addressed in section III of the chapter.

A second important feature of general purpose models which has limited their applicability to agricultural issues is their failure to distinguish land from other capital inputs. Yet the presence of farm land in the agricultural production function is critical. It is perhaps the most distinguishing feature of this sector of the economy. Furthermore, land can also be an important instrument of public policy. Historically, a significant aspect of intervention in U.S. agriculture involves the idling of productive acreage in order to raise commodity prices. The European Union and Japan have recently also directed more of their policies towards limiting land use. In addition, farm land prices are themselves often a policy target. With relatively limited alternative uses (outside of agriculture), the price of farmland not adjacent to cities tends to be determined predominantly by expected farm product prices. Therefore land prices are potentially quite volatile. Since land usually represents the major form of wealth holding for the farm population, the impact of public policy on farm prices and hence returns to landowners is of paramount importance to farmers and agricultural policymakers. There is simply no way around dealing with land markets if one wishes to appropriately model the agricultural sector, and so disaggregation of factors of production, including land, is also dealt with in section III.

A third critical limitation of the most common, general purpose AGE models of the last two decades is their tendency to devote too little attention to the specification of key behavioral parameters in the farm and food system. As a consequence, there is a wide gulf between the partial equilibrium models currently used in agricultural policy analysis, and the partial equilibrium behavior of their AGE counterparts. In some cases these discrepancies may be justified. However, in most instances the AGE models' parameters simply lack sufficient empirical justification. As a consequence, they often generate implausible results.

Generous federal and state funding, and close working relationships with other scientists and with industry have combined to result in an agricultural economic data base which is the envy of many applied economists. There is also more than half a century of applied econometric analysis of supply and demand behavior in agricultural markets upon which to draw. To be effective, any AGE modeler who wishes to seriously tackle farm and food policy issues must be willing and able to capitalize on this wealth of data and behavioral information. In some cases this will require use of more general functional forms for representing preferences and technology in the AGE model. Section IV of this paper addresses the issue of parameter specification as well as the related questions of length-of-run and model closure.

Section V of this paper focuses on one of the specific hidden challenges identified by John Whalley - namely the need for explicit modeling of public policies. There are many cases in which simple ad *valorem* equivalent representations, common among general purpose models, give rise to inaccurate, or even misleading, conclusions. Of course, time spent at detailed modeling of individual policies must be balanced against the need to provide a comprehensive picture of distortions in the economy. For some purposes this extends to analyses of agriculture and the environment, which is the topic of Section VI.

Section VII addresses a few of the issues which arise in the context of product differentiation and imperfect competition. This can be very important when it comes to validation of AGE models, which is the subject of Section VIII. The chapter closes with some thoughts about future directions for AGE analysis of agricultural and resource policies.

Data and Aggregation Issues: How Detailed Should the Model Be?

Sectoral and Commodity Disaggregation

Obviously there are limits to the amount of detail which can be provided by an economywide model. The general purpose models have logically opted for a relatively balanced treatment of the entire economy, given the constraints imposed by national accounting conventions. For example, the U.S. tax model outlined in Ballard, Fullerton, Shoven, and Whalley has nineteen sectors. Sectoral gross output, as a percentage of the U.S. total, ranges from slightly less than one percent (mining) to a little more than ten percent (services). But most sectors fall in the 2-8% range (Ballard, *et al.*, 1985a, table 4.13).

A special purpose model focused on agricultural policy will necessarily be more lopsided in order to focus attention on particular issues. Perhaps the most extreme example of this is the world wheat model of Trela, Whalley, and Wigle (1987). In their framework, each country consumes two goods: wheat, and everything else. This permits them to focus on the global effects of wheat policies within a consistent AGE model. It also makes data and calibration particularly straightforward. Benchmark equilibrium wheat production and consumption data are readily obtained from (e.g.) the FAO and they may then obtain data on the other sector as a residual. Constant elasticity of substitution (CES) or transformation (CET) preferences and technology are calibrated to reproduce published supply and demand elasticities for wheat, and they are “off and running" with a model. The IIASA model was based on the same idea, only its authors disaggregated agricultural production into ten commodities, with one residual, "nonagriculture" commodity (Fisher, et al., 1988). The multiple commodity work of Horridge and Pearce (1988)—based on the Tyers and Anderson (1992) PE trade model)— as well as that of Peterson, Hertel and Stout (1994) and McDonald (1990) — both based on USDA's SWOPSIM model (Roningen *et al*., 1991) —are similar in spirit.

Given the difficulty of constructing a benchmark equilibrium data base for an AGE-trade model, there are obvious advantages in a model specification which has a large "residual˜ sector. However, there are important drawbacks associated with this backdoor approach to arriving at a complete AGE model. The first of these is due to aggregation bias. Gehlhar and Frandsen (1998) illustrate how aggregation of agricultural sectors changes key qualitative findings with respect to APEC trade liberalization. This is due to the tendency to create false competition between countries producing fundamentally different products (e.g., rice and wheat). Excessive aggregation also can alter the welfare effects by smoothing out tariff peaks which may exist at a disaggregate level. Bach and Martin (1997) show how this problem can be overcome via the use of Anderson and Neary's Trade Restrictiveness Index in concert with an AGE model. They find that the welfare gains from tariff reform in China double when their analysis begins at the level of individual tariff lines, as opposed to simple aggregation to 10 sectors.

Another problem with excessive sectoral and commodity aggregation stems from the fact that the dividing line between the agricultural and nonagricultural economy is not at all clear. Furthermore, in the case of some agricultural policies, the "grey area" between these two groups of sectors is where the most interesting "action" is. Consider, for example, the U.S. sugar program. Support for U.S. sugar producers is achieved indirectly by administering an import quota on partially refined sugar, which is adjusted until the domestic price of sugar reaches a prespecified target. The greatest source of pressure on the U.S. sugar quota has come not from the farm sector's supply response, but rather from the manufacturers of substitute sweeteners - in particular high fructose corn sweeteners (HFCS). The HFCS industry is dominated by a handful of firms who have become a very effective lobby for the sugar program. They have also made a concerted attempt to mobilize corn producers in support of this import quota on sugar, arguing that the derived demand for corn generated by production of this sweetener substitute lends considerable support to the market price of corn. While it has already been partially processed, traded sugar must be further refined for use in the domestic market. As a consequence, successive tightening of the quota has seriously hurt domestic sugar refiners.

Rendleman and Hertel (1993) show how the sugar quota can be analyzed using a special purpose AGE model. They conclude that short-run losses to sugar producers and the manufacturers of substitute sweeteners are, to a great extent, offset by gains to the ailing sugar refiners when the quota is eliminated. They also conclude that corn producer support for the U.S. sugar program is likely misplaced, since the HFCS industry produces by-products, corn oils and gluten food, which competes with corn grain. Consequently analysis of the sugar program which ignored the livestock sector seriously overstated the impact on corn prices. The message here is that analysis of particular commodity programs often requires disaggregation of nonfarm, food manufacturing activity as well.

Applied GE models attempting to address the overall impact of farm and food programs need to disaggregate sufficiently to isolate distinct types of commodity market intervention. Hertel, Thompson, and Tsigas distinguish nine different farm products and about a dozen agri-processing sectors in their attempt to assess the impact of unilateral agricultural policy liberalization in the United States. In their work on U.S. agricultural policies, Robinson *et al.* began with a model in which 3 farm sectors were broken out (Robinson, Kilkenny, and Adelman, 1989). They subsequently found it desirable to disaggregate to 8 agricultural and 8 food processing sectors (e.g., Hanson, Robinson and Tokarick, 1988; Kilkenny and Robinson, 1990) in order to capture the major differences among various farm and food policies.

The question of disaggregation becomes more difficult in those cases where the general equilibrium modeler wishes to deal explicitly with agricultural trade and related domestic policies, among a variety of countries. This is because multiple data sources must be used, making disaggregation more difficult. The OECD “Rural-Urban, North-South” RUNS model (Burniaux and van der Mensbrugghe, 1991), had 15 commodities, of which 8 pertain to farm and food products. More recently, the Australian Industry Commission developed a 16 region, 37 commodity model with 11 farm and food sectors, nicknamed SALTER (Dee, *et al.*,1992). Much of the data base underpinning SALTER was adopted by the Global Trade Analysis Project and built into the GTAP model (Hertel, 1997). The most recent version of the GTAP data base disaggregates 20 farm and food products and 30 non-food products. However, obtaining this degree of sectoral detail for many different countries necessarily involves some compromises. Also, even with that degree of sectoral detail, the breakdown may not be sufficient for a particular policy issue in a specific country.

Household Disaggregation

From the point of view of welfare analysis, disaggregation of *households* in the economy is probably even more important than sectoral disaggregation. Unfortunately, data on factor payments to households is difficult to obtain. For this reason many researchers choose to aggregate all private consumption into a single household. Some notable exceptions in the case of research on U.S. agriculture, include Boyd (1988), who distinguishes households by income class, and Kilkenny (1993), who distinguishes rural and urban households. Of course income distribution is often much more skewed in the case of developing countries and consequently there has been more of this sort of work done in that context (e.g., Brandao, *et al.*, 1994; de Janvry and Sadoulet , 1987; Robinson, *et al.*, 1993; Warr and Coxhead, 1993). If AGE analysis is to address the important *distributional* implications of farm and food policies, this type of household disaggregation must become standard practice. This will require additional data work on the part of the researcher.

Given the strong interest in income distributional consequences of public policies, some researchers have adopted a second-best approach to the problem. In particular, they first solve a household-aggregated model for a set of relative price changes for commodities and factors of production. They then engage in *ex post* calculations of the implied welfare changes for different household groups. This can make it feasible to examine the welfare implications for thousands of different household types. A recent example of this approach in the analysis of Vietnamese rice policies is provided by Minot and Goletti (1997). Provided the implied changes in income distribution have minimal implications for aggregate commodity demand, this is a very attractive approach to the problem of household disaggregation, since it permits the researcher to report results at a very high level of detail.

Regional Disaggregation

Just as it is often necessary to disaggregate sectors and households, so too is regional disaggregation frequently required to adequately capture the impact of agricultural and resource policies. Such disaggregation can take place at the sub-national level. For example, Kraybill *et al.* (1992) disaggregate the U.S. into the State of Virginia and the rest of the U.S. in order to analyze the regional incidence of national macroeconomic policy. A major challenge in such efforts at sub-national disaggregation arises from the scarcity of state-level social accounting matrices or input-output tables. Typically these must be "estimated" based on national accounts and selected sate level information (e.g., employment by sector and final demand). Another problem arises from the absence of observations on intra-national (inter-state) trade flows. As a consequence, multiregion AGE models are more common at the international level, where researchers can build on national accounts and international data sources on trade-flows.

International AGE models may be broken into two groups: those with a regional focus, and those with global coverage. In some cases, the issue being considered has a clear regional dimension which suggests analysis in the context of a two or three country model. The U.S. - Mexico component of the North American Free Trade Agreement (NAFTA) was successfully analyzed by Robinson *et al.* (1993) in a two region (US - Mexico) model wherein the rest of the world responses were simply captured with excess supply and demand equations. Harrison *et al.* (1989, 1991) develop a disaggregated data base for the European Union in order to analyze the welfare and distributional consequences of policies associated with the European Community.

Increasingly, however, many policy makers are seeking answers to global economic policy questions. In this case, global applied general equilibrium analysis is often the most appropriate tool. The drawn-out negotiations under the Uruguay Round of the GATT/WTO provided ample opportunity for quantitative analysis. The volume edited by Martin and Winters (1996) offers the most comprehensive analysis of the Uruguay Round Agreement. All five of the quantitative assessments contained therein are based on global AGE models. While these global models generally share the same basic structure as the national and regional models, there are some specific issues which arise in making the transition from one to the other. Hertel, Ianchovichina and McDonald (1997) provide an extensive discussion of these differences.

In some cases, global modeling is desired, not because the policy scenario under consideration is global in nature, but rather because the consequences of a regional shock are expected to be widespread. Thus Arndt *et al.* (1997) use a global AGE model to analyze which countries gain, and which lose, from rapid economic growth in China. Coyle, McKibbin and Wang (1998) use a global AGE model to analyze the impact of the Asian financial crisis on U.S. agriculture. One reason why the list of global AGE analyses has been growing so rapidly in recent years is the public availability of a global economic data base to support such studies. Nicknamed GTAP (Global Trade Analysis Project), this data base is now on its fourth release (Hertel, 1997)[5].

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[5]For a comprehensive listing of references to global AGE studies based on the GTAP data set (150 at the time of this writing), the reader may visit the following web site: *www.agecon.purdue.edu/gtap/apps*

Agriculture as a Multiproduct Industry

The generic, general purpose AGE model is typically characterized by single commodity, constant returns to scale industries. However, agriculture departs significantly from this mold. Econometric tests for nonjointness in aggregate agricultural production are consistently rejected (e.g., Ball, 1988). There are numerous explanations for this apparent jointness in production including technological interdependence, the presence of lumpy/shared inputs, and the presence of an allocatable fixed input, namely land (Shumway, Pope, and Nash, 1984).

The problem posed by the presence of multiproduct sectors in an AGE model is that the addition of potential output-output, and input-output interactions vastly increases the number of parameters to be specified. One common solution is to impose input-output separability (e.g., Dixon, *et al.*,1982). The implication of this particular restriction is that the optimal output mix is invariant to changes in relative input prices. This is a strong assumption which violates one's intuition (e.g., the optimal mix of corn and soybeans is sensitive to the price of fertilizer). It also is persistently rejected by the data (e.g., Ball, 1988).

Another problem confronting the modeler seeking to treat agriculture as a multiple product sector is the presence of commodity-specific factor market interventions. For example, in order to qualify for corn output subsidies in the U.S., it was previously necessary to idle a certain percentage of one's established corn acreage. This in turn had a differential effect on the shadow price of land in corn vs. (e.g.) soybean production. Lee and Helmberger (1985) demonstrate how this can result in own-price effects which are "too small" relative to cross-price effects. As a result, nonconvexities can arise in a multiproduct profit function representation of the farm sector.

If one is willing to argue that jointness in agricultural production is solely due to the presence of an allocatable fixed input, then it is possible to revert to modeling commodity production as a set of single product activities -- bound together by the presence of a fixed amount of land. Indeed, attempts have been made to estimate agricultural technology under these assumptions (Just, Zilberman, and Hochman, 1983). It is also a common specification in agriculturally focused AGE models, and has the advantage of facilitating commodity-specific interventions in the land market (Hertel and Tsigas, 1991; Kilkenny, 1991).

Producer Heterogeneity

Another type of heterogeneity in the farm sector is that which arises due to differences in producers. This could arise due to differences in entrepreneurial capacity, as hypothesized by Friedman, 1976), or due to differences is risk preferences, or for other reasons. In any case, we observe a great deal of variation in farm size as well as production technology in the farm sector. One reason which such differences can persist in the face of market forces is the tendency for farmland to absorb any differences in profitability. As long as the farmer owns his/her own land, and as long as he/she is willing to take a sub-market return on this asset, then they can remain in farming in spite of lower levels of efficiency. This is particularly likely in the case of smaller, part-time operations in which farming is part of the household’s lifestyle.

In the U.S. a relatively small group of commercial farms produces the majority of agricultural output. There are a great number of small farms, many of which are part-time operations. For example, in 1987, 52% of the farms had sales of less than $10,000 and consequently accounted for only 6% of gross farm income (Sumner, 1990). The inexorable downward slide of average costs leaves small producers with below average, sometimes negative, returns to their equity and own-labor. This process is driven by persistent technological change, and at any particular moment, the agriculture sector is in a state of disequilibrium with regard to the composition and size of farms. For example, in their econometric analysis of the period from 1947-74, Brown and Christensen (1981) show that, while family labor in agriculture dropped by two-thirds over this period, the estimated optimal level of this input also dropped dramatically. As a result, the ratio of observed to optimal family labor hardly changed.

While the issue of farm size is an important one, it is essential that AGE modelers with an interest in agriculture focus on aspects of the farm sector: (a) which are central to the questions they seek to answer, and (b) to which they can contribute some added insight. I would argue that neither of these applies (in most instances) to the farm size issue in developed market economies. Most production comes from a relatively small group of commercial farms. These operations dominate the data used to estimate price elasticities, and their behavior is more nearly consistent with the neoclassical paradigm prevalent in AGE analysis. Thus, in most cases, we should focus on modeling representative commercial farm operations. Modeling the evolution of the distribution of farms by size is an important policy issue, but not one in which AGE models have any comparative advantage.

Of course there are exceptional cases in which farm size becomes relevant for AGE analysis of agricultural policies. A good example is provided by the Canadian dairy program, whereby individual farms are assigned a production quota. Econometric evidence indicates that this has contributed to the presence of unexploited scale economies (Moschini, 1988). Thus it is important to build this inefficiency into the initial equilibrium. Robidoux, Smart, Lester, and Beausejour (1988) have done this (both for dairy and poultry) in their analysis of Canadian farm policies. They find that agricultural policy liberalization generates considerable "rationalization" in the dairy industry as some farms exit and the remaining operations move down their long-run average cost curve.[6]

Establishing an Appropriate Benchmark

The vagaries of weather, long gestation periods, price-inelastic demands, and heavy (but unpredictable) intervention by governments all contribute to greater volatility of agricultural assets, relative to their nonfarm counterparts (Irwin *et al.,* 1988). It is not uncommon to find enormous swings in the components of agricultural value-added reported in the national accounts. This volatility in observed “cost shares” can translate directly into volatile model results, as has been

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[6]In addition to the differences in farm size, there are other observed types of heterogeneity which can have important policy implications. Using USDA survey data, Hertel, Stiegert and Vroomen (1996), show that Indiana corn producers exhibit strikingly different propensities to apply nitrogen fertilizer to their crops. Even after controlling for terrain, soil type, manure applications and crop rotation, those authors observe application rates ranging from 30 to more than 200 lbs./acre in 1989. In the face of a proposed tax on nitrogen fertilizer, the authors argue that this producer heterogeneity can give rise to an additional source of nitrogen-land substitution — namely a composition effect. As the price of fertilizer rises, it has a strong negative impact on profitability for the most profligate users of this input. This induces a shift of corn land from the high-intensity users to the low-intensity farm managers.

demonstrated for Australia by Adams and Higgs (1990), using the ORANI model. Since the share of fixed capital and land in the primary factor aggregate is a key parameter in the calibration of ORANI's agricultural supply response (see also Section IV below), variation in this share translates directly into variation in the supply elasticity. The authors show that such variation can even alter the predicted macroeconomic consequences of farm sector shocks. This led Adams and Higgs to the development of a "representative year" data base for Australian agriculture.

In a somewhat more ambitious undertaking, Harrison, Rutherford, and Wooten (1989) construct a sequence of SAMs for the European Community with which they proceed to analyze the same experiment (removal of the Common Agricultural Policy) over a period of 12 years. A logical extension of this effort would be to use this time series data to estimate a representative benchmark equilibrium for the entire economy. A more modest undertaking might involve the econometric estimation of cost shares for the agricultural sector alone.

Finally, there is a question of what benchmark should be used to assess the impact of policies which are due to be implemented over a relatively long period of time. A good example is provided by the Uruguay Round Agreement (UR) which was concluded in 1995 but which was due to be phased in over ten years. Furthermore, in the most contentious areas — agriculture and apparel — many of the reforms are “back-loaded” with the deepest cuts in protection scheduled for the later years. Yet most of the studies of this agreement employed data bases which described the global economy in the early 1990's. Bach *et al.* (1998) evaluate the difference between the welfare effects of the URA in 1992 vs. 2005, where the latter benchmark is constructed by projecting the global economy forward using World Bank estimates of endowment and productivity growth. Since the deepest UR cuts are in Asia, and since this region was projected to growth rather rapidly as well, the authors found that the global gains from the UR were larger in 2005. In addition, they projected that without the UR, the textile and apparel quotas would have become significantly more binding. This, too, serves to make the UR more valuable in 2005 than would have been foreseen in the context of the 1992 global economy.

Treatment of Land in AGE Models

The role of land in agricultural production is arguably one of its most distinguishing features in terms of AGE analysis. This section focuses on the treatment of farmland in these markets. Here there are two key issues which I will address. The first pertains to the sector-specificity of land. I.e., are there significant alternative nonfarm uses for this input which might contribute to determining its price in the long run? The second issue has to do with the heterogeneity of farm land and subsequent limitations on its mobility among uses within the ' agricultural sector.

Sector-Specificity of Farm Land: Unlike labor and capital, land is geographically immobile. As a result, it is common to assume that it is a sector-specific asset which ultimately bears all of the producer burden of a reduction in farm support. For example, Hertel, Thompson, and Tsigas (1989) estimate an 18% reduction in land rents following unilateral elimination of U.S. farm programs. Vincent (1989) estimates that Japanese farm land rents would fall by 68% following unilateral liberalization in that country's agricultural sector. Is there a chance that such price reductions might stimulate nonagricultural uses of farm land? If so, this type of quantity adjustment would serve to dampen the landowner losses (e.g., McDonald, 1990). The answer to this question will clearly vary by region and by country. In the U.S., nonagricultural uses have been shown to play a role in determining the value of farmland in selected metropolitan areas (Lopez, *et al.*, 1988), but this has not proven to be an important determinant of aggregate agricultural land values. Furthermore, most of the commodities grown near urban areas are not the traditional program commodities which are most dramatically affected by U.S. farm policy. Thus the potential for nonfarm uses of agricultural land dampening the downward adjustment of rental rates following unilateral agricultural liberalization would seem quite limited.

The case of Japan is quite different. There, the capitalized value of farm program benefits represents a larger share of land's claim on agricultural output. Furthermore, the proximity of farm land to major population centers is much greater. Thus the demand for residential, recreational, and commercial land may be expected to place a significant floor under farm land values. Of course, the degree to which such adjustment can occur depends on accommodating changes in land use legislation. In Japan, "landowners must obtain the permission of the prefecture or of the Ministry of Agriculture, Forestry, and Fisheries in order to transfer farmland into other uses" (ABARE, 1988, p. 75). Extremely favorable property and inheritance taxation of farmland, coupled with high rates of capital gains taxation serve to further discourage movement of land into nonfarm uses. As a result, the percentage of land devoted to agricultural uses in the three major metropolitan areas in Japan (16%) exceeds the share of this land devoted to residential, commercial, and industrial plant uses (11.5%). It also exceeds the share of farmland in Japan's total land area (15%) (ABARE, 1988, p. 316). Despite these distortions in the land market, there is evidence that nonfarm demands support agricultural land values. For example, between 1979 and 1985 the relative price of rice to rice paddy land fell by about 20% (ABARE, 1988, p. 321).

Heterogeneity of Land: Abstracting from the question of how much land might move between farm and nonfarm uses, there are important modeling issues deriving from the heterogeneity of such land in agricultural production. The capacity of a given acre of land to produce a particular farm product varies with soil type, location in the watershed, and climatic conditions. These characteristics all combine to determine the yield, given a certain level of nonland inputs. To treat all farmland as homogeneous is to assert that one can grow oranges in Minnesota at the same cost as Florida (i.e. without greenhouses)! Models based on this structure will overstate supply response, since they don't take into account the agronomic and climatic constraints placed on the production of specific farm commodities. The trick for an AGE model is to capture the essence of such constraints without being forced to develop a full-blown model of agricultural production by locality and land type.

Perhaps the simplest method of constraining acreage response in a AGE model is that employed by Hertel and Tsigas (1988a). They specify a transformation function which takes aggregate farm land as an input and distributes it among various uses in response to relative rental rates. Given a finite elasticity of transformation, rental rates will differ across uses and acreage response may be calibrated to econometrically estimated values.

The next level of complexity in modeling the heterogeneous nature of agricultural land involves drawing a distinction between land types and land uses. In this framework, equilibrium in the land market involves the equalization of after-tax rates of return on any given type of land. However, provided these land types substitute imperfectly in the production of a given crop, there may exist differential rental rates across land types. Robidoux, Smart, Lester, and Beausejour (1989) adopt this type of specification in their AGE model of Canada. They specify CES aggregator functions that combine three land types, each of which is used - to some degree -- in the production of six different farm products. An interesting wrinkle in their approach is the way in which they estimate benchmark equilibrium rental rates, by land type. These are obtained by regressing total land rents in each sector on the observed quantity of each land type used in that sector. In equilibrium, the land-specific rental rate (i.e., the coefficient on acreage) must be equal across uses.

The Robidoux, *et al.* approach deals with differences in land type, but not regional or climatic differences. Models designed to assess the effects of climate change, or the regional implications of policy shocks must disaggregate land endowments still further. Darwin *et al.* (1995), have taken a similar approach to their analysis of the economic impacts of climate change in a global AGE model focused on agriculture. They disaggregate land classes into six types, each of which is characterized by its length of growing season. These land classes are employed differentially across farming and forestry sectors, according to current patterns of production. In addition, the authors explicitly identify water as an input into the production function of each crop. The authors then turn to the results of the global climate simulation models in order to assess the impact of alternative climate change scenarios on the temperature and precipitation by region. This causes a shift in each region's land endowment across land classes and therefore causes patterns of agricultural production to change. Darwin *et al*, are then able to assess the consequences of climate change for patterns of trade, consumption and welfare.

The Role of Water

As can be seen from the previous example, it is often important to distinguish farm land by its access to water. Berck, Robinson and Goldman (1991) provide an overview of the use of AGE models to assess water policies. A key question is how to model water supply. Decaluwe, Petry and Savard (1997) have wrestled with this issue in the context of an AGE model of the Moroccan economy. In particular, they distinguish between groundwater and surface water collected by dams. Supply response is modeled via a Weibull distribution, and their analysis focuses on the economywide implication of water pricing policy in Morocco. In contrast, Robinson and Gehlhar (1995) develop an AGE model of Egypt in which land and water are combined in a linear fashion in the sectoral production function. As water scarcity becomes an increasingly important issue in the drier areas of the world, appropriate modeling of the water supply and demand in AGE models will become a pressing area for research

Parameter Specification and Model Closure

Specification of Preferences and Technology

Consumer Demand: The long history of applied econometric work in agricultural economics represents an asset which AGE modelers must capitalize on if their work is to have an impact on farm and food policy analysis. In the area of consumer demand, for example, there is a considerable body of work available which reports the results of disaggregated, complete demand systems for food and nonfood commodities (e.g., George and King, 1971; Huang and Haidacher, 1993). While there is a strong tendency for food products to be price- and income-inelastic, individual elasticity values vary widely among food groups, with consumer demands for grains being quite unresponsive to price and income, while livestock products are more responsive. It is impossible to capture this diversity of price-responses with simple, explicitly additive demand systems such as the Constant Elasticity of Substitution (CES) on the Linear Expenditure System (LES). Some studies simplify even further, by assuming Cobb Douglas preferences (e.g., Robidoux, *et al.* (1989);Robinson, Kilkenny, and Adelman (1989)). In so doing, the authors risk overstating some uncompensated price elasticities by a full order of magnitude. This is particularly problematic when agricultural price policies are being examined, since consumer demand elasticities are critical in determining the incidence of changes in these policies. By overstating consumers' ability to respond to a price increase, such models will overstate the backward shifting of the effects of such a shock.

This naturally takes us into the problem of functional form, which lurks beneath the surface in any discussion of parameter specification for AGE models. Since the demand (and supply) relations in these models are the outcome of well-defined optimization problems, it is not possible to arbitrarily specify some elasticities and then plug into the model equations. Any elasticities must be compatible with the parameters of the underlying utility function. This part of the "calibration problem" can be quite challenging. Most of the work on functional forms has focused on "fully flexible" forms, i.e. those which do not arbitrarily restrict the matrix of N * (N-1)/2 partial substitution elasticities, where N is the number of commodities. Here the work of Diewert and Wales (1987); and Perroni and Rutherford (1995, 1997) on global well-behaved flexible forms is particularly important. However, for significant disaggregations of commodities and sectors, obtaining this much information is simply not possible. Therefore some intermediate ground is often needed.

In a somewhat overlooked 1975 article, Hanoch proposed a class of implicitly additive functional forms which are associated with N independent substitution parameters. He made precisely the argument alluded to above - namely that there may be cases where a generalization of the CES which falls short of being "fully flexible" might be useful. Furthermore, under implicit additivity, N is precisely the number of free parameters required to match up with a vector of N own-price elasticities of supply (demand). In addition, unlike explicitly additive functions, implicit additivity does not rule out complementary relations. The implicit additivity restriction was first employed empirically in order to represent production possibilities in Australian agriculture, within the context of the ORANI model (Vincent, Dixon, and Powell, 1977). These authors used the CRETH (Constant Ratio Elasticity of Transformation Homothetic) system, which is a primal specification. The Constant Difference Elasticity (CDE) functional form is a dual (potentially non-homothetic) specification. It has been employed to estimate demand relationships in agriculture (Hjort, 1988; Surry, 1989; Herrard *et al.*, 1997). Recently, it has been used in AGE analysis to calibrate consumer demand to a vector of own-price and income elasticities of demand (Hertel *et al.*, 1991).

Most of the literature on functional forms has focused on flexibility in price space. This is generally the most relevant dimension for comparative static analysis of agricultural policies with highly aggregated households, since the impact of these policies on aggregate income is generally quite small, compared to the impact on relative prices. However, when the AGE analysis involves accumulation of factors of production, as in a dynamic AGE model, or exogenous shocks to endowments in a comparative static AGE model (e.g., Anderson *et al.*, 1997), then the income elasticities of demand can play a very important role in the results. In such cases it will be important to not only capture variation in income elasticities of demand across commodities, but also the tendency for the income elasticity of demand for food products to fall over time. The need for this type of "Engel-flexibility" has been emphasized by Rimmer and Powell (1994), based on non-parametric analysis. This precipitated development of a new functional form, nicknamed AIDADS, which restricts the price space via implicit additivity, but which provides third-order Engel flexibility (Rimmer and Powell, 1996). AIDADS can capture the change in the income elasticities of demand for food over time, as per capita incomes rise (Cranfield *et al.*, 1998).

Producer Technology: The predominance in AGE models of Leontief (fixed coefficient) technology with CES substitution in value-added has its origins in the computational advantages which once flowed from this specification. By assuming fixed intermediate input coefficients, the entire equilibrium problem can be reduced to one of finding a fixed point in factor price space (Ballard, *et al.,* 1985a). This vastly reduces the computational cost of AGE analysis, which was an important consideration prior to the development of more efficient algorithms and more powerful computers. However, intermediate input substitution plays an important role in the farm and food system.

Wohlgenant (1987) shows that substitution of agricultural products for marketing-inputs plays a key role in determining farm-level demand elasticities. The potential incidence of farm programs is also closely circumscribed by the ability of livestock producers and food processors to substitute among raw agricultural products. As noted above, high fructose corn syrup has been widely substituted for sugar in the U.S. food and beverage sectors, as a consequence of the sugar import quota. In the EU, the gains from price support programs for grains have been shared with non-grains producers in the EU and overseas. Peeters and Surry (1997) review the literature on price - responsiveness of feed demand in the EU, where this issue has received a great deal of attention due to the constraints it has placed on the Common Agricultural Policy. They distinguish between three approaches: linear programming, the synthetic modeling approach and econometric approaches. One of the more innovative is offered by Folmer *et al.* (1990) who incorporate a detailed treatment of feed demand into the European Community Agricultural Model (ECAM) using the Linear Expenditure System.

Substitution among intermediate inputs and between intermediate and primary inputs also plays an important role at the farm level. Empirical evidence from U.S. agriculture (e.g., Hertel, Ball, Huang, and Tsigas, 1989) indicates greater potential for such substitution, than for substitution within the primary factor aggregate (land, labor, and capital). Warr (1995) also finds significant substitution possibilities between fertilizer and some primary factors. Because many important farm policies represent interventions in the primary factor markets (e.g., acreage reduction programs and subsidized investment), proper assessment of their impact on target variables such as employment and land rents hinges crucially on the specification of farm technology.

Trade Elasticities: Since cross-price effects play an important role in the domestic farm and food economy, it is no surprise that they also show up in the rest of the world's response to domestic price movements, and hence in the trade elasticities facing food exporters (Carter and Gardiner, 1988). Unfortunately such cross-price export demand elasticities are notably difficult to estimate (Gardiner and Dixit, 1986). Thus, single region models are forced to rely on simulation results from global trade models to measure them. Based on Seeley's (1985) work with the IIASA model, these cross-price effects are empirically quite important. For example, while he estimates a four-year own-price elasticity of export demand for U.S. wheat of -2.15, he finds that the *total elasticity* (when all grain and oilseed prices move together) is only -0.54. Since most farm sector interventions affect these commodities simultaneously, cross-price elasticities of export demand can be expected to play an important role in any policy simulation. Yet most one-country, general purpose AGE models abstract from cross-price effects in export demand.

One of the special features about agricultural trade — particularly in grains— is that it is controlled by state marketing agencies in many regions. This has led Abbott, Patterson and Young (1997) to conclude that the appropriate model for analysis of grains trade does not treat the individual agents in the economy as the decision makers for imports, but rather focuses on the problem faced by the individuals managing the state trading agencies. The resulting "plans and adjustment" model, which these authors propose, appears to fit the data quite well. Given the emerging importance of state-trading as a topic in multilateral trade negotiations, it may be worthwhile for AGE modelers to work on ways of incorporating this type of behavior as an explicit policy regime into their analysis of grains trade.

Implications for Policy Analysis: There will always be limitations in the way one is able to represent the basic structure of an economy in an AGE model, and so the critical question becomes: Are these limitations sufficient to warrant the extra effort involved in remedying them? In order to investigate this issue I have chosen to focus on one of the most inefficient farm policy tools - namely the idling of productive acreage in order to boost farm prices. Results are based on a special purpose AGE model outlined in Hertel, Ball, Huang, and Tsigas (1989), which utilizes a flexible representation of consumer preferences and producer technology. I then ask the question: What is the cost of successively restricting preferences and technology along the lines suggested by some of the general purpose models?

The results from the unrestricted experiment are summarized in Hertel and Tsigas (1991). Results for the restricted cases are reported in an appendix which is available on request from the author.[7] They indicate that a generic, general purpose AGE model which oversimplifies consumer preferences (Cobb Douglas case) and producer technology (no intermediate input substitution), and which omits cross-price effects in export demand, will overstate the welfare costs of acreage controls. In particular, the welfare cost of incremental acreage controls designed to raise program crop prices by 10% is overstated by 60% ($4.2 billion vs. $2.6 billion in the unrestricted model). This follows from two basic flaws in the general purpose models. First of all, they tend to overstate the farm level demand elasticity for these crops. Secondly, they tend to overstate the ability of farmers to substitute away from the land input. It should be noted, however, that the direction of bias is ambiguous. For example, when taken alone, the assumption of no substitutability in intermediate uses leads to an understatement of these welfare costs. Of course none of these parameters can be specified without some reference to the time frame for the simulation, and this is the subject to which we now turn.

[7]Readers can access this appendix on the worldwide web at *www.agecon.purdue.edu/gtap/wkpapr*.

Short, Medium. or Long-run?

Commodity Stocks: The time frame chosen for a AGE simulation has important implications for a variety of features which are critical to the outcome of the experiment. In the very short run, crop production has little scope for adjustment and, in the absence of stocks, supply shocks cause wide swings in commodity prices. As a result, there are substantial incentives for stockholding - either private or public - in the case of nonperishable crop commodities. In the longer run, the importance of stocks is diminished, since continued stock accumulation or decumulation quickly becomes infeasible in the context of a global agricultural economy.

Since the majority of AGE analyses focus on deterministic, comparative static analysis with respect to the medium run (which I take to be 3-4 years), it is common to abstract from commodity stockpiling - assuming that the associated price effects will only be transitory. However, any annual agricultural data set will include this type of "inventory demand" (or supply). One solution is to purge such demands from the benchmark equilibrium data set, in the process of constructing a representative year data set (Adams and Higgs, 1990 ; James and McDougall, 1993).

An alternative approach is to explicitly incorporate the stockpiling of commodities into the AGE analysis. Harrison, Rutherford, and Wooten (1989) develop a model of the European Community's Common Agricultural Policy in which excess market supplies are purchased, and either stored or unloaded onto world markets (with the help of an export subsidy). Stored commodities "are 'eaten' by EC government agents" (presumably they are stored until they spoil). Thus, they do not return to the marketplace, and hence do not generate future utility for private agents in this model.

Factor Mobility: As the time horizon for an AGE model lengthens, there is increased potential for production to adjust in response to a policy shock. In the limit, if all factors were perfectly mobile and the farm sector were relatively small, supply response would be perfectly elastic. However, some farm factors of production are probably never perfectly mobile. As noted above, farm land, in particular, often has few alternative uses and thus experiences more of a price adjustment than other factors in the long run. Also, family labor, farm structures, and some types of capital are relatively immobile in the short- to medium-run (Vasavada and Chambers, 1986).

To highlight the importance of factor mobility assumptions in determining the incidence of farm programs, consider the following evidence taken from Hertel, Thompson, and Tsigas (1989). (See also Kilkenny and Robinson, 1990, for further analysis of factor mobility). They analyze the impact of unilateral elimination of U.S. agricultural support policies in both the short run and the long run. The short run is characterized as the period over which both U.S. and foreign farm labor and capital are unable to adjust to this major shock. Thus short-run export demand elasticities are used, and U.S. farm labor, crop and livestock capital are all assumed immobile out of agriculture. The estimated short-run loss to these factors (in 1987 dollars) is $12.8 billion. The distribution of these losses is determined by the estimated elasticities of substitution in the farm sector. In this case the losses are distributed as follows: labor 37.3%, land 36.5%, livestock capital 18.2%, and crop capital 8.0%. In the medium run, the effect of mobile labor and capital on the elasticity of farm supply dominates the impact on farm level demand of larger export demand elasticities. As a result, the total producer burden falls to $5.7 billion. However, now all of this is borne by the sector-specific factor -- land. Thus the pattern of factor incidence can vary considerably, depending on assumptions about factor mobility.

Exactly how "long" is the medium run in models assuming over which perfect mobility of labor and capital is realized? This depends in part on the size of the shock. In the above experiments, the adjustments to attain a new equilibrium include a 5.5% reduction in the agricultural labor force, and a 14% decline in the stock of farm capital. Are these adjustments large? Not when compared to other forces at work in the farm sector. For example, Hertel and Tsigas (1988b) estimate that the average *annual* decline in the derived demand for farm labor as a consequence of technological change during the post WWII period was 4.3%. The needed capital stock adjustment is also not too large when compared to average annual rates of economic depreciation for farm machinery, which range from about 10% to 25% depending on the equipment in question. Of course, these relatively modest adjustments likely mask more dramatic regional and farm-specific effects. Also, if yours is the farm that goes under as a result of the new policies, the adjustment is hardly marginal! Nevertheless, in view of the fact that: (a) rigidity is greatest for downward price movements, and (b) this policy experiment is the most dramatic one that could be inflicted on U.S. agriculture (policies are *completely and unilaterally* eliminated), it seems reasonable to expect that the period of adjustment required to obtain a new equilibrium is not more than the 3-4 year time horizon usually assumed.

It would be inappropriate to conclude this section without mentioning the increasing importance of *international* factor mobility. Given the relatively small share of the total national capital stock employed in agriculture, international capital mobility is probably not an area of central concern. However, concerns about international migration of labor have placed that issue at the center of the debate over possible effects of a North American Free Trade Agreement (NAFTA). Advocates of NAFTA cited the need to stem the tide of migration from Mexico into the United States. In their AGE analysis of this issue, Burfisher, Robinson, and Thierfelder (1992, 1994) conclude that such an agreement would likely *increase* migration from Mexico to the U.S., largely due to its negative impact on the demand for agricultural labor in Mexico. This reversal of conventional wisdom is an important reminder of the need for careful empirical analysis of agricultural and trade policy questions.

Supply Response

Assumptions about factor mobility and technology combine to determine the supply elasticities for agricultural commodities in an AGE model. In order to highlight this interaction, it is useful to consider a simple CES production function which combines two groups of inputs with a constant elasticity of substitution (σ). The first group of (variable) inputs is assumed to be in perfectly elastic supply and comprises a share of costs equal to C_v. The second group is in fixed supply with cost share C_F. In this case, the sector of supply elasticity may be computed as: $\eta_s = \sigma(C_v / C_F)$. Calibration of this model may proceed by one of two routes. The first is to take some estimate, $\hat{\eta}_s$ such as that from the cross-section study of Peterson (1988), and combine this with the benchmark equilibrium values for C_v and C_F and to obtain $\hat{\sigma}$. The problem with this approach is that η_s varies as a function of relative prices, (provided $\sigma \neq 1$). In the developed market economies in Peterson's sample, where purchased inputs are cheap relative to the opportunity cost of family labor, we observe a large value of C_v relative to C_F . In this case, Peterson's cross-section estimation of η_s will understate supply response. In the poorer economies the opposite will be true.

The second approach to calibration of supply response in an AGE model involves estimating σ directly and inferring something about η_s based on alternative factor mobility assumptions. Problems with conventional estimates of supply response led Griliches (1960) to this type of indirect approach. Using factor demand relationships he estimated a long run supply elasticity for U.S. agriculture to be between 1.2 and 1.3. (This is quite close to the cross-section estimate by Peterson (1988) of 1.19.)

Hertel (1989) generalized the indirect approach to estimation of supply response to the case of multiple, quasi-fixed factor, and a fully flexible production technology. He combines an estimated matrix of Allen partial elasticities of substitution with two alternative factor mobility assumptions. In the first case, land and capital are assumed fixed and aggregate farm labor is partially mobile with a factor supply elasticity of 0.5. This generates a commodity supply elasticity of 0.84. In the second case, with labor and capital perfectly mobile, the aggregate supply elasticity is simply equal to the absolute value of the own-Allen partial elasticity of substitution for land, which is estimated to be 3.2.

These indirect estimates of supply response are all considerably larger than those obtained using single equation models fitted to time series data. Such studies have generally yielded aggregate agricultural supply elasticities in the range of 0.1 to 0.4 (Peterson, 1988). In such an environment output subsidies look a lot like lump sum transfers! One problem with such studies is that multicollinearity often precludes inclusion of a complete set of disaggregate prices (or quantities). Consequently, it is unclear what is being assumed about particular decision variables facing the farm firm. Are they fixed or variable? To overcome such problems a preferred approach to the direct estimation of supply response from time series data involves specification of a restricted profit function which, in turn, gives rise to a complete system of supply and demand equations in which the treatment of decision variables is explicit. Use of symmetry, homogeneity, and curvature restrictions help to overcome the problem of collinearity in such a system.

One example of the profit function approach is provided by Ball, who estimates a 5 output, 6 input system for U.S. agriculture. It is restricted on an exogenously determined quantity of own-labor (i.e., self-employed farmers). He obtains individual commodity supply elasticities ranging from 0.43 to 1.11. Furthermore, his outputs all exhibit gross complementarity (the so-called "normal case" (Sakai, 1974)). Thus aggregate supply response is larger than individual commodity response. Indeed, revenue share-weighted row sums of the output price submatrix sum to an aggregate supply elasticity of 3.6, which is again much larger than traditional estimates. If this is correct, then agricultural price support policies are much more distorting than is indicated by the agricultural sector models based on conventional time series estimates of supply response.

Model Closure

Economists using the comparative static, AGE framework face a fundamental problem in closing their models. This is because any SAM will have an activity related to investment, yet there is no intertemporal mechanism for determining the level of this activity in a static model. Sen (1963) defined this as a problem of *macroeconomic closure*. Following Dewatripont and Michel (1987), four popular solutions to this problem may be identified. The first three are non-neoclassical closures in which investment is simply fixed and another source of adjustment is permitted. In the fourth closure, investment adjusts endogenously to accommodate any change in savings. This, neoclassical closure, is the most common one in comparative static AGE models.

In addition to adopting a closure rule with respect to investment, it is necessary to come to grips with potential changes in the current account. (Recall from equation (1) from Section II above, that the difference between national savings and investment must equal exports plus international transfers less imports.) How much of the investment will be financed by domestic savings and how much by foreign savings? This question is difficult to address in the context of a single region, comparative static model. Therefore, it is common to fix the trade balance exogenously, in which case any change in investment must be financed out of national savings. In opting to exogenize this balance, the modeler is acknowledging that it is largely a macroeconomic phenomenon. To a great extent, the causality in equation (1) runs from left to right. That is, changes in global capital markets dictate what will happen on the current account. This approach also facilitates analysis by forcing all adjustment onto the current account. In addition, if savings does not enter households' utility function, then fixing the trade balance is the right approach for welfare analysis, since it prevents an arbitrary shift away from savings towards current consumption from being confused with a welfare improvement.

Finally, there is the question of labor market closure. The most common alternatives involve either assuming flexible wages and full employment on the one hand, or fixed real wages and unemployment on the other. In their review of alternative modeling approaches and the implications for the incidence of agricultural policy in India, de Janvry and Sadoulet (1987) explore the implications of these two extreme specifications, as well as an intermediate case in which wages are partially indexed to the cost of living. They find that the labor market closure plays a significant role in determining the incidence of techological change in agriculture on the rural population — particularly the landless poor.

Equilibrium Demand Elasticities

One very useful way of summarizing the combined effect of all of the assumptions about preference, technology, factor mobility and model closure is via a matrix of equilibrium demand elasticities. Each column in this matrix captures the change in demand for all products in the model, when the market price of one particular product, say corn, is raised by one percent and all other markets in the model are permitted to clear. Brandow (1961) was the first to use this technique for summarizing his multi-market, farm-to-retail model of US agriculture. Hertel, Ball, Huang and Tsigas (1989) updated Brandow's work in a general equilibrium setting. They find, for example, that feedgrains and foodgrains are GE, farm-level substitutes, while feedgrains and livestock products are complements.

Systematic Sensitivity Analysis

We cannot conclude this section on parameters in AGE models without a discussion of systematic sensitivity analysis. Anyone who has been involved in quantitative economic analysis is familiar with the concept of sensitivity analysis. It is also common in AGE modeling to vary key assumptions and parameters. However, given the large number of parameters involved in any economywide model, some sort of *systematic* sensitivity analysis (SSA) is advisable (Harrison *et al.*, 1987). Unfortunately, since most realistic AGE models require more than a few seconds to solve, standard Monte Carlo analysis (typically involving thousands of solutions) is generally infeasible. Pagan and Shannon (1987) proposed an approach based on a local, Taylor series approximation of the model results, expressed as a function of the model parameters. Harrison and Vinod (1992) have proposed an approach based on a numerical integration procedure, whereby they sample from a discrete approximation to the true distribution of parameters.

Recently a new approach to SSA has been proposed by DeVuyst and Preckel (1997). Like Harrison and Vinod, their approach is based on numerical integration techniques. They use multi-variate Gaussian Quadrature, which draws a sample and associated weights in order to satisfy a set of conditions equating the moments of the approximating distribution to the moments of the true parameter distribution up to some finite order of moments (usually 3 to 5). This has proven to be a very powerful tool. For example, in their SSA of the Whalley-Wigle carbon tax model, DeVuyst and Preckel find that a Gaussian Quadrature requiring only 12 model evaluations vastly dominates both the Pagan and Shannon approach using 25 evaluations and Harrison and Vinod approach using 64 model evaluations. Indeed, the *error* from the true mean of the carbon tax required (to obtain a prespecified reduction in omissions) is only one-tenth of that with Pagan and Shannon's method and one-hundredth of that with Harrison and Vinod's method. The good news for AGE modelers is that the Gaussian Quadrature approach to SSA has now been automated for the case of symmetric, independent distributions (Arndt, 1996; Arndt and Pearson, 1996).

Modeling Policies That Affect Agriculture

As noted in the introduction, one of the important areas for future work identified in Whalley's "Hidden Challenges" paper involves improved modeling of public policies. This is nowhere more important than in agriculture, where, for some commodities in certain countries, the value of policy transfers exceeds the gross domestic value of production (USDA, 1988). Such interventions are not only large, they are also diverse. For example, it is not uncommon for agricultural policies to send conflicting signals regarding resource allocation. Input subsidies frequently coexist with supply control measures. Furthermore, many agricultural policies are not easily amenable to "ad valorem equivalent" modeling (Gohin *et al.*, 1998; Kilkenny, 1991; Kilkenny and Robinson, 1988; McDonald, 1990; Veenendaal, 1998; Whalley and Wigle, 1990).

Modeling Voluntary Participation

One of the more vexing problems in agricultural policy modeling has involved the search for an appropriate framework with which to model voluntary farm programs. Voluntary participation has been a hallmark of the U.S. grains programs. Until recently, they required farmers to idle a certain proportion of their base acreage in order to qualify for a variety of program benefits including payments on output. The fact that participation rates varied from year to year, indicated that producers are an economically heterogeneous group (see discussion of this topic above). The most common approach to modeling these programs was to derive an average "incentive price" which, when combined with the supply shift due to idled acreage, would have induced the observed market supply of the crop in question (Gardner, 1989). However, such efforts ignored the impact that changing program parameters on important components of the problem such as variable costs per acre, optimal yields, and the nature of the supply shift. In reality, this is a complex, highly nonlinear problem.

Whalley and Wigle (1990) propose an alternate approach to modeling participation in the U.S. grains programs. They specify an explicit distribution of farms that reflects differences in their underlying cost structure such that the incentive to participate varies across five broad classes of farms. As program parameters or market conditions change, the participation rate varies endogenously. Hertel, Tsigas and Preckel (1990) extended this framework to incorporate a continuous distribution of land capacities, which in turn provide the motivations for differential participation. Shoemaker (1992) incorporates the voluntary participation decision in a dynamic model examines steady-state effects of the farm programs. All of this work highlights the differential incidence of farm programs on participants, nonparticipants, and those who are roughly indifferent to participation.

Interventions in the Processed Product Markets

A large void in many AGE models with an agricultural policy focus rests in their treatment of the food manufacturing and marketing sectors. In the U.S., only about one-third of every dollar spent on food goes to the farmer. Value-added in food manufacturing, and in wholesale/retail activities, are each roughly equal to that of agriculture. Furthermore, in many cases, support for farm commodities is provided indirectly, by purchase of (or protection for) processed products. For example, the primary mechanism for supporting U.S. fluid milk prices involves purchases of cheese, butter, and skim milk powder by the Commodity Credit Corporation (CCC). This type of indirect approach to supporting the farm sector can have important implications for policy analysis, and hence for the appropriate structure of AGE models. For example, CCC purchases of dairy products have generated considerably more processing capacity in the industry than would otherwise be required. Any lowering of support prices translates into redundant capacity. As a consequence, dairy processors have moved into the forefront of the dairy lobby. Similarly, as noted above, the U.S. sugar quota generated a new set of advocates in the corn milling industry. These processing sector impacts, in addition to the change in returns to dairy and sugar farms, must be captured by any model choosing to focus on such policies.

Agricultural Policies in a Changing World Economy

In many cases agricultural policies are tied to particular targets. For example, the policy makers may be required to defend a given level of domestic price, to maintain farm incomes, or to ensure a given level of self-sufficiency. Also, it is not uncommon for those seeking reform to legislate constraints on budgetary outlays. In the case of the Uruguay Round Agreement on Agriculture, export subsidies were constrained both in terms of volume (21% reduction in the volume of subsidized exports) and value (36% reduction). Such policy targets introduce the potential for endogenous changes in policy regimes once the constraint becomes binding. Of course whether, for example, the EU export subsidy commitments become binding will depend on conditions in the EU, as well as those in the world markets. Frandsen, Bach and Stephensen (1998) have explored this issue in the context of a global AGE model. Their analysis focuses on the eastward enlargement of the European Union to include a number of Central and Eastern European countries (CEECs). They consider projections from 1992 to 2005 with the Uruguay Round commitments, as well as the explicit specification of compensatory payments, set-aside requirements, base area restrictions and milk quotas. The authors conclude that the current specification of policies is likely to render EU enlargement infeasible. Some sort of reform of the Common Agricultural Policy will be necessary.

Political Economy of Policies: General Equilibrium Dimensions

The AGE framework can also provide valuable insights into the political economy of agricultural policies.[8] For example, there is a strong tendency for relative rates of protection to shift as countries grow wealthier. Poor countries tend to tax agriculture and subsidize industry. While wealthier countries tend to subsidize agriculture, relative to industry (Anderson and Hayami, 1986). Anderson (1995) has used a small AGE model to illustrate why this particular pattern of intervention is so compelling[9]. The model which he employs has three sectors: agriculture, industry and non-tradeables (services). Capital is sector-specific, and the welfare of farmers and industrialists is closely tied to the return to their respective capital stocks. Anderson then proceeds to analyze the relative impact of trade policies on farmer and industrialist returns in each of these two archetype economies. He concludes that farmers who successfully seek agricultural price supports in poor countries reap only one-sixth to one-ninth the percentage improvement in returns, as compared with their counterparts in the rich economy. This has to do with a variety of features of lower income economies, including: (a) the relatively large share of agriculture in GDP, (b) the large share of food in household consumption, and (c) the relatively lower dependence of farming on industrial inputs. By contrast, industrial protection in the lower income country yields ten times the benefits for manufacturing lobbyists, as compared to their counterparts in the industrialized economy. These findings lead Anderson to conclude that these *general equilibrium,* structural differences in rich and poor countries are a key force between observed differences in protection patterns.

AGE analysis also has an important role to play in the political economy of reforming agricultural and trade policies. The IMPACT project in Australia turned to AGE analysis in the early 1970's in an attempt to stem the tide of special interests in tariff deliberations (Powell and Snape, 1992). The goal of the AGE modeling work developed under this project was to explicitly identify the opportunity cost of pursuing protectionist policies. While any individual tariff hike might not cost the average consumer very much, when taken together the costs of protection were quite substantial. It is interesting to note that, in the wake of these studies, the position of Australian agriculture with respect to policy reform was eventually reversed. AGE analysis showed that the effects of trade

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[8]Some authors have used AGE models in conjunction with game theory to examine the endogenous formation of agricultural and trade policy (Rutstrom, 1995; Rutstrom and Redmond, 1997).

[9]de Janvry and Sadoulet (1992) also seek to explain the differences in observed policies affecting agriculture and the rural sector in India and Ecuador using an applied general equilibrium framework which captures linkages between rural and urban activity. They develop an index of political feasibility which permits them to take six different determinants of political power into account.

liberalization in Australia was to leave agriculture *better off* after removal of support - provided similar measures are taken in the industrial sectors (Higgs, 1989). The insight that relatively higher support for the Australian manufacturing sector amounted to an implicit tax on agriculture was an important revelation which could not have been communicated without AGE analysis. Similarly, in those economies where agriculture is relatively heavily protected, one of the best hopes for reform involves enlistment of export-oriented manufacturers who stand to benefit from a more competitive economy.

In sum, appropriate modeling of agricultural policies is an important, but difficult task. There is much to be gained by focusing on a particular policy and doing a good job of modeling it. However, in some circumstances it will be essential to incorporate a relatively complete set of economywide distortions in order to capture the consequences of potentially second-best interventions. This tradeoff between breadth of coverage and depth of analysis is evident in most areas of AGE analysis. There is no simple answer as to which approach is correct. Indeed, in many cases, both will be needed.

Agriculture and the Environment

Increasingly agricultural policy is being driven by environmental considerations (Gardner, 1993). Therefore, demand for analyses of the impact of agricultural and trade policies on the environment has been rapidly increasing (Bredahl *et al.*, 1996). Many environmental issues are very location-specific. This might lead one to conclude that there is little role for AGE analysis. However, Shively (1997) shows that GE interactions can also be important at the level of an individual watershed. He examines the case where deforestation and erosion from an upland region lowers productivity in lowland agriculture. In addition to being linked through erosion, the two regions are also linked through the labor market and diminished productivity in lowland agriculture puts downward pressure on wages, thereby reducing off-farm income opportunities for upland farmers. This leads to more deforestation and a downward spiral. Technological change aimed at increasing employment opportunities for upland farmers in the lowland region can have the opposite effect, by relieving pressure on the upland forest, thereby improving downstream productivity and wages.

In the context of national-level, environmental applications, it is most common for AGE modelers for focus on the economywide costs of restricting pollution. Rendleman (1993) analyzed the impact of chemical restrictions on US agriculture. Komen and Peerlings (1995) used an AGE model to calculate the costs of manure restrictions in the Netherlands as well as to assess the impact of environmentally motivated energy taxation on agriculture (Komen and Peerlings, 1998). However, ultimately the policy problem is one of weighing the costs of abatement against the benefits of a cleaner environment. Perroni and Wigle (1994) argue that, despite the conceptual and empirical pitfalls, it is essential to build the benefits of environmental clean-up into AGE models. They do so by specifying an initial endowment of environmental quality, some of which gets consumed by pollution activities. Firms can abate pollution by substituting commercial inputs (e.g., new machinery) for emissions. Households value the environment as a consumption good, and the marginal valuation rises with per capita income. They use this model to explore the interactions between trade policy and environmental policy.

Tsigas, Gray and Krissoff (1997) have built upon the approach proposed by Perroni and Wigle with an application which focuses on agriculture in the Western Hemisphere. In particular, they incorporate estimates of soil erosion, pesticide toxic releases, and nitrogen releases from agriculture, in addition to industrial pollution. Like Perroni and Wigle, they are forced to extrapolate from the US, where relatively good emissions data are available, to other regions in their analysis (Canada, Mexico, Brazil and Argentina). The authors use this AGE model to analyze the impact of Western Hemisphere free trade on environmental quality in the region. They find that environmental damages in Mexico, Brazil and Argentina are likely to increase under free trade, unless trade liberalization is combined with more stringent environmental policies. When the two are undertaken in concert, the welfare gain to these three countries is considerably enhanced.

However, agriculture not only generates pollution, it also provides environmental amenities (Legg and Portugal, 1997). There is increasing interest in linking farm payments to the level of such amenities provided. The OECD's Joint Working Party between the Committee for Agriculture and the Environment Policy Committee is currently developing a set of agri-environmental indicators to support policy analysis in this area (OECD, 1998). The initial set of indicators will cover the areas of farm management and financial resources, agricultural land conservation, soil and water quality, nutrient balance, pesticide use, greenhouse gases, biodiversity and wildlife habitat, landscape and the agricultural use of water resources.

Product Differentiation and Imperfect Competition

The theme of product differentiation has come to play an increasingly important role in analysis of agricultural trade policies (Carter, McCalla, and Sharples, 1990). A computational motivation for product differentiation is the specialization problem in small open economies facing exogenous world prices (de Melo and Robinson, 1989). By differentiating home and foreign goods, the elasticity of world price transmission into the domestic economy is dampened and drastic swings in the sectoral composition of output are avoided. This also opens the possibility of intra-industry trade, which is a commonly observed phenomenon. The oldest tradition in this area is the so called Armington approach in which products are *exogenously* differentiated by origin. This seems most appropriate in the case of those agricultural products for which agronomic and climatic considerations limit the scope for production of particular types of commodities [e.g., wheat (by class) or fruits and vegetables (by season)]. The market share rigidity provided by the Armington specification also serves as a proxy for non-price considerations which often play an important role in agricultural trade (Hjort, 1988). This specification may also be modified so that the law of one price applies in the long run (Gielen and van Leeuwen, 1998). However, in light of the increased importance of trade in processed food products, and the globalization of the food manufacturing industry, the Armington approach seems increasingly irrelevant for many sectors. Consumers pay less and less attention to the origin of the products which they consume.[10]

[10]Another criticism of the Armington approach has to do with functional form. Winters (1984) and Alston *et al.*, (1990) argue that the CES representation is too restrictive and that the non-homothetic, AIDS specification is preferable. Robinson *et al.*(1993) have used this functional form in their AGE analysis of the North American Free Trade Agreement (NAFTA). As with the specification of consumer and producer behavior, more flexibility is better than less, provided sound estimates and calibration procedures can be provided. The main problem with a non-homothetic specification for import aggregation is the absence of a well-defined price index for the resulting composite commodity, since unit expenditure now depends on the level of utility. This eliminates the scope multi-stage budgeting which is the

While consumers are growing less concerned with the country of origin, they appear to be growing more aware of brand names. The fact that firms have become important actors in the field of product differentiation fundamentally changes the appropriate modeling approach, since this differentiation is now *endogenous*. That is, firms invest fixed costs in research and development and marketing activities in order to establishing a market niche, which then permits them to markup price over marginal cost. This type of formulation was originally introduced by Dixit and Stiglitz (1979) in order to investigate the trade-off between fixed costs and the benefits which accrue to consumers as additional varieties are provided. It has since provided a foundation for much of the work on international trade under imperfect competition. This approach seems highly relevant for large parts of the farm and food complex. Food manufacturers are among the most important sources of advertising expenditures, accounting for 32% of all manufacturer outlays but only 12% of total sales (Connor, *et al.*, 1985).[11] In these circumstances, product differentiation is quite clearly endogenous, and supported by firms pricing above marginal cost. Lanclos and Hertel (1995) demonstrate that this alternative approach to product differentiation tends to magnify the impact of trade liberalization on the US food manufacturing industries. Philippidis and Hubbard (1998) find similar magnification effects in their analysis of the European Union's Common Agricultural Policy.

The number of AGE analyses of trade policy incorporating imperfect competition has mushroomed since the pathbreaking work on Harris (1984). Many alternative approaches have been identified and the key constraint seems to be availability of high quality data to support the calibration of markups, excess profits and scale economies. Francois and Roland-Holst (1997) offer a comprehensive survey of this topic. They distinguish between the cases in which products are homogeneous and the market power is derived from barriers to entry, and those in which products are differentiated in the manner discussed above. They also distinguish between the so-called "small group" and "large group" cases. In the former instance, markups are endogenous and vary with the nature of inter-firm rivalry, relative prices and the number of firms in the industry. This is often difficult to implement in AGE models, since industries tend to be highly aggregated. In the small group case, firms ignore potential interactions with other firms and markups are dictated by the degree of product differentiation.[12]

Model Validation

One question which consumers of AGE model results often ask is: "Has the model been validated?" This is a reasonable question to expect from an analyst seeking advice on a policy reform which may end up shifting hundreds of millions of dollars around the economy. How can we be assured that the model bear any relationship to reality? The typical answer is that the AGE model,

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foundation of most disaggregated AGE models of consumer and producer behavior.

[11]Peterson (1989) provides some of the first attempts to incorporate imperfect competition in food manufacturing into an AGE model.

[12]One important feature of the Francois and Roland-Holst chapter is their approach to handling endogenous product differentiation. By cleverly re-scaling output to obtain "variety-scaled output" they are able to introduce this additional complexity into a standard AGE model at relatively low cost. Anyone thinking about introducing imperfect competition into an existing AGE model should definitely take a look at this before proceeding.

like any simulation model, has not been econometrically estimated and therefore cannot be subjected to the usual forecasting tests. To the extent that (a) the individual components of the system are based on plausible, perhaps even econometrically estimated, relationships, (b) the underlying social accounting matrix is accurate and reflects the best economy-wide data available, and (c) the equilibrium assumptions and macro-closure are plausible, then the assertion is that the results will indeed shed relevant light on what might actually happen if the proposed reforms were implemented.

However, if AGE modelers are successful in obtaining a higher policy profile for their results, more will be demanded in the way of model validation. Several relatively ambitious validation efforts have been undertaken in recent years. Kehoe, Polo and Sanchez (1991) conducted an *ex post* analysis of the impact of tax reform in the Spanish economy. They conclude that, with some adjustments, their AGE model is able to predict the broad pattern of resource reallocations precipitated by the change in tax policy. Fox (1998) has conducted a similar, *ex post* analysis of the predictions made by Brown and Stern (1989) using the Michigan model to evaluate the U.S.- Canada Free Trade Agreement. He finds that the model performs better for Canada than for the U.S. This is likely due to the fact that this agreement was of much greater significance to the Canadian economy. In contrast, its role in redirecting the sectoral allocation of resources in the U.S. was much more modest, and therefore difficult to detect.

Gehlhar (1997) attempted a somewhat different validation exercise, whereby endowments and productivity are shocked instead of policies. In this “backcasting” exercise with the multiregion GTAP model in which he attempts to predict 1982 East Asian export shares based on a model calibrated to 1992 data. Unlike the usual econometric models which have hundreds of exogenous variables, he uses only exogenous shocks to primary factor endowments and technology. Once he incorporates a proxy for human capital, he finds that the model performs reasonably well as regards prediction of changes in export shares. Coyle *et al.* (1998) attempt something similar, but more narrowly focused than Gehlhar. They seek to explain the dramatic change in composition of world food trade which occurred between 1980 and 1995. They employ a modified version of the GTAP model incorporating an econometrically estimated demand system. Coyle *et al.* (1998) are able to explain about half of the observed shift from bulk to non-bulk food trade over this period.

Realistically, any such “validation” effort will inevitably involve a certain amount of tinkering with the model in order to improve its performance. In this sense, such exercises are really a more elaborate method of calibration (but something short of formal econometrics) in which the model is fitted to multiple data points.[13] In this sense they do not constitute proof that the model will perform well in future simulations. However, such efforts to compare model performance to economic history will go a long way to addressing the criticism that AGE models bear little or no relationship to reality. As such, this type of work should be a high priority for future research.

Conclusions

As noted in Section II, this paper may be viewed as a survey of agriculturally-related attempts to meet some of the "hidden challenges" outlined by John Whalley in the mid-1980's. I am happy to

[13]Arndt and Robinson (1998) have recently used a 5 year time series of data on the Mocambique economy to formally adjust their AGE model parameters based on the maximum entropy approach.

report that considerable progress has been made. Many of the AGE-based studies reported in this survey represent excellent applied economic research with important policy insights and implications. In fact, there is a clear parallel with developments in other areas of applied economic research. Most of the hidden challenges which Whalley identifies — appropriate disaggregation, parameter specification, modeling of strategic behavior and treatment of policies — are universal challenges facing applied economists. Of course, GE modelers face some special challenges. In particular, the constraints imposed by the requirement for an economy-wide, micro-consistent data set have precluded systemwide econometric estimation. Nor do AGE modelers have the luxury of specifying reduced form elasticities. Agricultural supply response must be the outcome of producers' constrained optimization decisions subject an explicitly specified technology, and conditioned by clear assumptions about factor mobility. Nevertheless, there are fewer differences between AGE analysis and other areas of applied economics than many would suggest.

Indeed, I believe that one of the main avenues for improvement in AGE analyses of agricultural policies over the coming decade will be through increased collaboration with economists working on partial equilibrium studies. As highlighted in Section II of this chapter, the AGE approach has many important benefits in the context of policy analysis. However, in order to be fully effective, those working in this field must learn from economists with detailed knowledge of the sector, industry, households, or policies being analyzed. In order for this collaboration to blossom, AGE modelers will have to extend themselves in a number of ways.

The first area in which improvements need to be made involves the communication of key assumptions and parameters in a form which others can interpret and evaluate. Very few AGE analyses of agricultural policy report their assumed supply and demand elasticities for key products. Yet we all know that these are key parameters in determining the economic incidence of any price intervention. Why this paucity of information? The main problem is that AGE models are not typically specified in terms of supply and demand elasticities. Rather they involve the specification of explicit production and utility functions. Deriving the supply and demand elasticities involves some further computations. In addition, there is no longer one simple "supply elasticity". What is to be assumed about factor market adjustment? Are non-agricultural prices and incomes assumed constant? Similar problems exist with the specification of demand elasticities. However, this multiplicity of options is also a strength.

The researcher can report elasticities under a range of assumptions, showing how they are altered as one moves from partial to general equilibrium.[14] In so doing, they will assist the partial equilibrium analyst who is trying to grasp the differences between the two approaches.

A second step which will help to facilitate communication between AGE modelers and other economists involves a more widespread use of systematic sensitivity analysis (SSA). Economists accustomed to dealing with models with only a few behavioral parameters are often quite skeptical of models in which there are dozens of elasticities of substitution. Given the difficulty we have of obtaining robust estimates of such parameters, how can we have any confidence whatsoever in the results from such a model? This is a legitimate question, and it can only be addressed by the use of

[14]11For a discussion of partial and general equilibrium elasticities of demand in a multiregion AGE model, see Hertel, Lanclos, Pearson and Swaminathan (1997).

parametric SSA. In the past, authors of prospective journal articles could plead that their model was so big that it would take several months of computing to implement a complete Monte Carlo analysis. However, as pointed out in Section IV above, recent developments in this field have rendered SSA eminently practicable. In some cases, researchers have been pleasantly surprised with the robustness of AGE results to parametric uncertainty. This is because the data base and equilibrium assumptions also play key roles in determining the range of possible outcomes. Furthermore, as more of the AGE-based work draws on high quality, published data bases, the data dependence of these studies will be viewed as a strength of the approach.

Once non-AGE economists have been convinced that the findings are based on reasonable assumptions and that they are robust, they will want to know more about what is driving the results. This is where experienced AGE modelers and novices have parted company in the past. While some results are easy to explain (e.g., why output falls in a sector when a subsidy is removed), the welfare impact of a marginal change in policies in the context of a heavily distorted economy can be very difficult to interpret. AGE modelers interested in policy analysis need to invest much more time and energy in techniques of analysis which permit them to understand, and explain to others, the basic mechanisms driving their results. One illustration of this is the welfare decomposition technique derived by Keller.[15] He fully decomposes the change in economywide welfare into the efficiency consequences for each market captured by the model. Thus one can make statements such as: "25% of the welfare gain was due to improved allocation of labor in the economy". Or: "the welfare loss came about because the partial tax reform lured resources into the relatively protected agricultural sector." Without recourse to such explanations, backed up by detailed tables of data and results, the consumer of AGE model results is left with a black-box which they must either accept or reject as a matter of faith.

In my experience, once an AGE modeler has convinced the audience that the analysis is not only robust, but also sheds light on an important issue, s/he will very likely face requests by others to replicate the study. Replication is standard practice in other sciences, but it has been slow to penetrate the economics profession (Dewald, Thursby and Anderson, 1986). However, given the availability of a number of relatively easy to use software packages for AGE modeling (Harrison and Pearson, 1996; Rutherford, 1997), it is now within reach for most studies. In fact, I would like to see journal editors require that all AGE-based articles be submitted along with those files needed for replication. Ideally, reviewers would also have the opportunity to vary key assumptions such as model closure and parameter settings. This would greatly enhance the credibility of work in the area. It would also aid those seeking to build on previously published work, thereby facilitating more rapid scientific progress.

One reason why AGE modelers have been reluctant to make their models easier to use is the fear that they will be mis-used. This fear is well-founded. There is no doubt that as construction and implementation of an AGE model becomes routine and accessible to those outside the close-knit fraternity of modelers, foolish applications will abound. However, this is no different from any other branch of quantitative economics. The only distinguishing feature of AGE analysis is that, due to the

[15]Keller's technique provides a local approximation to this decomposition. for a small, open economy. Huff and Hertel (1996) have adapted Keller's approach to the case of large changes, and apply this in the context of the multiregion GTAP model.

size of many of these models, one can generate foolish numbers at an extremely rapid rate! Ultimately it will be up to the process of professional peer review to sort the wheat from the chaff. It will no longer be the case that when one gets an AGE application to review, you can assume that the individual writing the paper has assembled the data and built the model themselves. This is a drawback. They may be ill-informed, simply offering a mechanistic set of model runs. However, an experienced reviewer can quickly identify such a paper. Furthermore, since model construction is no longer such an onerous task, one can now reasonably expect much more from the author in the way of analysis and exposition of results.

Indeed, I believe that successful AGE applications related to agricultural and resource policies in the future will increasingly exhibit six key features:

(1) Relevant institutional and behavioral aspects of the sector in question are taken into account.
(2) Key policies are modeled explicitly. Voluntary program participation, quantitative restrictions, price ceilings and floors, as well as state trading, are all common types of farm sector interventions which lend themselves to explicit treatment in an AGE framework.
(3) Key behavioral parameters are reported and related to econometric work in the literature.
(4) Results are reported in terms of means and standard deviations generated by SSA procedures which take parametric uncertainty into account.
(5) Central findings are exhaustively decomposed and explained.
(6) Finally, results can be easily replicated, and key assumptions altered, by the reviewer.

Regardless of how forthcoming the partial, and general equilibrium analysts are in their dialogue, one cannot avoid the fact that there is an inevitable tension between the mandate for AGE studies to be comprehensive and the need to delve into the specifics of the industries / households directly affected by specific policies. By definition, compromises are required, and the most distinguishing feature of high quality AGE policy applications is that they make the *right* compromises. In particular, they preserve key features of the sector in question. For this, a dialogue with industry experts is essential. Such dialogue is often cumbersome and, at times tedious. However, it is the only way applied general equilibrium studies can avoid falling prey to Robert Solow's (1973) criticism of Jay Forrester's early work on global modeling. In this debate, Forrester asserted that rather than "go to the bottom of a particular problem ... what we want to look at are the problems caused by the 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 that he lost money on every item sold, but made it up on the volume.

In summary, after several decades of rapid development and application to many different areas of economic analysis, AGE models are maturing. They must be subjected to the same scrutiny and skepticism, and validation efforts as other models. Ultimately their usefulness in delivering policy insights and guidance will determine whether or not this field of endeavor has been a success.

Some striking examples of AGE-based impact in the policy sphere exist.[16] However, the ratio of policy-oriented, AGE applications to effective policy input is still quite low. If this situation is to be rectified, it is essential that the use of AGE analysis extend beyond the narrow modeling community to a broader group of policy economists. It is my hope that this survey will encourage such cross-fertilization.

[16] See Powell and Snape (1993) on the Australian experience. Francois and Shiells (1994) describe the importance of AGE analysis in the NAFTA debate.

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