Articles and Notes

Discovering Production and Supply Relationships: Present Status and Future Opportunities

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In this paper the current state of supply modelling in agriculture is reviewed. It is argued that (1) the stock of knowledge of elasticities is depreciating, (2) historical estimates are misleading because many phenomena are confounded in few parameters, (3) available data are not being efficiently exploited, and (4) a proliferation of hypotheses is leading to an inability to discriminate in an appropriately comprehensive context. The latter problem is leading to an inability to do forward-looking analyses. Several suggestions are made for dealing with these problems that involve some relaxation of the standard of objectivity which in reality is unattainable in many kinds of practical applied work.

1. Introduction

Understanding the behavior of individual agricultural decision makers is perhaps the most basic endeavor of the agricultural economics profession. Understanding agricultural prices and markets, agricultural finance and credit institutions, the effects of alternative agricultural and environmental policies, and the effects and benefits of new technology all depend fundamentally on understanding the behavior of farmers. Many new developments have occurred in microeconomic theory and empirical measurement over the past decade or two. These include applications of flexible functional forms and theoretically-consistent systems of behavioral equations derived from duality, the economics of information (asymmetric information and principal-agent theory), capital asset pricing models and generalized risk analysis, unstructured non-parametric methods of data analysis, and a host of other techniques and concepts. These developments have broadened and generalized the set of explanations that can be provided for observed behavior of agricultural firms. However, it is not clear that these basic developments have led to anticipated enhancements of knowledge in the problem areas of agricultural economics — that is, in prescribing production behavior, forecasting prices, evaluating marketing alternatives, analyzing the impacts of alternative policies, considering the implications of alternative financial institutions, etc. For example, the quality of estimates of supply and demand elasticities is arguably no better than two decades ago. A recent survey of agricultural supply shows that estimates of elasticities vary by more that an order of magnitude for most crops depending on specification — in many cases even for the same investigator of the same data with the same methodology (Just 1991). Anyone who has worked in applied econometrics knows that sometimes a small change in specification can drastically change the results. This is not surprising to practitioners but is disturbing to businessmen and public decision makers who need to rely on these estimates and analyses that use them.

Has the agricultural economics profession moved increasingly toward a passive role of understanding past behavior and away from an active role of prescribing and predicting future behavior? Over the first quarter century or so of its existence, the bread and butter of the profession was earned by prescribing behavior for farmers to increase profits. Over the second quarter century or so, the major contribution was predicting farmers behavior for market analyses supporting private decisions and for policy analyses supporting government decisions. More recently, the sophistication of explanations for observed behavior has increased and the attention of the journals has tended toward presenting alternative theoretical and conceptual conjectures explaining observed (past) events. As the complexity and flexibility of the microeconomic paradigm has expanded, it has become increasingly possible to find multiple alternative explanations for observed behavior. Conversely, as the main-

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tained hypothesis representing the microeconomic paradigm has been generalized, the set of possibilities has become so large that identification and prediction is becoming difficult or impossible except under seemingly narrow assumptions.

Unfortunately, empirical work in the context of more general models has, for the most part, been unable to support either the more specific models used historically or any equally specific alternatives. For example, the flexibility of dual models has made possible testing for the nonjointness and separability imposed traditionally and conclusions almost always favor more general specifications. To be sure, the new generation of sophistication has broadened the thinking of agricultural economists and has thus served a useful educational purpose for the profession. Also, many of the arguments put forward have been convincing and suggest at least an occasional degree of validity for the alternative concepts and mechanisms. But does the development of a plethora of models and explanations in the context of limited data imply that the profession is increasingly doomed to study the past passively rather than actively prescribe and predict the future based on empirical work that identifies how the various mechanisms and explanations will come into play under alternative policies, technologies, and institutional arrangements? Or alternatively, has testing these hypotheses under inappropriate maintained hypotheses incorrectly rejected more simplistic models?

In this paper some of these recent developments and the extent to which they contribute to understanding the behavior of individual agricultural decision makers are considered. The focus is on agricultural producers because the state of empirical modelling is relatively poorer than for consumers (Tomek and Robinson 1977) and because many of the principles carry over to analyzing the behavior of other agents. A review of supply response analysis has been presented previously by Coleman (1983) and Just (1991). Compared to those papers, this paper is presented not as a review of supply analysis *per se*, but as a proposal for addressing current empirical problems and needs of the profession. Supply analysis is used for examples. The paper begins with a short characterization of leading empirical approaches to supply and production analysis. It is argued that the curse of dimensionality still reigns and that the profession has been neglectful of true and complete micro-level empirical analysis in favor of flexible aggregate analysis that sweeps under the rug many of the problems from which better empirical knowledge can be gained. As a result, the profession is not producing models that facilitate active forward-looking analyses that support prediction, prescription, and comparison of alternative future policies, institutions, and practices[1].

2. The Basic Firm Model Underlying Agricultural Supply

As a backdrop for the discussion, consider a generic representation of the agricultural producer's decision problem. Suppose agricultural production problems are characterized by (i) production relationships, (ii) constraints due to resource availability, short-run asset fixity, and government restrictions, (iii) accounting relationships which describe constraints between market transactions and the variable input allocations among production activities, (iv) the behavioral criteria of the producer, and (v) characteristics of the producer including beliefs, opinions, education, experience, and information held by the producer. In a dynamic context, these relationships must be augmented by (vi) equations of motion that determine the dynamic adjustment of fixed asset/resource/government constraints, and (vii) equations reflecting intertemporal variations in behavioral criteria and producer characteristics including information.

Let the production function be represented by

$$(1)\ q = f(X,Y,z),$$

where q is a m-vector of outputs, X is a m x n matrix of allocations of n variable inputs to m production

[1] Without doubt, policy advice should be derived from first principles rather than blindly based on quantitative models. However, empirical work is sometimes needed to determine which principles are applicable. Sometimes, first principles alone are not sufficient and some quantification of first principles is necessary to offer advice. In general, quantitative models are useful in putting likely outcomes of future courses of action in perspective. If models are not adequately forward-looking or cannot discriminate among alternative sets of principles, then these opportunities are lost.

activities, Y is a m x k matrix of allocations of k fixed inputs to m production activities, and z is a h-vector of non-allocatable fixed factors and producer characteristics. The production function may also depend on stochastic components about which information is imperfect but these arguments are suppressed for simplicity[2]. Let the short-run constraints of resource availability, asset fixity, production credit availability, and government restrictions be represented by

(2) Ye = y

where y is a k-vector of farm-level allocatable resources and fixed inputs and e is a m-vector of ones. For example, for an allocatable fixed input such as land or an allocatable resource such as family labor, the sum allocated to all production activities cannot exceed the total available (the potential inequality in this constraint will be ignored for simplicity). Similarly, the accounting relationships for variable inputs are represented by

(3) Xe = x

where x is a n-vector of farm-level purchased-input quantities. This relationship reflects the constraint whereby farm-level purchases of variable inputs must equal the sum allocated to all production activities.

The behavioral criteria are described by U(p,q,w,x,X,y,Y,z) where p is a vector of output prices associated with q and w is a vector of variable input prices associated with y. Decision makers have imperfect information on prices but, as is customary, competitive (price-taking) behavior is assumed. Where prices or production are stochastic or subject to imperfect information, U is taken to depend on the subjective distribution of information held by the producer, e.g., as with expected utility[3]. In principle, the behavioral criteria imply input decision and allocation equations

(4) Y* = Y*(p,w,y,z)

(5) X = X(p,w,y,z)

where Y* is a (m-1) x k matrix consisting of the first m-1 columns of Y [the last column of Y is then determined by (2)]. For simplicity, Y = Y(p,w,y,z) will be used to represent determination of Y according to (4) and (2). Substituting (2), (4), and (5) into (1) obtains the supply equations,

(6) q = q(p,w,y,z),

and substituting (5) into (3) obtains the variable input demand equations,

(7) x = x(p,w,y,z).

The model in (1)-(5) is the basic microeconomic model underlying agricultural production analysis, supply and demand estimation, agricultural policy and trade analysis, and a host of related endeavors. A synthesis of traditional approaches can be provided in the context of this model and some of the successes and failures of these approaches can be evaluated accordingly. This synthesis reveals how standard practices have made less than optimal use of available data. A methodological critique of these approaches then leads to some suggestions for coping with the problems of microeconomic empirical measurement. Four broad traditional empirical approaches are considered: (i) myopic econometric modelling, (ii) the programming approach, (iii) structured direct econometric modelling, and (iv) structured indirect econometric modelling (duality). These four approaches are not intended to be exhaustive but are sufficiently representative to facilitate the major points of this paper.

3. Traditional Empirical Approaches

3.1 Myopic Econometric Analysis

Traditionally, the agricultural production problem has been dissected and analyzed in small pieces. For example, prior to the development of dual techniques, most econometric production studies attempted to estimate single-equation production functions corresponding to a scalar component of

[2] Also for simplicity of notation, the number of production activities is the same as the number of outputs.

[3] For example, dependence on prices and, implicitly, on production disturbances implies dependence on the decision maker's joint subjective distribution of the two.

(1) often characterized by Cobb-Douglas technology (Heady and Dillon 1961). Most market analyses attempted to estimate single-equation supply functions corresponding to a scalar component of (6) characterized by the Nerlovian supply model. For example, by far the most common approach to supply analysis historically was to estimate a single-equation specification corresponding to (1) where quantity supplied is explained by own price and some subset of competing prices, input prices, and asset fixities represented by lagged quantities (for a survey, see Askari and Cummings 1976; or Henneberry and Tweeten 1991). Coleman (1983) calls these models directly estimated partial commodity supply models and claims that the majority of agricultural supply response studies fall in to this class. The overwhelming popularity of these methods stems from convenience. For example, a simple linear regression of (logged) output quantity on price and lagged output (logged inputs) produces estimates of the useful concepts of both short- and long-run supply elasticities (production elasticities).

Some of the major problems with a myopic single-equation or partial approach are as follows. First, because these models are usually estimated with an incomplete view of the decision model, little interaction with other phenomena in the overall model is considered. For example, single-equation supply models usually omit the prices of most competing outputs and the prices of many inputs. Second, by estimating the equations individually, theoretical inconsistencies result in the estimated relationships. As a result, profit and welfare calculations can become ambiguous (Just, Hueth and Schmitz 1982). Third, by ignoring theoretical relationships among equations, opportunities for econometric identification and efficiency are lost. For example, single-equation production function estimation ignores the information that price data and behavioral equations can contribute to identification of production parameters. Fourth, the simplicity of *ad hoc* specifications of these models is probably a gross simplification of reality. Fifth, and a likely result of the fourth, the estimated parameters from these simple models seem to be unstable over time so that forward-looking prediction and policy analyses are not well supported.

An additional difficulty with the single-equation approach is the inability to represent multiple-output technologies. Originally, attempts to capture the production possibilities of multiple-output technologies considered single-equation specifications following Klein (1947). Such relationships, however, may not simply carry technological information but may confound behavioral and technological relationships. Consider solving (6) and (7) in principle for the inverse (price-dependent) demands and supplies obtaining

(8) $p = p(q,x,y,z)$, $w = w(q,x,y,z)$.

Because one of the prices can be taken as a numeraire under homogeneity, one of these equations is solely a relationship between inputs and outputs, say,

(9) $g^*(q,x,y,z) = 0$.

Clearly, this input-output relationship is not simply a technological relationship but is a reduced-form equation summarizing the interaction of behavioral and technical information in the larger underlying system. As they are normally applied, such relationships are estimated assuming separability with respect to inputs and outputs, $g^*(q,x,y,z) = g^*_1(q) - g^*_2(x,y,z) = 0$. In the constant elasticity case used by Klein, for example, this has the absurd implication that an increased fertilizer application to wheat (X_{ij}) can go entirely to increase maize production ($q_{i'}$) with no change in wheat production (q_i). In the underlying structure which leads to (9), however, these possibilities do not exist. The production system in (1)-(5) thus imposes restrictions on the functional form of (9) that are not embodied in flexible functional forms as they are ordinarily applied. These considerations underscore the importance of representing technology properly by a sufficient number of estimable equations to reflect the true inflexibility of the decision maker's input-output choice set.

3.2 The Programming Approach

The programming approach has been used to analyze agricultural production, policy, finance, and supply by creating a complete model representing the relationships in (1)-(5). For example, the case of expected profit maximization is represented by

$$\text{(10)}\quad \max U(p,q,w,x,X,y,Y,z) = E(p'q) - E(w')x$$
$$\text{s.t.}\quad q = f(X,Y,z)$$
$$Xe = x$$
$$Ye = y.$$

This model is used to describe behavior by a region or representative farm subject to prices and resource availability (Heady and Candler 1958; see Coleman 1983 for other references). Equations (1)-(3) are represented explicitly and equations (4) and (5) are represented implicitly by the behavioral criterion. If prices and production are nonstochastic and the production technology follows fixed proportions for individual outputs, i.e., $q_i = f_i(X._i,Y._i,z) = \min\{\min_j X_{ji}/a_{ji}, \min_j Y_{ji}/a^*_{ji}\}$, then the problem becomes a typical agricultural linear programming problem where the technology matrix [aside from the aggregation constraints in (2) and (3)] is $A = \{\{a_{ji}\};\{a^*_{ji}\}\}$.

In the methodological spectrum of this paper, programming models are at the opposite extreme from myopic single-equation models. Myopic single-equation models estimate the smallest components of the overall model, require many observations on a minimal set of variables, and impose minimal structure on the data. Programming models represent the overall model completely, implicitly require one observation on all the variables (to calculate the a_{ji} and a^*_{ji}), and impose a highly specific structure on the data requiring both input and output nonjoint Leontief technology. Basically, the need for information on the production functions in (1) is filled by making simplistic fixed proportions technology assumptions so that one observation from a "representative" farm is sufficient for estimation.

The strengths of the programming approach are that (i) cross effects of all input prices and other output prices are inherent in the model and can be easily derived, and (ii), as programming models have usually been applied, they do not require long data series as do econometric approaches. On the other hand, because coefficients in the model are often estimated on the basis of only one or a few data points if objective data are used at all, the statistical precision is suspect. Furthermore, evaluating statistical precision of programming solutions corresponding to equations (6) and (7) is impractical. Thus, the precision of results may be poor with little warning. Also, programming models are typically adapted to available data or beliefs by calibration constraints. Calibration constraints substitute for true understanding and cause underestimation of producer response. In practice, these constraints are necessitated by a restrictive representation of technology; inadequate representation of short-run versus long-run adjustment, price expectations, and aggregation problems; and inapplicability of representative farms. See Coleman (1983) for further discussion.

3.3 Structured Direct Econometric Modelling

Originally, a major purpose envisioned for both programming models and single-equation production function estimation was to make profit-maximizing recommendations for production plans and input use to farmers (e.g., Swanson *et al.* 1973). While some of the early work on production function estimation relied on carefully generated experimental data (e.g., Heady *et al.* 1964), most production function estimation has relied on market generated data at either the micro or aggregate levels. The difficulty with market-generated data is that the behavioral equations (e.g., first-order conditions) tend to result in highly correlated input variables and do not reflect response over a very wide range of input use. For example, most input levels tend to increase as output price increases. The associated multicollinearity makes identification and precise estimation of production functions from market data difficult.

An early step toward better use of available data was developed by Marshak and Andrews (1944) who combined first-order conditions implicit in (4) and (5) with the production function in (1) for the single-output case. Where the data are generated by market conditions under profit maximization, this enables identification and efficient estimation even with perfectly collinear input data. For example, in the Cobb-Douglas special case, one estimable equation is available to identify each input elasticity.

An insightful yet simple system approach to deal with multiple outputs was developed by Powell and Gruen (1968). Although their system is only applied as a linear approximation, assuming constant elasticities of transformation results in identifying restrictions across supply functions that permits better identification and more efficient estimation.

More generally, structured econometric modelling attempts to estimate all of the observable relationships simultaneously in a consistent framework so more information is available for parameter estimation and identification. This can be accomplished by adopting a specification for the production functions in (1) and the behavioral criteria and then deriving equations (4) and (5) possibly in implicit form. For example, in the case of (10), equations (4) and (5) are equivalent to the mn + (m-1)k first order conditions which determine all of the X_{ji} and Y_{ji} subject to the fixed input constraints in (2),

$$\begin{aligned} &\Sigma_i \partial E(p_i f_i)/\partial X_{ji'} - E(w_j) = 0, \\ &i'=1,\ldots,m; j=1,\ldots,n; \\ (11)\quad &\Sigma_i \partial E(p_i f_i)/\partial Y_{j1} - \Sigma_i \partial E(p_i f_i)/\partial Y_{ji'} = 0 \\ &i' =2,\ldots,m; j=1,\ldots,k. \end{aligned}$$

In the case of input nonjointness, the production relationships in (1) become $q_i = f_i(X_{\cdot i}, Y_{\cdot i}, z)$ where $X_{\cdot i}$ and $Y_{\cdot i}$ are the *ith* columns of X and Y, respectively. Thus, with known prices, the conditions in (11) become the more familiar

$$\begin{aligned} &p_i \partial E(f_i)/\partial X_{ji} - w_j = 0, \\ &i =1,\ldots,m; j=1,\ldots,n; \\ (12)\quad &p_1 \partial E(f_1)/\partial Y_{j1} - p_i \partial E(f_i)/\partial Y_{ji} =0, \\ &i=2,\ldots,m; j=1,\ldots,k. \end{aligned}$$

Under expected utility maximization or other less common behavioral criteria, (4) and (5) are comprised of the same number of nonredundant equations as long as all of the input decisions and allocations are uniquely determined by the behavioral criteria.

This approach has been developed for the case of multiple outputs and constraints across production activities by Just, Zilberman and Hochman (1983). The strengths of this approach are that it takes account of the theoretical relationships that exist among equations and parameters, produces estimates of all cross-elasticities, allows an assessment of statistical precision, and attains econometric efficiency. Three important problems with the approach are as follows. First, data for all necessary endogenous variables are often not available. This problem can be addressed by solving unobserved variables out of the model and estimating remaining equations. A second problem is that only simple specifications of production functions and behavioral criteria are tractable because of the need to solve and estimate a system of first-order conditions. A third and related problem is that errors in specification of any component of the model can adversely affect estimates for other components of the model because of cross-equation parameter constraints necessary for theoretical consistency.

3.4 Structured Indirect Econometric Modelling — Duality[4]

One of the few approaches that has gained increasing interest over the past fifteen years is based on duality. Following Shephard (1953), McFadden (1978) recognized econometric simplifications made possible by a duality between production and profit or cost functions. In the context of historical methodologies (myopic and programming), the dual approach is clearly a major advance in consistent interpretation of agricultural data and more efficient estimation of agricultural supply because it facilitates consistent specifications for supplies and demands. For example, a consistent system of input equations such as (7) can be derived from an underlying cost function specification (e.g., Binswanger 1974) and a consistent system of input demands and output supplies such as (6) and (7) can be derived from an underlying profit function specification (e.g., Antle 1984). Furthermore, specifications for supplies and demands are derived by simple differentiation of a specification of the cost

[4] The indirect econometric approach discussed here is not to be confused with the "two-stage" procedures which Coleman differentiates from "direct estimation" procedures. Coleman uses the term "two-stage" to refer to cases where functions other than supply are estimated and then supply is inferred indirectly from estimated production, profit, or cost functions. The poor performance of these approaches is well documented and not discussed here. See Coleman (1983). The term "indirect" is used here to refer to cases where estimable specifications are derived by means of duality.

(profit) function. Thus, more flexible representations of the production technology are tractable than with direct methods that derive profit-maximizing supplies and demands as a nonlinear solution of a system of first-order conditions associated with a production function specification. Because of the greater flexibility that is possible with the dual approach, testing a host of general hypotheses about technology also becomes feasible.

The dual approach, however, also has its problems. First, as the approach has often been applied (e.g., Weaver 1983; Shumway 1983; Antle 1984), it has either not differentiated short- and long-run behavior or not estimated long-run behavior. Originally, cost and profit functions considered all factors variable. Associated empirical estimates imply that long-run response is obtained in the short run because the long-run is not differentiated from the short-run (e.g., Weaver 1983). With more general restricted cost and profit functions, some inputs are held fixed. Estimates in this case reflect short-run elasticities (e.g., Shumway 1983) but additional relationships determining fixed factor adjustments are needed to obtain longer-term elasticities. Some work along this line has been done by Vasavada and Chambers (1986) but consistent representations of multiple decision horizons with appropriate expectations are yet to be applied.

A second problem is that, while duality allows flexibility in the technology representation, it restricts the behavioral criteria to profit maximization. Profit maximization is popular but risk aversion has been verified empirically for agriculture (Just 1974; Pope and Just 1991) and this invalidates the profit function approach (Pope 1982). A third problem is that aggregation can invalidate the relationships imposed by duality. The dual framework applies for a single, profit-maximizing firm but the technology, land quality, prices, and thus the set of production activities can differ among firms. Aggregation over the associated corner solutions can cause the systematic relationships imposed across estimated supplies and demands to fail. A fourth problem is that some of the most important inputs in agriculture such as land are fixed inputs but easily allocatable across production activities (Shumway *et al.* 1984).

A means of dealing with the latter problem in the dual profit function approach has been developed only recently (Chambers and Just 1989).[5] By defining individual profit functions for each production activity, $\pi_i = \pi_i(p,w,Y,z)$, consistent specifications for all estimated relationships can be derived so that (1), (4), and (5) are represented equivalently as

$$q = \Sigma_i \, \partial\pi_i(p,w,Y,z)/\partial p,$$

$$(13) \quad X_{\cdot i} = \partial\pi_i(p,w,Y,z)/\partial w,$$

$$\partial\pi_i(p,w,Y,z)/\partial Y_{ji} = \partial\pi_1(p,w,Y,z)/\partial Y_{j1} \quad j=1,\ldots,k;\ i=2,\ldots,m,$$

respectively. In the case of input nonjointness, this system simplifies substantially (the number of estimated parameters is reduced by almost a factor of m) because profit functions for individual production activities can be represented as $\pi_i = \pi_i(p_i,w,Y_{\cdot i},z)$. In either case, this system has the typical advantage of duality allowing more functional flexibility than is tractable with the primal approach. However, with a multiplicity of profit functions that all have flexible form, this approach can result in very large numbers of parameters even for modest problems (see the application by Chambers and Just 1989).

4. Problems with Traditional Approaches and Promising New Directions

While the above discussion indicates briefly the problems that tend to differentiate the methods, many problems are common to several or all of the approaches in varying degrees. A more detailed consideration of these problems is useful for motivating suggestions for future improvements and choosing among the alternative empirical approaches. In the remainder of this paper some of the most important problems encountered with microeconomic empirical approaches in agriculture and possible suggestions for dealing with them

[5] Leathers (1991) suggests a similar generalization of the cost function approach but does not provide an empirical framework or application.

are considered. Some promising directions are suggested by the improvements that have been made previously. These suggestions involve drawing together more sources of information to gain better understanding by consistent, conceptually plausible, and simultaneous interpretation of available data.

4.1 Variable Specification and Missing Data

One of the major problems with microeconomic empirical work is specification of the variables to be included. Which input variables or prices are to be considered? How are inputs to be categorized? What is the set of related outputs? Which variables are needed to reflect producer characteristics, government program controls, technology, and the environment? How is each variable to be measured? Is the supply variable appropriately measured by quantity produced or quantity marketed? Is it measured by weight or volume? Some studies measure supply by acreage planted or acreage harvested. In some cases, price variables are deflated by a consumer price index, an index of input prices, or an index of prices of other outputs.

Part of the problem, particularly with myopic *ad hoc* or partial reduced-form models, is that the appropriate set of variables may be changing over time. For example, new government controls may be instituted or new inputs may come into play as new technologies are adopted. Moreover, most studies consider only a small set of outputs and inputs empirically even though more are involved in reality. In this context, the appropriate measure of some variables may be changing over time because of a changing importance of omitted variables.

Another part of this problem arises because of missing data. When data are simply unavailable for some prices, inputs, or competing outputs, a common practice is simply to ignore them. However, the role of missing variables can change the appropriate specification and interpretation of results. For example, if an allocatable fixed input is ignored, the production technology can falsely appear to be joint (Shumway *et al.* 1984). While efforts are needed to improve data availability, efforts are also needed to understand the implications of missing data for specification, estimation, and simulation of microeconomic models.

Several general principles can help to address these problems. First, consideration of the complete structure of the underlying problem regardless of data availability helps to reveal which variables are involved and which components have less noise. Second, such a structure can help to determine the implications of missing data and the properties that are appropriate to impose on relationships among observable variables. For example, unobservable endogenous variables can be solved out of the complete model structure. Third, to maximize efficiency in estimation, the estimated system of equations must be determined as a maximal number of nonredundant observable relationships associated with the underlying model.

4.2 Econometric Model Structure and Estimation Efficiency

A general principle developed from econometric theory and practice is that estimators for structural systems of equations are more efficient than reduced-form (single-equation) estimators when either equations contain common parameters or stochastic disturbances are correlated across equations (Dhrymes 1973). Furthermore, in many cases, estimators are biased or unidentified except with simultaneous estimation of the entire system (Judge *et al.* 1985, Chapters 13-15).

These principles are reflected by lessons learned from agricultural production, supply and policy model estimation. Experience has taught that more structured agricultural models that break measurements into observable components tend toward more accurate, efficient, and plausible estimation than aggregate and reduced-form models (Just 1990; Rausser and Just 1981). Essentially all general econometric models of agricultural economies including large commercial econometric models have come to estimate agricultural supply by components consisting of separate equations for yield, acreage, inventory adjustment, and herd size. Such models apply this general econometric principle to isolate shocks in the environment (weather, insects, and disease) and the dynamic nature of fixed asset adjustment. For example, weather creates noise in observed market variables that does not necessarily reflect underlying decision-making behavior. Structured models separate economic decisions from noise in the environment by focusing on planted acreage and input use rather than directly on harvested acreage or output. These intermediate variables give a better measurement of how farmers translate their expectations into action (Askari and Cummings 1976). Additional equations are then used to translate input decisions into planned or actual supplies. In short, developing more complete structural representations has helped greatly to improve supply assessment and holds considerable promise for further refinement.

4.3 Efficient Estimation and Structural Representation of the Production Problem

In reality, a farmer does not simply determine the amount of land to farm and the total amount of water or fertilizer to apply, but rather must also determine the allocation of land, water, tractor hours, and fertilizer among production activities. Just as the dual approach uses information carried by total purchases of one input to help identify parameters affecting others, the observability of allocations provides further information that can be used to identify other relationships. Allocation equations generally have common parameters that work together to determine the supplies and demands of the firm. Thus, joint estimation permits more efficiency than if a reduced set of equations is estimated. The important problem then becomes determining the appropriate scope of estimation given data availability.

The general model in (1)-(5) provides a framework that facilitates a comparison of efficiency attained by alternative representations of the production problem considering the observability of some allocation variables. This comparison reveals weaknesses of various short-run methodologies given alternative possibilities of data availability. The number of observable equations in (1)-(5) depends on how many variables are observed. The maximum number of nonredundant equations that can be expressed solely in terms of observable data under quite general conditions is the number of observable variables less the number of exogenous variables. The number of exogenous variables is $m+n+k+h-1$ which includes the $m+n-1$ prices in p and w (considering one price as the numeraire under homogeneity), the k quantities of allocatable fixed inputs in y, and the h nonallocatable fixed inputs in z. The maximum number of nonredundant observable equations can be obtained by solving for unobservable endogenous variables and replacing them in remaining equations.

Several likely cases with associated maximum numbers of nonredundant equations are as follows. For observed data (q,p,w,x,X,y,Y,z), i.e., where all $2m+2n+k+h-1+mn+km$ variables are observed, the maximum number of nonredundant estimable equations are the $m+n+mn+mk$ equations in (1)-(5),

$$(14)\quad q = f(X,Y,z),\ Ye = y,\ Xe = x,\ X = X(p,w,y,z),\ Y^* = Y^*(p,w,y,z).$$

If variable input allocations are not observed, then observed data consist of (q,p,w,x,y,Y,z), a reduction of mn variables. Here, aggregating the variable input decision equations in (5) using (3) obtains $x = Xe = x(p,w,y,z)$. These n equations replace the mn variable input allocation equations in (5) and the n aggregation equations in (3). In addition, the variable input allocations in the production function in (1) must be replaced using (5) obtaining $q = f^*(p,w,Y,z) \equiv f[X(p,w,y,z),Y,z]$ so the estimable system becomes

$$(15)\quad q = f^*(p,w,Y,z),\ Ye = y,\ x = x(p,w,y,z),\ Y^* = Y^*(p,w,y,z)$$

which has the maximum $m+n+mk$ nonredundant estimable equations.

If no input allocations are recorded and observed data consist of (q,p,w,x,y,z), one can further substitute (4) and (2) into the production function obtaining $q = q(p,w,y,z) \equiv f[X(p,w,y,z),Y(p,w,y,z),z]$. Thus, the estimable system becomes

$$(16)\quad q = q(p,w,y,z),\ x = x(p,w,y,z)$$

which has the maximum $m+n$ nonredundant equations consisting of the output supply and input demand equations. Alternatively, this system can be estimated in price dependent form as in (8) which also has $m+n$ nonredundant equations, one of which corresponds to the numeraire and is solely a relationship between inputs and outputs as in (9).

Finally, consider some cases of limited data availability. If variable input use is unobservable and available data consist solely of (q,p,w,y,z) then the estimable equations from (16) reduce to only the m supply equations in (6). If available data consist of (x,p,w,y,z), then the system reduces to the input demand system in (7). If prices are not observed and available data consist of (q,x,y,z), then the only estimable equation is the scalar input-output relationship, (9), contained as one of the equations in (8). Many other cases can be developed similarly.

A comparison of these systems of equations demonstrates how information is often thrown away in production and supply estimation thus causing a loss in econometric efficiency. Generally, the production function parameters in (1) also appear in (4) and (5). Thus, the estimated equations in (14)-(16) have common parameters. In addition, econometric disturbances are likely to be related stochastically across equations. Thus, econometric theory implies that if the system in (15) is estimated when data are available to estimate (14), or if (16) is estimated when data are available to estimate (15), then efficiency is lost and estimates/predictions tend to be more erratic.

The most common situation of data availability in both aggregate time series data and micro-level cross section data is probably closest to (15). Available data include output prices and major variable input prices (used by the dual profit function approach), major variable input quantities aggregated across crops (used by input demand studies), output quantities (used in various supply studies), and land allocations among crops (used in acreage response studies of supply). Farm records typically reflect purchases of specific inputs but not their allocation to specific production activities. Likewise, aggregate public data generally do not report variable input use by crop. In cases with this level of data availability, production and supply studies that estimate more simplified systems are inefficient and are thus likely to produce models that are less useful for prediction and policy analysis.

These considerations imply fundamental problems with traditional microeconomic empirical approaches in agriculture. Myopic econometric analysis of single-equation or partial systems cannot attain efficiency because some available data and information are ignored. For example, estimation of one supply equation in isolation ignores the information that supply equations for other outputs carry when all represent decisions by the same decision maker(s) with the same set of resources. Programming models alternatively demand more data than are typically available. These needs are filled by making simplistic fixed proportions technology assumptions so that as little as one sometimes judgmental observation from a representative firm can be used to "estimate" the technology matrix.

By comparison, the approach in (15) represents a blending of the traditional methodologies of myopic econometric estimation and programming models tailored to the data available. The modern applications of duality also represent a blending of these approaches but the standard methodology in the literature is not tailored to exploit available data. Standard duality approaches correspond to (16) and fall short of the efficiency potential of (15) because additional estimable relationships associated with input allocations are ignored. Additional estimable relationships with consistent specifications can be incorporated using either the generalized dual approach in (13) or the direct approach of Just, Zilberman, and Hochman (1983) which estimates (15) following the specification in (12).

4.4 Complete System Estimation with Specification Error

While econometric theory generally implies that parameter estimators for complete systems are more efficient than for partial systems when the systems are correctly specified, this may not be the case for incorrectly specified systems. For example, using information from the behavioral equations in (4) and (5) to help identify production parameters in (1) may lead to biased estimates of (1) if the behavioral equations are misspecified. This realization suggests that some case can be made for estimation of partial systems or single equations. For example, consider estimation of production functions where production elasticities or the structure of technology are of interest. The remaining equations in (14)-(16) other than the identities from (2) and (3) depend on the behavioral specification. Thus, if the behavioral specification cannot be approximated, estimation of (14) or (15) could cause a loss in efficiency even it all needed data were otherwise available.

On the other hand, once an assumption is made, the maximum number of nonredundant estimable equations associated with that assumption should be employed for efficiency. For example, the dual profit function approach assumes profit maximization and, by the specification of the profit function, determines the production function. If profit maximization is not applicable as a behavioral specification, then inferences drawn about technology from estimates of (16) assuming profit maximization will not be appropriate. But, given profit maximization, estimation of more complete systems such as (14) and (15) appears preferable if data are available (as is usually the case).[6]

As Askari and Cummings (1977) note in their critique of traditional approaches to supply estimation, even in traditional myopic econometric models the correct specification depends on what motivates the farmer to change output. That is, even in traditional *ad hoc* supply specifications, these types of assumptions are imposed implicitly. If behavioral and technological assumptions must be imposed implicitly in any case, then why not impose them in a systematic way where all associated observable nonredundant equations are estimated jointly so as to allow more efficient estimation and/or rejection of inappropriate assumptions manifested by inconsistencies among equations?

4.5 Unstable Parameters and Approximations

Another major problem encountered with empirical microeconomic approaches from the standpoint of active forward-looking analyses is that important parameters seem to change over time. The traditional problem of production function estimation provides a well-understood example of this problem. Production function parameters change over time as a result of technological development. Because production parameters influence firm supply and demand decisions, this problem also applies to estimates of supply and demand parameters. Parameters estimated accurately in the context of a given data set may not be applicable for predictive market analyses or analyzing alternative future policies and institutions.

Many studies have recognized that elasticities change over time and attempted to track those changes. A common approach is to divide a sample into a few time periods and estimate different elasticities in different time periods (Antle 1984). Alternatively, Rosine and Helmberger (1974) used the Marshak and Andrews (1944) methodology to show that United States production elasticities change continually over time with a significant long-term trend. While such efforts track changes in elasticities historically, models are needed to show how these changes in elasticities are determined if the empirical results are to be useful for forward-looking predictions and analyses of future policy alternatives. Two approaches that can help to support forward-looking analyses are (i) developing better global functional structure so that functions can conceivably apply across policy regimes and, thus, beyond the sample period, and (ii) better modelling of the phenomena that causes changes in parameters such as changes in technology, information, and preferences.

4.6 Functional Specification

One of the problems of empirical microeconomic analysis manifested by unstable elasticity estimates is errors in specification of functional forms for production, supply, demand, profit, and cost. Many studies have recognized, for example, that the log-linear convenience of constant-elasticity functions is probably a gross simplification. Some studies have used varying parameters models where little substantive explanation is provided for parameter variation. Alternatively, more generalized forms such as translog functions and a host of other so-called flexible forms have been used in an effort to

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[6] This may not be the case if the specification of $f^*(p,w,Y,z)$ in (15) is less clear than the specification of $q(p,w,y,z)$ in (16). However, (16) is derived from (15) so this could hardly be the case with a direct derivation. Alternatively, standard applications of duality rely on second-order flexibility of functional forms to dissipate any problems of misspecification but these arguments would apply to (15) as well.

better approximate true functional relationships by allowing elasticities to depend on other variables in the model. However, the variation in short-run elasticities over time may depend on factors that do not appear in the short-run problem.

Increasing the generality of functional forms also multiplies the number of parameters that must be estimated. With limited data, this reduces possibilities for econometric identification. According to econometric theory, as more terms are added to improve the approximation, the R^2 statistics become higher but the statistical significance of individual parameter estimates often decreases. For example, adding second-order terms may increase the R^2 statistic but, because they contain common variables, the second-order terms may be highly collinear resulting in large standard errors for the individual coefficients. If the likelihood of both equation errors and parameter estimation errors is taken into account, the confidence intervals on predictions often increases as more functional flexibility is added. If functional flexibility reflects what little is known about the true specification, perhaps unacceptably wide (but appropriate) confidence intervals on predictions are generated. Furthermore, increasing the functional flexibility by adding higher-order continuous terms *ad infinitum* may never be able to approximate well global relationships that have several discontinuities due to technological indivisibilities or one-sided government limitations.

An example of the loss in predictive ability associated with functional flexibility is provided by Chambers and Just (1989). They estimate a system similar to (13) for Israeli farmers under both first- and second-order flexibility using the dual approach and then use the estimated profit functions to predict unobserved water allocations. A similar approach is taken with a first-order direct approach using equations (1)-(3) and (12). The results are depicted in Figure 1 for the cases of bell peppers and onions where the distributions illustrate predicted behavior across all farmers. The first-order (Cobb-Douglas) system produces plausible results using either the dual approach or the direct approach in the sense that positive predictions are obtained for all allocations. The second-order flexible (translog) system produces clearly absurd predictions with many farms using negative amounts of water and others virtually flooding their fields — particularly for bell peppers. The (im)plausibility of predictions is further evidenced by production norms developed by extension agents describing normal water application rates. These norms show that normal water use is between 1,100 and 1,300 cubic meters per dunam for bell peppers and between 900 and 1,100 cubic meters per dunam for onions. The predictions made with flexibility are almost entirely outside of these norms whereas the predictions with the first-order direct approach are roughly centered on and substantially within the production norms. Although increased functional flexibility can improve the fit of estimated equations, this example demonstrates how predictive ability can decrease as a result.

4.7 Flexible Functional Forms Versus Global Functional Structure

One of the great attractions of the dual approach has been that more flexible functional forms are tractable than with the primal approach. Most applications can claim a second-order approximation of the true profit or cost function (although imposition of theoretical constraints on parametric relationships reduces the flexibility somewhat from a true second-order approximation). These properties have made researchers more comfortable with the choice of functional forms compared to the traditional approach of *ad hoc* econometric specification. In another sense, however, these properties may be providing a false sense of security. The problem is that smooth functions with continuous first- and second-order derivatives may not apply. While one approximation may apply with one set of data or in one time period, a different approximation may apply for another. Thus, applicability outside of the sample period may be limited. Even with methods that claim global approximation, because of lack of data outside of the sample period, a poor approximation may result for data that is applicable to the forecast period. Finally, while one may start with a second-order approximation of, say, the profit function, the associated supplies and demands will only be first-order approximations because they are derivatives.

Understanding the changes in elasticities that occur

Figure 1 (a). The Predicted Water Allocation Distribution for Peppers

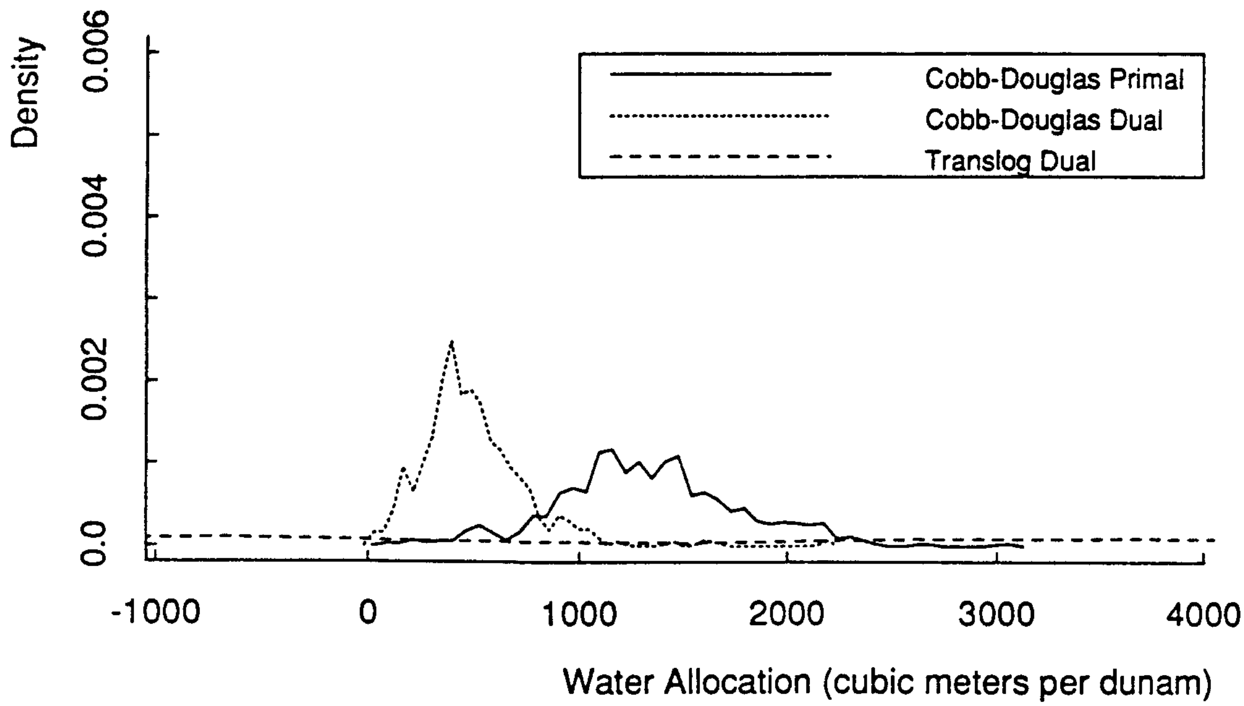
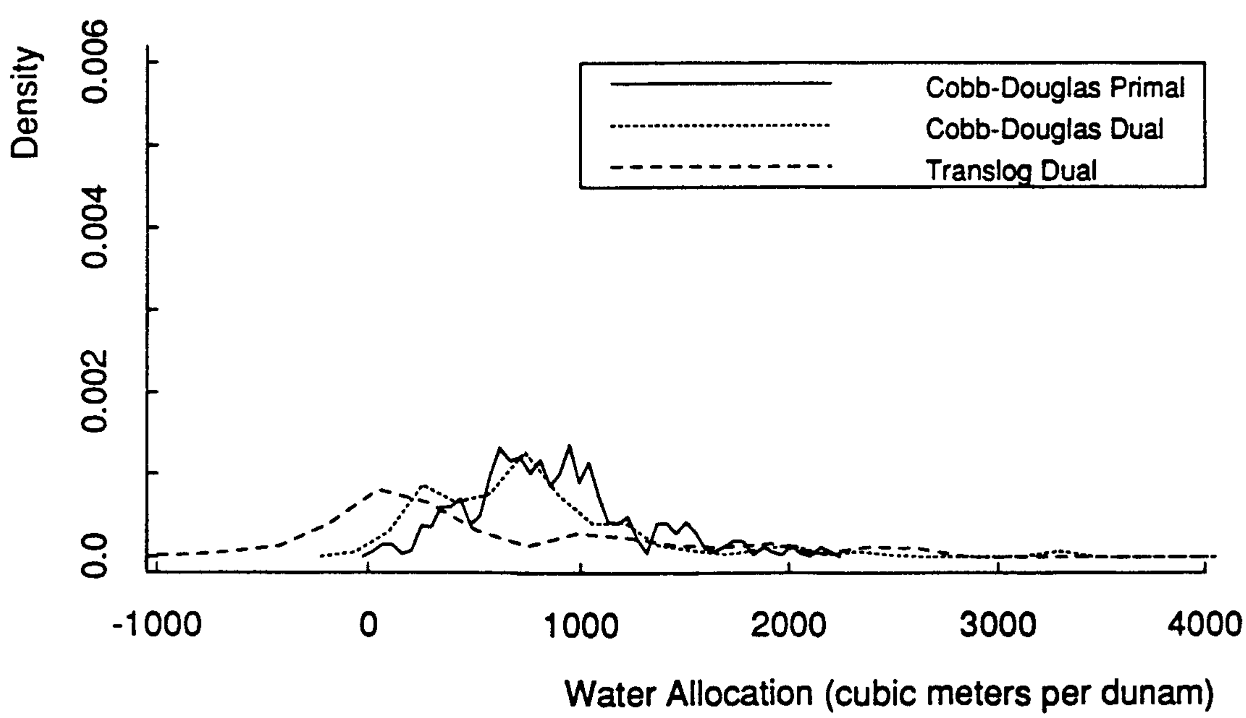


Figure 1 (b). The Predicted Water Allocation Distribution for Onions



over time may depend more heavily on achieving a globally plausible functional structure rather than a close approximation to any particular point on a supply curve. In this context, the second-order flexible functional forms of the dual approach might be only slightly less *ad hoc* and perhaps even less useful than the traditional myopic econometric approach. For example, with a translog profit function, each supply or demand elasticity is essentially a first-order approximation involving all other price variables. Thus, an extreme price level can cause a supply or demand elasticity to switch signs. The empirical results of Antle (1984) serve as a not uncommon example. At sample means, the implied elasticities are plausible in sign and perhaps magnitude. Interpreting estimated parameters in the context of 1978 data (the last year of his sample), however, a rise in output price of just 5 per cent is sufficient to cause the land demanded to increase in rental rate, a rise in output price of 7 per cent causes output supply to increase with rental rate, and a rise in output price of 9 per cent causes output supplied to decrease in output price.

These problems are not unique and are not intended to single out any particular study. They are characteristic of many second-order forms such as the translog that are used for flexibility in dual approaches. For example, if a supply equation derived from a profit function quadratic form in logs has a positive own-price elasticity but the first-order and second-order price terms have different signs, then either a sufficiently high price or a sufficiently low price will cause the elasticity of supply to reverse signs. Clearly, such forms are not plausible globally and, thus, large variations in policies that generate large changes in prices cannot be appropriately addressed thereby.

4.8 Government Programs

These considerations are particularly true given the role that government programs play in agriculture. Changing government programs present one of the most difficult problems for micro-level empirical analysis. Not only are policy instruments varied frequently but the set of active policy instruments is often changed for the major commodities in major countries. Even in countries such as Australia that have somewhat more simple and stable agricultural policies, the implications of frequent policy changes in major competing countries such as the United States can have substantial implications for world markets.

To further complicate matters, many of these controls affect agricultural producers in ways quite different than normal market variables. Participation in United States programs has been mandatory at times and voluntary at others. Decisions to participate are discrete decisions that change the applicable sets of prices and constraints. Some price controls impose one-sided price bounds on input use restrictions that alter functional structure (e.g., price supports or acreage limitations). For the most part, government programs have been represented by adding a simple representative government program variable as a continuous regressor in econometric equations. This approach is clearly a victim of the Lucas critique whereby the parameters of econometric models embody the effects of policies and therefore cannot be used to evaluate alternative policies even historically (Lucas 1976). A few studies have attempted to take into account how policy variables can be represented systematically in agricultural supply models (Houck and Ryan 1972; Just 1973; Just, Zilberman and Rausser 1991). Approaches must be generalized to reflect the structure according to which policy instruments operate in order to show how parameters depend on policies. Only then will estimated models have relevance for forward-looking prediction and policy evaluation.

Some of the most fundamental questions about agricultural policy instruments involve major changes in policy instrument sets rather than simple marginal changes in instrument levels. Analysis of policy alternatives considered in recent General Agreement on Tariffs and Trade (GATT) negotiations is one such example. Under various proposed alternatives, either domestic subsidies would be phased out or replaced by instruments justifiable on environmental or other nondistortionary grounds. Given frequent changes in government program instruments and the need to analyze such widely differing policy alternatives, a useful approach is to refine representation of the global role of government program instruments rather than find *nth* order local approximations.

A brief example of United States feed grain/wheat supply provides an example. Analyses that account for the voluntary nature of government programs typically specify an *ad hoc* acreage equation depending on both profit per acre (or prices) under compliance, π_c, and noncompliance, π_n, as well as other variables such as lagged acreage and profit per acre for competing crops, X,

$$(17) \quad A = A(\pi_c,\pi_n,X),$$

(see, e.g., Rausser 1985; Love 1987). The problem is that over wide changes in compliance, the profits under compliance (noncompliance) may be highly important at some times and unimportant at others. An approach that imposes more globally-relevant structure is to represent free market acreage following $A = A_f(\pi_n,X)$ with nonparticipating acreage following this free-market equation on the nonparticipating proportion of farms, $A_n = (1-\phi)\, A_f(\pi_n,\pi_a,A_{-1})$ where ϕ is the rate of participation. For participating acreage, theory suggests that participation in a voluntary program and access to its price subsidies would tend to not be attractive unless the acreage limitations were effective. Thus, participating acreage is largely determined by program limitations, $A_p = B\phi(1-\theta)$, where B is the program base acreage and θ is the required diversion rate. The estimating equation for acreage combining the participating and nonparticipating components is thus

$$(18) \quad A_t = B\phi(1-\theta)+(1-\phi)A_f(\pi_n,X).$$

In this model, the level of participation can be described by another equation that determines the weights attached to the market and program variables. Assuming that farmers participate if anticipated profit per acre is greater under compliance than noncompliance ($\pi_c>\pi_n$) and that individual anticipated profits differ stochastically across farmers, the participation rate at the aggregate level can be represented by a probit or logit relationship, e.g.,[7]

$$(19) \quad \ln(\phi/1-\phi) = \phi^*(\pi_n,\pi_c).$$

These relationships may not apply exactly and more accurate local approximations may be attainable. For example, some complying farmers may not have a binding acreage limitation. Alternatively, complying acreage may be better represented by relationships with somewhat more flexibility. However, for forward-looking analyses, the issue is whether estimates of equations (18) and (19) are a more reasonable global approximation than estimates of an *ad hoc* specification of (17). With highly correlated profits per acre under compliance and noncompliance, a purely data-based approach to (17) makes the possibility of obtaining even plausible signs remote.

To illustrate the difference in performance, both (17) and (18)-(19) were used to estimate acreage response of wheat and of feed grains in the United States over the period 1962 to 1982 and then to forecast acreage in the 1983-1986 period (see Just, Zilberman and Rausser 1991, for details). The results are given in Table 1. The results for equation (18) take the participation rate as exogenous whereas the results for equations (18) and (19) include forecasting errors for the participation rate as well. In the case of feed grains, the *ad hoc* formulation in (17) leads to a much smaller standard error in the sample period even though the structural form performs better in *ex ante* forecasting of the post-sample period. The model combining equations (18) and (19) obtains an even lower standard error. In the case of wheat, the structural form fits the sample data better and performs sub-

[7] Further plausible structure reflecting United States program instruments for feed grains/wheat is also imposed by letting short-run profit per unit of land under noncompliance follow $\pi_n = P_m Y_a - C$ where P_m is the anticipated market price, Y_a is the anticipated yield, and C is variable production cost per acre. Then short-run profit per acre (of both producing and diverted land) on complying farms follows $\pi_c = (1-\theta-\mu)\pi_p + \theta G_m + \mu \max(G_v,\pi_p)$ where μ is the maximum additional diversion proportion of base acreage, G_m is the payment per acre for minimum diversion, G_v is the payment per acre for additional diversion, π_p is the short-run profit per unit of producing land under compliance, $\pi_p = [\max(P_t,P_m)\, Y_p + \max(P_s,P_m)\max(Y_a-Y_p,0) + \max(r_m-r_g,0)\, P_s^p Y_a - C]$, P_t is the government target price, Y_p is the program yield, P_s is the price support, r_m is the market rate of interest, and r_g is the government subsidized rate of interest on commodity loans under the program. The latter term suggests no voluntary additional diversion if $G_v < \pi_p$ and voluntary additional diversion to the maximum if $G_v > \pi_p$. This reflects the complicated (global) relationship through which a participating farmer is entitled to at least the target price on his program yield, at least the (lower) support price on all of his production, and gains an additional interest subsidy on a loan against his stored crop (at harvest time) evaluated at the support price. These benefits must be balanced against the opportunity loss of having to divert land.

Table 1. The Performance of Structural Versus *ad hoc* Models: The Case of U.S. Wheat and Feed Grain Acreage

Crop	Model Definition (Equation)[a]	Estimation Period	Forecast Period	Standard Error Within Sample (million acres)	Standard Error Post-Sample (million acres)
Wheat	(17)	1962-82	1983-86	4.41	14.90
Wheat	(18)	1962-82	1983-86	3.32	6.21
Wheat	(18),(19)	1962-82	1983-86	[b]	9.07
Feed Grain	(17)	1962-82	1983-87	1.73	6.40
Feed Grain	(18)	1962-82	1983-87	6.26	6.38
Feed Grain	(18),(19)	1962-82	1983-87	[b]	5.50

[a] See the text for equations which define the various models.
[b] No within sample error is computed since the model is derived by combining the estimated equations corresponding to (18) and (19).

stantially better in *ex ante* simulation. This superior performance of the structural model carries through when errors in forecasting participation are also considered.

The reason the structural form works better, even in the sample period for wheat, is that changes in parameters over a wide range of policies put a premium on global properties of the relationships. The participation rate over the sample period ranges from zero to nearly 90 per cent. As a result, the effects of profits with and without compliance cannot be well represented by a smooth approximating function following (17). The recent work of Westcott (1991) further demonstrates graphically the many kink points that these government controls can cause in acreage allocation relationships and suggests further that flexible forms cannot be expected to determine functional relationships globally.[8] In summary, a flexible approach is likely to be inadequate on two grounds. First, a flexible form with continuous first- and second-derivatives cannot approximate well the kinks and switching caused by agricultural policy instruments. Second, data may not be sufficient to identify all of the parameters of a flexible specification. Time series data are typically only sufficient to estimate models such as (17) in linear form because of the limited duration of policy regimes.

4.9 Multiple Interpretations of Data

Perhaps the most troublesome problem involved in discovering microeconomic relationships is that the same observed data are often effectively "explained" by more than one competing model or hypothesis. When this is the case, the model is, in reality, not identified. Nevertheless, competing studies often test and support competing working hypotheses associated with alternative explanations. This seeming conflict in the literature occurs when each study myopically ignores other competing hypotheses and/or works within an inappropriately narrow maintained hypothesis.

A standard problem with the Nerlovian supply model provides a simple, well-known example to facilitate the discussion. The Nerlovian model includes a lagged dependent variable in addition to price to reflect a limited response in the short run. However, the limited response in the short run is attributed either to adaptive expectations or to partial adjustment. Is limited short-run response due to a tendency of price expectations to respond in a limited way to current circumstances or to a tendency to adjust output slowly due to habit per-

[8] These kinkpoints arise from relationships such as discussed in footnote 7 and are also reflected in the empirical results of Table 1.

sistence, costs of adjustment, and/or technological/institutional rigidities — or to both? When a study tests for the importance of adaptive expectations (partial adjustment) with a maintained hypothesis that the lagged dependent variable represents adaptive expectations (partial adjustment), then considerable statistical significance is usually found. If the maintained hypothesis is expanded to include both, then statistical discernment is not possible except with considerably less convenient models that tend not to be used (Dhrymes 1971).

But consider the usefulness of models that do not properly discern the underlying mechanisms or depict the lack of identification. In using a Nerlovian supply model to compare policies that subsidize prices and policies that limit acreage, the results would be very different depending on which underlying mechanism is assumed. Similarly, a dual model that considers only profit maximization may suggest with apparent clarity a considerably different effect of imposing controlled prices on a free market than a model with risk aversion. On the other hand, if the inability to discern underlying mechanisms is calculated statistically, then confidence intervals on policy results may be unacceptably (but appropriately) wide.

4.10 Inability of Data to Discern Model Applicability

Because of the great complexity of microeconomic agricultural problems and the limited amount of data that can be generated practically under each technological/policy regime, the persistent problem of econometric identification has proven that purely data-based estimation has not been successful. Data availability and econometric techniques are simply not sufficient to determine structure, functional form, and coefficients of all potentially important variables or, in other words, to discern among all possible behavioral and technological possibilities. Under the current econometric paradigm, appropriate statistical measures of significance and parametric tests are conditional on joint hypotheses of functional form and other aspects of model specification associated with tenuous maintained hypotheses and assumptions. As a result, most hypothesis tests are suspect (Leamer 1974). Alston and Chalfant (1991) have recently demonstrated this problem in showing that apparently innocuous specification errors can greatly increase the probability of finding significance. More rigorously, White (1980) has shown that least squares has a very limited ability to provide information about partial derivatives and elasticities when approximating functional forms are used. If standard statistical concepts of significance only have significance when the proper model is known and the proper model is almost never known, then perhaps a different empirical paradigm is needed for discovering microeconomic relationships. One approach that has attempted to deal with this problem is nonparametric analysis of data (e.g., Chalfant and Alston 1988). While this approach can broaden the context of functional flexibility and determine whether any plausible functional forms consistent with theory can explain data, it does not determine functional forms and so cannot facilitate forward-looking analyses.

One of the great problems in microeconomic empirical work has been an obsession with choosing structures to minimize sampling error. McCloskey (1985) argues that when specification errors are serious, as they are usually believed to be, then focusing on sampling error is somewhat like looking for a lost wallet under a lamp post because the light is better there. In practice, a closer fit is often obtained when only part of a system is estimated and more flexible forms are used. This occurs because data typically do not fit a complete system or global functional form implied by an arbitrary specification (even an arbitrary flexible form). But the poor fit or implausibility may only become apparent in a global context or in the context of a complete system of equations that imposes internal consistency. For example, the specification for each individual equation may be capable of approximating the relationship of included variables in the sample period but, when internal consistency is imposed (e.g., by cross-equation parameter constraints), poorer fits of the individual equations are obtained.

These observations imply that a false sense of precision can be perceived when reduced or partial systems are estimated and reported. These problems undoubtedly lie at the root of the poor performance of production, supply, and policy models outside of sample periods. This problem is somewhat akin to the problem of pretest estimation bias in econometrics. If a researcher chooses to fit only a partial representation of the problem and chooses to report estimates for the part where the best fit is obtained (either by search or by custom), then the significance statistics are not appropriate and precision is overstated. In addition, even though plausible results are obtained in fitting individual components, implausible predictions can result from the combined use of such relationships because theoretical relationships are not satisfied.

An important source of information that substitutes for the inability of purely data-based approaches to discern structure and specification and which serves to evaluate and impose internal consistency in estimated systems is economic theory. The argument that has been used against imposing theoretical structure is that it necessitates assumptions about the behavioral criteria and technology. From a purely statistical point of view, classical econometric practice has correctly resisted imposing behavioral and technological assumptions and functional forms because, as the Alston and Chalfant (1991) results show, statistical significance measures are not properly applicable when the specification is unclear. However, if available data are insufficient to identify structure and functional form, then perhaps the empirical paradigm needs to abandon the guise of strict statistical standards.

As an alternative empirical paradigm, perhaps empirical models with better out-of-sample applicability and more usefulness for forward-looking analyses can be generated by adapting tightly structured theoretical models for empirical use with the sampling error of standard econometric approaches serving as a standard of comparison. Just and Miranowski (1992) provide such an example.

4.11 Utility of Models and the Use of Theory for Specification

While economic theory can serve as a source of additional structure that can improve estimation efficiency and identify the role of a wider range of variables, it can also increase the utility of estimates for various analytical purposes. For example, many of the useful policy applications of microeconomic relationships involve evaluating the welfare effects of changes in policies or institutions. However, if the estimated supplies and demands used for welfare calculations do not satisfy theoretical restrictions, then the welfare concepts become ambiguous (Just, Hueth and Schmitz 1982). Silberberg (1972), for example, showed that arbitrary consumer surplus calculations can be generated from ordinary demand estimates. Even Willig approximations do not apply if the estimated system of equations describing behavior of an individual or group do not satisfy theory. The point here, is that if the purpose of a model is to make welfare comparisons, then a model that is estimated with the assumptions of the comparison methodology is more useful and possibly necessary for correct application. Furthermore, imposition of the assumptions at the stage of estimation provides for more efficiency (or opportunity to reject inappropriate assumptions) than if the assumptions are only applied in using an estimated model.

For the problem of consumption, estimation has considered theoretical consistency of demand relationships among markets for three decades (e.g., Brandow 1961; George and King 1971; and Huang 1985). These efforts have provided the most useful and reliable estimates of cross elasticities of demand available. Such cross elasticities are crucial to prediction of the effects of policy and institutional changes on related markets. However, similar needed sophistication in estimation of cross elasticities of agricultural supply has not been forthcoming even though the supplies of agricultural commodities are clearly related by competition for the same resources used in production. Complete models of supply are needed to identify interactions with efficiency and to develop estimates that will satisfy the theoretical properties that are required by economic welfare calculations.

4.12 Aggregation and (Versus?) Imposition of Theory: Applicability of Micro-Level Structure

One impediment to the use of consistent systems of equations for agricultural supply has been the seeming necessity of using aggregate data. Typically, only highly restrictive assumptions such as requiring all firm's profit functions to be affine transformations of one another have facilitated use of firm level models to analyze aggregate data (e.g., Chambers and Vasavada 1983). When different firms are involved in different sets of production activities, the presence of different corner solutions for different firms may make some theoretical properties inapplicable at the aggregate level that are applicable at the firm level. Similar problems are encountered in using individual consumer models at the aggregate level but the presence of corner solutions is more obvious in supply. These problems call for more work on aggregation of specifications which may lead to better consideration of distributional issues in aggregate specifications and/or development and use of more disaggregated data.

Traditionally, the potential inapplicability of cross-equation theoretical constraints at the aggregate level (and the reluctance to impose technology and behavioral assumptions explicitly) has resulted in little attention to complete system estimation of supply. As a result, microeconomic empirical studies have failed to produce useful and needed estimates of cross supply elasticities. The few multi-output applications of duality are exceptions but these studies generally consider obviously incomplete sets of competing crops in a seemingly experimental mode. One of the more complete applications available is by Lawrence and Zeitsch (1990) who use aggregate data to estimate a profit function with 6 crop outputs and 7 livestock outputs with 5 variable inputs and one fixed input.

4.13 Needed Emphasis on True Micro-Level Modelling

One reason that empirical supply models have failed to produce estimates of cross elasticities is that microeconomic models of acreage allocation are poor. Programming models can produce drastic changes in acreage with small changes in prices. Farmers tend not to be so ready to abandon traditional activities as programming models sometimes suggest. On the other hand, econometric models are generally very poor in explaining differences in cropping patterns among farms except with dummy variables. When the models of the profession perform poorly in reflecting individual farm behavior, questions arise about whether these structures are sufficiently applicable for aggregate estimation. Generally, micro-level econometric studies of production and supply have been extremely limited because of lack of data. Few truly micro-level data sets have been developed and those in government hands often have restricted use because of confidentiality considerations. A new generation of models and research is needed at the micro level to support aggregate model specification and related forecasting, market, and policy analyses. For example, some recent research has shown that farmers may stay with accepted practices when the deviation from profit maximization is not great but that major changes tend to cause profit maximizing adjustments (Just, Zilberman, Hochman and Bar-Shira 1990). Models with costs of learning and adjustment may offer possibilities for better understanding the allocation of farm resources among alternative production activities.

As a result of the poor state of positive modelling of farm-level decision making, the profession has not produced good aggregate models of acreage and supply response. Econometric models (including those of the dual approach) tend not to reflect the phenomena whereby two crops may be highly competitive and thus have large direct- and cross-price elasticities of supply when the relative profitabilities of the two are similar, but may not be competitive with a 10 or 20 per cent change in either one of the prices. Conceptually, a relatively plausible price change can greatly alter the elasticities in this case. Programming models, on the other hand, can have abrubt changes between zero and infinite elasticities with small changes in prices. These problems are often handled by "calibration" or "habit" constraints so the sensitivities of the results suit the intuition of the researcher. Both of these approaches ignore the real underlying relationships and leave the profession with poor models of how elasticities and cross elasticities change in response to changing prices and other conditions.

Other factors that affect changes in elasticities include expectations of permanence of current conditions, changes in cropping toward or away from perennials, changes in technology, and changes in government programs and policy instruments. When a larger part of acreage is tied up in 30-year tree crops, supply response for other crops is likely to be much smaller. Important innovations have been made to improve the structural representation of planting, removal, and bearing acreage for perennials (French and Matthews 1971) but the implications for cross effects on other crops have not been developed. Similarly, if technologies with expensive and specialized machinery are adopted, then supply response will likely decrease (Chern and Just 1978) and this will likely cause cross elasticities to decrease for the whole set of competing crops.

Efforts to estimate cross elasticities must also recognize the dependence of own price elasticities on the extent to which cross elasticities are included. If an own-price elasticity of supply is estimated without conditioning on prices of other outputs, then the resulting estimate tends to be an equilibrium estimate that measures quantity response taking into account equilibrium adjustments in other markets. Similarly, if an own elasticity is estimated without conditioning on the prices of inputs, then the resulting estimate is an equilibrium elasticity that tends to take account of equilibrium adjustment in input markets in response to changes in output price (Just, Hueth and Schmitz 1982). These considerations tend to be overlooked in practice but can have important implications for how the elasticities should be used. For example, suppose input prices tend to get bid up over a sustained period of high prices but not for a short-lived price increase. Then a supply elasticity estimated without conditioning on input prices over a period of stable or long-term price changes may be inapplicable for a period of short-term price volatility.

To some extent, using complete models of firm decision making can help to improve the focus on needed estimation of cross elasticities. However, unless the models are further developed to account for the issues that affect functional structure, the forthcoming estimates of cross elasticities are likely to be misleading.

4.14 Stochastic Specification

Additional problems of estimation stem from stochastic disturbances. These disturbances may arise from (i) random behavior due to stochastic behavioral criteria, (ii) errors by the decision maker in achieving the behavioral objectives, (iii) omitted variables, e.g, weather variables, (iv) errors in observations of the true variables, or (v) other specification errors. The source of stochastic disturbances is crucial for econometric purposes. Some underlying mechanisms cause disturbances to be correlated among equations while others do not. Some cause systematic bias in parameter estimates while others do not. Some cause a model to become inapplicable outside of the sample period while others do not. As illustrated early by the work of Dhrymes (1971) for the Nerlovian supply model and more recently by McElroy (1987) for estimation of production, cost, and derived demand systems, a correct understanding and modelling of the underlying source of random components is crucial to proper estimation and use of empirical models. Again, more work at the individual firm level can help to identify which sources of random disturbances are important and the structural role they play. Some of these problems may be uncovered only by compiling data on additional variables such as expectations and intentions.

4.15 Expectation Specification

A fundamental difficulty for both estimation and empirical use of microeconomic models is appropriate representation of expectations, producer information, and associated subjective distributions of prices and random production factors. Errors in measurement of expectations are important because they translate into errors in estimated parameters such as supply and demand elasticities.

Adaptive Expectations

Historically, expectations have been represented in the literature by adaptive expectations mechanisms. Following the formal literature on price expectations in the tradition of Muth, price expectations follow stable and decaying lag weights whenever the structure of the economy follows a stable stochastic process (Just 1977). Specifically, the most common (Nerlovian) assumption in empirical models is that price expectations change by a constant proportion of the error of expectations regardless of the source of the price change. A major problem with adaptive expectations is that a price change in reality may not always suggest a change in price expectations for the following production period. An unusually high price can occur either with a one-time crop failure or a permanent increase in demand. In reality, major shocks tend to occur erratically from time to time but the magnitude or permanence of effects is initially unclear. Thus, the proportion by which price expectations change will likely differ depending on whether the producer perceives price changes to be permanent or transitory. If this problem is important, then the expectations adjustment parameter should depend on other factors (Fisher 1962, Chapter II). For example, the expectations mechanism could be refined to consider uncertainty with respect to structural change by implicitly including tests for consistency over time with lag weights determined accordingly. This approach would lead to a more tightly structured model with weights on past prices that vary with circumstances as opposed to the constant free-form lag distributions that have evolved in the literature.

Alternatively, the argument that price changes must persist for several periods before they are fully translated into changes in expectations has led to the use of lag distributions of increasing generality (e.g., frequency domain regression and Box-Jenkins analysis). The problems with these kinds of generalizations are threefold. First, they introduce additional parameters that may be difficult to identify with limited data. Second, the form of the lag distribution that fits best tends to depend heavily on the time period used for estimation. Third, unless a clear framework is provided explaining the form of these distributions, the use of estimates outside of the sample period is likely to be inappropriate. In fact, any lag distribution that remains constant over time is generally inconsistent with the motivating explanations that weights on price changes depend on their perceived permanence or that price changes must persist for several years before they are incorporated into expectations. In any conventional distributed lag model, the lag weights are constant so the effect is simply to delay the price impact — not alter the effect according to consistency or perceived permanence. Models are needed that explain varying lag weights in terms of perceived permanence.

Rational Expectations

More recent applications in the literature have used rational expectations mechanisms. These mechanisms suppose that the decision maker has a complete understanding of the market economy generating prices and can thus calculate a "reduced-form" price expectation based on the exogenous variables of a model representing that economy. The difficulties here are again threefold. First, even the best available econometric techniques are often inadequate for determining with much confidence how a market economy generates prices. Second, even if the operation of the market economy is understood, one still has the problem of forecasting the exogenous variables. Third, the way rational expectations are usually represented empirically, they offer little improvement over the more *ad hoc* adaptive approaches.

One way of generating a rational expectations mechanism is to solve a theoretical market model for a rational expectation equation which specifies the expectation in terms of other parameters estimated in the market system. The problem here is that if the model has a continuous and stable stochastic structure with additional random forces affecting the market and its evolution each period, then the rational expectation is represented by a simple function of the lagged price assuming current stochastic forces are unknown at the time of decision making (Turnovsky 1979) — the same problem as with fixed-lag-weight adaptive models. Another common way of generating rational expectations is to regress observed prices on all exogenous variables available. While this method is theoretically defensible with abundant data in a stable environment, it is subject to identification problems because of the multiplicity of exogenous variables that are potentially important and because spurious correlations in unstructured reduced-form specifications tend to make the results heavily dependent on the sample period. In the small sample case of supply estimation, for example, these "expectations" can fit prices too close and thus cause the elasticity of supply to be underestimated.

Finally, as either of these approaches are traditionally applied, a sufficient mechanism is not included to allow different effects depending on whether recent phenomena is considered temporary or permanent. Ideally, this should be determined within the rational model but in practice this is difficult without observability of the exogenous variable forecasts used by the decision makers. The 1973 Soviet grain market shock suggests the kind of information that is needed. In 1973 following this initial shock, the United States Secretary of Agriculture encouraged farmers to plant "fence row to fence row" indicating that a new era of United States agricultural demand had arrived. As a result, the response to the price increase was likely larger than if farmers had been better informed or uninformed by the Secretary. This problem suggests price expectation mechanisms must include a wide range of information that makes identification difficult. Alternatively, survey data on price expectations held by decision makers is needed to improve agricultural supply estimation and determine the applicability of rational expectations.

Futures Expectations

One approach that has found some use in the literature is to represent price expectations by futures market prices (e.g., Morzuch *et al.* 1980). This approach can be justified by theoretical results that have demonstrated a separation of production and futures market trading decisions (e.g., Feder *et al.* 1980). However, not all crops have futures markets, and farmers using futures markets suffer from basis risk and transactions costs. Nevertheless, futures prices better incorporate information available at the time of planting decisions than other types of expectations based on annual data where prices are more closely associated with harvest time. Also, because of the way other expectation mechanisms are applied in practice, futures expectations are more effective for dealing with the wide range of information, such as statements by government officials, that can affect price expectations.

Mixtures of Expectations

Unfortunately, empirical studies to date have been unable to discern clearly which expectation mechanism or combination of them applies. In reality, different decision makers likely use different expectations and change from one expectation mechanism to another according to the cost of information, volatility, and the associated benefits of information. More sophisticated models are needed to explain these variations and work to discover these mechanisms is only beginning.

4.16 Specification of the Process of Adjustment

Another major problem of specification in the standard microeconomic agricultural problem relates to the process of adjustment. By far, the most common approach in supply estimation has been to include a lagged dependent variable to represent technological and institutional rigidities, costs of adjustment, and/or habit formation. This (Nerlovian) approach assumes that only a fixed proportion of a desired adjustment can be accomplished regardless of how great the desired adjustment — an assumption that is clearly absurd. Representation of the adjustment process can be improved if the specific phenomena affecting speed of adjustment are represented. This problem is important because errors in specification of the adjustment mechanism translate directly into errors of estimation of long-run response.

4.17 Limited Adjustment and Costs of Adjustment

One of the primary causes of slowness to adjust is the cost of adjustment. Buying or adapting machinery to new crops is costly. Costs of information and learning may also apply. Factors that affect these costs affect the rate of adjustment. Also, the ability to adjust may depend on institutional factors such as government acreage limitations and technological and biological factors such as the ability to expand a livestock herd or bring a grove or vineyard to bearing age. Myopic econometric models have attempted to determine the lags in responses to price changes for these reasons with data-based, free-form distributed lag analysis (e.g., Dean and Heady 1958; Chen *et al.* 1972). These models do not permit changing economic conditions to affect the speed of adjustment as may be necessary for active prescriptive and predictive economic analyses.

Generally, representation of adjustment phenomena by separate equations is useful for identifying the specific processes of learning, information acquisition, investment, maturity, and culling or removal rather than lumping all of this into a free-form lag distribution. The reasons are threefold. First, the reasons for lags and thus changes in them can be represented in plausible form thus leading to better specification. Second, when data are available for the relevant variables, more econometric efficiency is possible by breaking the responses into separately estimated components. Third, knowledge about the underlying biological or technological phenomena can be brought to bear on correct assessment of the parameters in a structural model of the various processes underlying adjustment. For example, a detailed structural specification allows one to impose plausibility with respect to the aging process and age required for maturity (e.g., the number of cows added to the herd this year cannot exceed the number of heifers last year).

4.18 Asset Fixity

Asset fixity has been a topic of great debate in agriculture. The debate centers around the inconsistency in the way asset fixity is modelled and the way it really works. The neoclassical concept was that the more fixed an asset, the longer it takes to change it once a decision is made to do so. Traditionally, this concept was implemented empirically by Nerlovian supply models where a smaller share of desired adjustment was possible with more fixed assets. In reality, most asset levels can be changed substantially within a single production period although a large change may be more costly particularly if acquired assets do not fit into future production plans. Recognizing this possibility, the fixity of assets in agriculture has been explained by a divergence in acquisition and salvage value (Johnson 1956) and the opportunity cost of resource allocation (Johnson and Pasour 1981). This properly places emphasis on length of service rather than time required for adjustment. While this class of explanations for asset fixity is represented generally by the putty-clay approach where fixed assets can be acquired quickly with an ensuing inability to adjust, Vasavada and Chambers (1986) have further found that agricultural production assets are not perfectly fixed once acquired but exhibit quasi-fixity that can be explained by costs of adjustment.

However, several important generalizations are needed. First, Edwards (1985) suggests that asset fixity is a micro-level problem and cannot be well understood at the aggregate level. His arguments follow the discussion above suggesting that better aggregate models can be developed by improving understanding of the micro-level firm problem upon which aggregate models depend. Second, although some factors like land are traditionally viewed as highly fixed factors, marginal lands can be broken up, resodded, or reallocated among production activities within short periods of time. Thus, while an allocatable asset may be fixed at the farm level, it may behave much like a variable asset for given production activities. These possibilities can be addressed using the allocatable fixed input models discussed above, but have not as yet. This approach may also explain some of the conflicting empirical results regarding irreversible supply and asset fixity at the aggregate level.

A third generalization is to consider expectations that rationally correspond to the horizon of asset fixity. A highly fixed asset remains productive over a long period of time so that ordinarily it must be used over a long period of time to be economical given costs of adjustment. Thus, more adjustment occurs when price changes are expected to last longer.[9] For example, the high grain prices of 1973 and 1974 apparently led many United States farmers to adjust long-term assets substantially and rapidly in expectations of long-term high prices which then left them poorly situated for the later financial crisis. With the commodity boom and bust of the 1970s and 1980s, a careful analysis with a better representation of expectations and asset fixity is needed. These considerations suggest that better estimates of supply depend on developing better estimates of the perceived permanency of price changes. Because the terms of expectations applicable to factors of different fixity vary, econometric identification and efficiency considerations suggest that multiple equations are needed with expectation horizons determined by asset life. Otherwise, short-run and long-run expectations will tend to be collinear and the role of short-term assets versus long-term assets is difficult to discern.

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[9] The applicability of different horizons for expectations is suggested, for example, by the work of Chambers and Vasavada (1983) but their model uses naive expectations so that expectations for all planning horizons are identical.

4.19 Technical Change and Induced Innovation

Finally, consider the role of technical change. Strong and irregular effects of new technology have been major impediments to empirical work with traditional microeconomic agricultural analyses. In traditional models of agricultural supply, technical change is commonly represented by a simple time trend (Askari and Cummings 1977). Although widely used, a time trend can hardly represent irregular waves of new technology affecting a particular crop. It has no possibility of reflecting the induced technology development that occurs in response to major permanent price changes. Again, the traditional methodology tends to approximate a given data set in a way that will likely not hold outside of the sample period. Alternatively, all of the effects of asset fixity, habit formation, etc., as well as long-term technical change are summarized in the Nerlovian partial adjustment mechanism. Such models implicitly tie the rate of technology development, a process that is largely out of farmers' hands, to the rate at which farmers are willing to adjust assets or habits in response to prices.

Technology development is likely the major source of long-term supply response. But the phenomena that govern technology development are very different than those that govern switching among crops or production activities on a farm. Time lags on returns to research are different. The source of funds to finance research is different. The regulatory environment and institutions are different. It makes little sense to estimate the role of technology development on the basis of a partial adjustment coefficient that measures the extent to which a farmer will change production activities from one year to the next. This implies that the Nerlovian partial adjustment framework may well yield a totally inappropriate assessment of long-term market response. These problems are also not overcome in applications of dual techniques that vary fixed assets holding technology constant.

If agricultural production and response elasticities are not conditioned on available technology, then they include and confound the effects of price-induced development of technology that may occur with price increases but are not reversed with price decreases. Alternatively, ways of adequately conditioning estimated supply relationships on available technology must be developed. Then the extensive work on technology development in the literature can be employed to improve assessments of long-term technology development which when used in conjunction with properly conditioned agricultural production models will give a useful assessment of long-term market response. This is another way in which additional structure can be imposed to improve empirical representations. Perhaps a useful approach to capture the structure of long-term response would be to use a restricted profit function approach where current fixed factor decisions associated with each planning horizon depend on price expectations associated with asset life. That is, the decision to purchase a productive asset with a life of n years should reasonably depend on output and variable input price expectations over the n-year life of the asset. Where these restricted profit functions depend on some exogenous representation of the level of technology development, a complete structure of long-term response is obtained once a model of technology development is incorporated.

To illustrate, consider a simple model with a two-period planning horizon. Suppose the short-run restricted profit function is $\pi(p,w|z,t))$ where p is output price, w is input price, z is a fixed input with a 2-period productive life, and t represents the exogenous level of technology development. Solving this problem with backward dynamic programming, the first-period problem is

$$\max_{z_1} E[\pi(p_1, w_1 | z_1, t_1)] - v_1 z_1 + \frac{1}{1+r} E\{\pi[p_2, w_2 | z_2^* + (1-\delta) z_1, t_2] - v_2 z_2^*\}$$

where subscripts denote time period, v is the price of the fixed input, r is the discount factor, z_2* is the optimal fixed factor acquisition in the second period, and δ is the rate of decline in asset service flow over time. Clearly, in such a model the acquisition of fixed assets depends on expected prices over the productive life of the asset as well as the expected rate of technology development.

4.20 Risk Aversion and Habit Formation

Similar comments about structural modelling apply to habits, preferences and other producer characteristics. For example, when risk changes relatively little from one period to the next, risk aversion is a response that can be picked up by a lagged dependent variable econometrically. Evidence has shown that a structural representation of risk response as opposed to estimation of an *ad hoc* lagged dependent variable model can lead to a quite different interpretation of data (Just 1976). Relatively little work has been done on a forward-looking structural representation of these phenomena. For example, expected utility maximization models have long held that risk aversion may depend on wealth or the scale of operations. However, little empirical information is available indicating how risk aversion depends on wealth (Binswanger 1980; Pope and Just 1991). Thus, it is difficult to determine how risk behavior might change in response to future policy alternatives that affect wealth and farm size. Furthermore, more general concepts of risk aversion have been developed that potentially explain observed behavior that is inconsistent with standard risk models (Machina 1982; Quiggin 1982) but empirical applications are needed.

Also, little work has been done on habit formation and the role of habits and preferences that may cause behavior to depart from profit maximization. The recent work of Just, Zilberman, Hochman and Bar-Shira (1990) suggests that farmers tend to follow accepted practices but modify practices with a profit motive after sufficient change. In other words, habits tend to persist when the opportunity cost is small but they are modified when much better opportunities arise. Other studies have used cost-of-information and learning models to explain the process of adoption of new technology in developing countries with similar effects (Feder and O'Mara 1981; Lindner *et al.* 1979). Again, ways of identifying the importance of these and other variations in behavioral criteria are needed in order to facilitate active forward-looking microeconomic analyses. Standard applications of duality are inapplicable in these cases regardless of how much functional flexibility is considered in the representation of technology. Either ways of generalizing behavioral criteria under duality must be developed or else further studies investigating applicability of specific behavioral criteria that depart from profit maximization must be conducted with the direct approach.

5. Conclusions and a Call for Action

Ever broadening experience in a changing world has produced a plethora of explanations, models, and hypotheses regarding observed behavior in the agricultural economy. As the complexity and flexibility of the microeconomic paradigm has expanded, identification and prediction is becoming difficult if not impossible except under seemingly narrow assumptions. Given the limitations of available data, purely data-based empirical practices have become increasingly unable to discern critical economic relationships. Consequently, general empirical studies that add to the cumulative empirical knowledge base of the profession (such as improved estimates of elasticities of key relationships) are disappearing from the journals of the profession. For example, studies that estimate supply and demand relationships for general purposes are now depreciating and are not being replaced by updated studies. This is a natural consequence of increasing vulnerability to referee criticisms of ignoring some hypothesis supported elsewhere and/or unacceptable statistical significance on coefficients representing competing alternatives. In addition, empirical information has become more difficult to accumulate as functional forms have become more general and varied. For example, empirical results are no longer well-summarized by simple estimated elasticities.

Alternatively, the primary product of the profession has become studies that enhance the sophistication of economic thinking regarding past observations. The journals are increasingly devoted to presenting alternative theoretical and conceptual conjectures explaining observed (past) events. These conjectures are usually justified with a statistical hypothesis test in the context of a maintained hypothesis sufficiently narrow to attain significance. But empirical studies have produced conflicting results with inconsistencies owing to differences in maintained hypotheses (specifications).

Counterbalancing studies that evaluate all leading hypotheses in the context of maintained hypotheses sufficiently broad to include all alternatives are often not published (presumably because they do not find significance).

Relevance and social productivity of agricultural economic endeavors can be enhanced by maintaining a mix of products that includes both (i) enhancing the sophistication of economic thinking within the profession (by passively considering alternative explanations of observed phenomena) and (ii) facilitating active forward-looking prediction, prescription, and evaluation of alternative future actions. The profession must continue to enhance its internal knowledge base but it must also develop ways to make its knowledge base useful externally. The fundamental point of this paper is that these alternative activities are not best served by the same set of models, principles, and practices. Most currently accepted approaches have been developed by the academic component of the profession in response to journal incentives that serve the former purpose. More creative activity is needed to improve forward-looking analyses and journal incentives need to be similarly restructured.

5.1 Methodologies for Knowledge Enhancement

While studies that propose new models and explanations with limited empirical support are a useful input into professional knowledge enhancement, several approaches can help to resolve conflicts and thus serve to further enhance knowledge. More synthesizing work is needed that evaluates competing hypotheses in the context of broad maintained hypotheses. For this kind of work, the standards of the journals for statistical significance may need to be relaxed in favor of evaluating the economic importance of competing hypotheses. A study that finds no statistical significance but partial economic significance for a host of competing hypotheses within a broad maintained hypothesis is more useful than a study which finds statistical significance for a single specific hypothesis within a narrow maintained hypothesis that excludes competing hypotheses.

Additionally, more complete models need to be specified and then tailored to data availability for estimation. When models are specified only to the extent of available data, the presence of unobserved variables can lead to erroneous conclusions. Furthermore, estimation of the maximum number of nonredundant equations considering all applicable parameter restrictions associated with each alternative hypothesis results in greater econometric efficiency and greater clarity of discernment. Sometimes analysis of a partial model or even partial analyses of all components of a model will not reveal inconsistency with a particular hypothesis even though simultaneous estimation with all associated parameter restrictions will.

5.2 Methodologies for Forward-Looking Analysis

In this paper a number of principles and approaches for forward-looking analyses are advanced. Many of these are motivated by observed failures of traditional practices. Traditional estimation of microeconomic relationships in agriculture is characterized mainly by direct econometric estimation of *ad hoc* production, supply, and demand equations. These equations have tended to follow simple forms that confound many phenomena within a single variable such as a lagged dependent variable. Specifically, simple relationships tend to confound behavior and technological phenomena, and parameter estimates tend to be highly dependent of policy regimes. As a result, parameter estimates have been unstable, limited empirical information on underlying mechanisms is available, and estimates cannot be used effectively for prediction under varied circumstances.

Improvements have been attempted by imposing theoretical consistency and increasing functional flexibility primarily through dual methods. While these approaches have served well to broaden maintained hypotheses in professional knowledge enhancement, some of these efforts have been counterproductive for forward-looking analyses. For example, estimated flexible forms often are only locally applicable, produce implausible relationships outside of observed data ranges, and thus do not support forward-looking analyses.

Models used for forward-looking analyses do not need the generality of the hypothesis testing models used for knowledge enhancement of the profession. For example, knowledge enhancement activities should include testing for applicability and refinement of economic theory whereas forward-looking analyses must incorporate economic theory if meaningful explanations are to be offered to users. Practical usefulness is benefitted by imposing in estimation all of the economic principles and practical information that is otherwise considered in evaluating plausibility of results. This results in models with globally plausible functional forms and implications rather than functional flexibility and embarrassing (and sometimes initially undetected) implausible implications. Complete and detailed specifications help to facilitate imposing plausibility and permit systematic estimation of all nonredundant observable relationships. Structured specifications also allow use of relatively precise relationships from engineering, production sciences, or other practical fields in place of relationships that cannot be well-estimated from economic data. Finally, structured representation of related phenomena is important so that analyses are not conditioned on factors that are endogenous in reality.

Imposition of theoretical structure is crucial in attaining global plausibility as well as econometric efficiency. Furthermore, the extent of theoretical structure imposed on forward-looking models must be carried to levels appropriate to specific uses. For example, if a model is to be used for welfare analysis of alternative policies, then the assumptions of welfare analysis should be imposed in estimation. If a system of demands or supplies do not obey microeconomic theoretical restrictions, then many key welfare measures become ambiguous and even common approximating results become inapplicable. Similarly, forward-looking models must represent the theoretical role of policy parameters, technologies, tastes, etc., that may change over the relevant horizon. For example, structural representation of policies according to theoretical principles permits their effects to be removed and replaced by others to analyze the effects of alternative policies (reduces vulnerability to the Lucas critique).

Finally, the development of better forward-looking models calls for reducing the emphasis on standard statistical concepts of fit. Econometric practices need to be revised to admit that functional forms and structure are not known so classical interpretations of statistics do not apply. Nonparametric methods serve this purpose well for knowledge enhancement activities but offer no basis for prediction and prescription. The crucial criterion for forward-looking analyses is the ability to represent out-of-sample phenomena. Adding n*th* order approximations may lead to superior within-sample fits but globally plausible functional forms may produce better out-of-sample predictions. Fitting sample data with heavily structured relationships (few estimated parameters) based on theory and plausibility may produce wider standard errors for predictions but the wider standard errors may be more indicative of actual out-of-sample forecasting performance than statistics associated with heavily-parameterized approximations. In particular, relationships that are heavily structured according to theory and plausibility but yet fit within-sample data as well as heavily parameterized relationships are likely to produce better out-of-sample predictions and prescriptions.

5.3 Data Enhancement

Finally, data enhancement is needed to refine the microeconomic models of the profession. Determination of behavioral criteria has been difficult in the context of broad maintained hypotheses because the problems of determining preferences and expectations are almost always confounded. Almost any decision can be "explained" by some set of expectations or some set of preferences. Development of a broad public data base on expectations can serve to identify both expectations and preferences. More generally, better understanding of firm-level decisions to change production activities, adjust asset levels, and adopt new technologies is needed to support and refine aggregate model specification and development. Many key micro-level issues in agricultural economics are investigated primarily with aggregate data that allow many phenomena to be confounded. Development of a public micro-level data panel is needed to support development of a new generation of models and research whereby many key issues can be more easily isolated thus improving the knowledge base of the profession. Then aggregate models can be refined by incorporating the results of micro-level data analysis to facilitate better forward-looking market analyses and better characterization of distributional impacts.

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