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Modeling Supply Response in a Multiproduct Framework Revisited: The Nexus of Empirics and Economics

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Introduction

Considerable effort has been devoted to the estimation of aggregate agricultural supply response models. Analysts and policy makers all seek to estimate the impacts of changes in government programs, exchange rates, commodity prices, and trade policies on relative prices of inputs and outputs, the distribution of economic rents, and on the output response of producers and input supply response of suppliers.

Supply elasticities indicate the speed and magnitude of output adjustments in response to changes in product price. The elasticity parameter for aggregate farm output is especially important for public policy since it measures the ability of the farm sector to adjust production to changing economic conditions. Tweeten and Quance (1969) note that public policies concerned with the earnings of all farm resources and total farm income must consider the aggregate response of farm output in a dynamic economy. The aggregate response of output to price depends on total resource adjustments in agriculture.

Agricultural supply response models include both commodity supply response models (Weaver; Whittaker and Bancroft; Whipple and Menkhaus; Chavas and Holt; Lin et al.; Schmitz) and regional supply response models (Fawson and Shumway; Shumway and Alexander; Mielke).

Marc Nerlove's adaptive model and partial adjustment model guided much of the empirical analysis of dynamic agricultural supply response over the last decades. Berndt notes that Nerlove's 1961 research on "Returns to Scale" was the first empirical application of duality of production and cost. Askari and Askari and Cummings surveyed the econometric evidence of the effects of prices on farm supply.

The Nerlovian model of agricultural supply response was quite popular in the past (Nerlove, 1956; Hossein and Cummings, 1976). However, more recently, econometric research has focused on supply analysis where agriculture is viewed as a multi-input, multi-product industry (e.g., Antle (1984, 1999), Shumway (1984, 1988, 1995), Chambers and Just (1989), S. Ray, Fulginiti and Perrin, Ball (1988), Binswanger et al., Mundlak). This research has produced useful estimates of agricultural output supply and input demand functions. Most of this analysis of aggregate supply response has relied almost exclusively on standard econometric methods. One seeks flexible functional forms that do not impose *a priori* restrictions on supply-demand elasticities. These include the quadratic (Shumway, Vasavada and Chambers, Huffman and Evenson), the generalized Leontief form (Lopez), and the translog (Antle; S. Ray; Ball, 1988, 1997; Fulginiti; Kumbhakar). Choosing among the many possible functional forms is difficult because different functional forms can sometimes fit the data relatively well while generating different supply-demand elasticities (Diebold and Lamb).

Most models of supply response in agriculture focus on aggregate (across commodities) supply or on own-price response for a single commodity. Moreover, most models that do recognize multiple outputs typically specify transformation functions which impose severe *a priori* restrictions on the structure of production (Ball, 1988).

The objective of this paper is to model supply response in agriculture using disaggregated output data and to test statistically key assumptions traditionally maintained in agricultural supply studies. Following Vasavada and Chambers (1986), Shumway (1984, 1988), and Ball (1988), we use U.S.-level data, 1948-1999 to estimate a multiproduct supply response model for U.S. agriculture, and report our preliminary results. In subsequent analysis we will impose the *a priori* assumption that the technology is weakly separable in major categories of outputs. With

this restriction, we propose to derive the disaggregated supply response functions (Ball, 1988; Ball et al., 1997).

In developing this model, we discuss conceptual issues regarding the estimation of restricted profit functions that form the “nexus” between empirics and economics. These include incorporating restrictions from economic theory (curvature), and complications caused by the presence of multiple quasi-fixed factors and cointegrated time series data.

The article is organized as follows. The next section discusses the restricted profit function model (Ball, 1988) and presents restrictions from economic theory. These restrictions on the empirical model are imposed as part of the maintained hypothesis. Separable and nonjoint production structures are among the features to be tested in further development of the model. In subsequent sections, the estimation procedure and data are described and empirical results are presented. We also discuss how measurement issues complicate the estimation of supply response. These issues include both difficulties in estimating variables at the state level, and also problems associated with estimating a residual return to fixed factors in the presence of one or more quasi-fixed factors. Some concluding comments are offered in the final section.

The Restricted Profit Function

Estimating the model requires that we specify a functional form for the restricted profit function and consider the question of aggregation (Shumway and Davis, 2001). Chambers states functional form and aggregation lie at the heart of applied production economics. He notes that the form should be as general as possible and should restrict the ultimate outcome as little as possible. Also, choosing a functional form limits the range that the analysis can take. Once a general model is specified, classical statistical tests can only be conducted under the presumption that the general model is valid (Chambers, pp. 158-159).

We choose the transcendental logarithmic (translog) form (Bandit and Christensen, 1973; Al, 1976) because this class of ‘flexible’ functional forms can model very general production structures. However, their application to the “many output case” is hampered by the fact that the estimating equations are simple monotonic transformations of prices or quantities which are often highly correlated.

We reduce the multicollinearity problem at the cost of imposing a priori the restriction that the production structure is weakly separable in major categories of outputs. Imposition of the separability restriction (Pope and Hallam; Blackorby et al.; Moschini, 1992) yields two key simplifying results. First, weak separability ensures consistent aggregation. Second, the existence of an aggregate that is homogeneous in its components implies a two-stage optimization procedure. Stage one, choose the optimal mix of commodities within the aggregate (this justifies the specification of a model in the components alone). Stage two, choose the level of the aggregate (this justified the specification of a model in the aggregates alone). In subsequent analysis we will estimate the disaggregated supply response functions for livestock, crops, and secondary outputs, as described in Ball (1988, 1997, p. 280).

The restricted profit function is approximated by the transcendental logarithmic (translog) function with arguments, P , X , and t , where time t indexes the level of technology. P is a vector of output and input prices, while X is a vector of output and input quantities. The subscript M refers to variable inputs and outputs, while N refers to the fixed input, land. Subscripts of the parameters of the translog function: $i, j = 1, \dots, l$, (outputs) $k = l + 1, \dots, M$ (inputs), and $s = 1, \dots, N$ (profit share equations).

$$\begin{aligned}
(1) \ln \pi = & \alpha_0 + \sum_{i=1}^M \alpha_i \ln P_i + \sum_{j=1}^N \beta_j \ln X_j \\
& + 1/2 \sum_{i=1}^M \sum_{j=1}^M \beta_{ij} \ln P_i \ln P_j \\
& + 1/2 \sum_{j=1}^N \sum_{k=1}^N \delta_{jk} \ln X_j \ln X_k \\
& + \sum_{i=1}^M \sum_{j=1}^N \rho_{ij} \ln P_i \ln X_j \\
& + \sum_{i=1}^M \gamma_{it} \ln P_i t \\
& + \sum_{j=1}^N \phi_{jt} \ln X_j t + (\theta_t t) + 1/2 \theta_{tt} t^2.
\end{aligned}$$

The translog function is viewed as a second-order Taylor's expansion about the unit point.

The following symmetry restrictions are imposed by the equality of cross-partial derivatives in a quadratic expansion

$$(2) \beta_{ij} = \beta_{ji}, \delta_{jk} = \delta_{kj}.$$

Homogeneity of degree one in prices requires

$$\begin{aligned}
(3) \sum_{i=1}^M \alpha_i = 1, \sum_{i=1}^M \beta_{ij} = \\
\sum_{i=1}^M \rho_{ij} = \sum_{i=1}^M \gamma_{it} = 0.
\end{aligned}$$

Following Ball (1988) let T be the set of all feasible input and output combinations. T is assumed to be a nonempty, compact, and convex set. In addition, the technology is assumed to exhibit constant returns to scale. Under the assumptions made on T , the restricted profit function is homogeneous of degree one in fixed inputs (Ball, 1988, pp. 813-814). In this case we assume one fixed input, land. This requires

$$(4) \sum_{j=1}^N \beta_j = \beta_1 = 1 \text{ (one fixed input)}, \quad \sum_{j=1}^N \delta_{jk}$$

$$= \sum_{j=1}^N \rho_{ij} = \sum_{j=1}^N \phi_{jt} = 0.$$

Using Hotelling's lemma,

$$\frac{\partial \ln \pi}{\partial \ln P_i} = \frac{P_i Y_i}{\pi} = S_i,$$

which applied to (1) yields the profit share equations

$$(5) \quad S_i = \alpha_i + \sum_{j=1}^M \beta_{ij} \ln P_j + \sum_{j=1}^N \rho_{ij} \ln X_j + \gamma_{it} t, \quad i = 1, \dots, M.$$

Because the translog function is an approximation about a point, the hypothesis tests will require that the hypothesis holds only at the point of approximation. Approximate weak separability imposes the restrictions

$$(6) \quad \alpha_i \beta_{jk} = \alpha_j \beta_{ik}, \quad \alpha_i \rho_{js} = \alpha_j \rho_{is} = \alpha_j \rho_{js},$$

$i, j = 1, \dots, l, \quad k = l+1, \dots, M, \quad s = 1, \dots, N$, on the parameters of the translog function.

Linear homogeneity of the aggregator function $h(\cdot)$ in output prices implies that the ratios of output supply functions are homogeneous of degree zero in output prices. Writing this condition using Euler's theorem yields

$$\sum_{k=1}^l \frac{\partial}{\partial P_k} \left(\frac{\partial \pi / \partial P_i}{\partial \pi / \partial P_j} \right) P_k = 0,$$

$$i \neq j, \quad i, j = 1, \dots, l,$$

which imposes the further restrictions

$$(7) \quad \sum_{k=1}^l \beta_{ik} = 0, \quad i = 1, \dots, l.$$

Finally, nonjointness in inputs requires that the parameters of the translog approximation satisfy

$$(8) \quad \beta_{ij} = -\alpha_i \alpha_j, \quad i \neq j, \quad i, j = 1, \dots, l.$$

The Empirical Model

The empirical model identifies three output categories (crops, livestock, and secondary outputs). Secondary outputs are those secondary activities whose costs cannot be separately observed from those of the primary agricultural activity. Examples include the provision of machine services, contract feeding of livestock, recreational activities, and other activities involving the use of the land and the means of agricultural production (Ball, 2002). There are three variable inputs (materials or purchased inputs, labor, and non-land capital), and a time-trend index. Land is treated as a fixed input.

We impose homogeneity and symmetry of cross-price derivatives restrictions. We shall test the cost function for homotheticity since rejection of this property would indicate that aggregation of agricultural production is invalid. We also examine whether there is jointness in the production of crops and livestock in the sense that the marginal cost of one is influenced by the output of the other.

Data

We analyze the structure of agricultural production using the translog approximation to the cost function using neoclassical duality results. Data are from the USDA, Economic Research Service. We use U.S.-level (1948-1999) estimates of the variable purchased inputs, labor, and capital inputs, plus the fixed input, land. We divided all prices by the price of materials (P6) so that the translog second order approximation holds “in the neighborhood of “ $\log(1) = 0$.

Gross Output

The measure of output uses disaggregated data for physical quantities and market prices of crops and livestock. The Economic Research Service (ERS) compiled these data. The quantity data exclude production that is used on the farm as input.

Prices corresponding to each disaggregated output reflect the value of that output to the producer; that is, subsidies are added and indirect taxes are subtracted from market values. Prices received by farmers, as reported in Agricultural Prices, include an allowance for net Commodity Credit Corporation loans and purchases by the government valued at the average loan rate. However, direct payments under federal commodity programs are not reflected in the data.

Intermediate Inputs

One of the components of intermediate inputs is feed, seed, and livestock purchases. Intermediate goods produced within the farm sector are included in intermediate input only if they also have been included in output. Another component is agricultural chemicals. To account properly for changes in input characteristics or quality, we construct price indexes of fertilizers and pesticides using the hedonic regression technique. The basic premise underlying this approach is that price differences across goods are due mainly to quality differences that can be measured in terms of common attributes. The final components of Intermediate Inputs are petroleum fuels, natural gas, and electricity; and other purchased inputs.

Labor Input

The indexes of labor input incorporate data from both establishment and household surveys. Estimates of employment, hours worked, and labor compensation are controlled to industry totals based on establishment surveys that underlie the U.S. national income and product accounts.

These totals are allocated among categories of the work force cross-classified by the characteristics of individual workers on the basis of household surveys. The resulting estimates of hours worked and average compensation per hour are used to construct the indexes of labor input.

Capital Input

Estimates of the capital stock were constructed for each asset type. For depreciable assets, we employ the perpetual inventory method to estimate capital stocks from data on investment. Estimates of the stocks of land and inventories are implicit quantities based on balance sheet data. We constructed estimates of rental prices for each type of asset. We derive implicit rental prices based on the correspondence between the purchase price of an asset and the discounted value of future service flows derived from that asset.

Depreciable capital assets include nonresidential structures, motor vehicles, farm tractors and other equipment. Data on investment are obtained from the U.S. Department of Commerce's Bureau of Economic Analysis's (BEA) *Fixed Reproducible Tangible Wealth in the United States*.

Land

Land stocks are measured as implicit quantities derived from balance sheet data (USDA-NASS and ERS). To obtain a constant quality land stock we compute translog price and quantity indexes of land in farms. Aggregation is at the county level (Ball, 2002). Land is treated as a fixed input in our model.

Empirical Results

Equations for profit shares were estimated using inequality-constrained maximum likelihood methods. The parameter estimates for the most general model are reported in table 1 together

with their estimated standard errors. The hypothesis of weak separability in output prices and the hypothesis that the technology is nonjoint in inputs are also tested. The rejection of this hypothesis is consistent with the observation of multiproduct farms. This suggests that policies which may be directed at a single output may be expected to affect all production decisions, not simply those made with respect to the particular commodity for which the policy is targeted.

US-level Supply Response

Marshallian gross elasticities of supply and demand are estimated for the maintained model, without imposing curvature restrictions (table 2). In subsequent analysis we will impose theoretical curvature restrictions using the Cholesky factorization. This ensures positive(negative) own-elasticities of supply (demand). These results are extremely important because they imply a set of inequality restrictions on the entire matrix of gross elasticities. All elasticity estimates satisfy the normal case restrictions when evaluated at the point of approximation.

Whereas in Ball (1988), the own-elasticities of supply were generally less than unity (table 3), these results are quite different. Most significantly, the output supply elasticity with respect to secondary output does not have the expected sign. Elasticities with respect to secondary output are more difficult to interpret. Also, whereas Ball (1988) found the input demand functions were generally price elastic, several of the input demand functions do not have the expected signs (positive) suggesting that an increase in the price of the factor increases the demand for the factor. This clearly contradicts economic theory. One reason for these contrary results is that whereas Ball imposed curvature restrictions on the model in 1988, we have not yet imposed them in this model.

Conclusion

Restricted Profit Function

U.S. level equations for profit shares were estimated using inequality-constrained maximum likelihood methods. We estimated the output supply and input demand elasticities using the parameter estimates from the restricted profit function and revenue and cost shares model without imposing curvature restrictions on the model. Accordingly, the signs and sizes of these estimates did not agree with those expected from economic theory. Therefore, in subsequent analysis, we shall impose curvature restrictions on the model.

As we estimate the translog supply response model, several issues emerge. These include: imposing curvature restrictions, estimating regional supply response models, possible measurement errors when there are more than one quasi-fixed factors, and cointegration of the time series data.

Curvature --- Cholesky Factorization

The estimates presented do not reflect the imposition of curvature restrictions (following economic theory) for a “well-behaved” production function (McFadden). Ball et al. (1997) note that in order for the normalized restricted profit function which is linearly homogeneous in prices to be a convex function, it is necessary and sufficient that the matrix A be positive definite. Lau (1978) has shown that every positive definite matrix has a Cholesky factorization. The matrix A can thus be written in terms of the Cholesky decomposition as $A = LDL'$ where L is a unit lower triangular matrix and D is a diagonal matrix with typical element D_{ii} referred to as a Cholesky value. Lau demonstrates that if the matrix is to be positive definite then $D_{ii} > 0$. Thus imposing positivity on the D_{ii} is sufficient to impose convexity on the restricted profit function.

Mundlak (2000, p. 327) notes that “those studies where convexity is not confirmed should go no further because the remaining results have no theoretical support.” This is exactly what our preliminary results have shown. They do not support the assumption of convexity in the profit function. However, we plan to re-estimate the model with curvature imposed (Ball, 1988; Fernandez-Cornejo; Paris and Howitt; Paris and Caputo; Barnett and Lee; Shumway, 1995).

Shumway’s (1995) examination of the static, applied, dual, agricultural-production economics literature yields these conclusions with respect to testing for monotonicity, curvature, symmetry, and homogeneity. First, many of the test rejections are not based on statistical tests but rather on failure of the unconstrained estimates to satisfy the hypothesis. The rejection may not be significant in either a statistical or an economic sense. Second, there is no reason to expect that all (or perhaps any) of the four tested implications would hold for an aggregate of firms even if they held perfectly for each firm. Shumway notes that to conduct a “critical” test of the theory requires micro-level data, data that are even more detailed than that used in most firm-level analyses. Nevertheless, one might well be cautious about imposing curvature on flexible functional forms. The curvature conditions arise from theoretical assumptions that characterize special operating environment (e.g, free disposability of inputs and outputs). Many firms do not operate in this environment. Even if the operating environment satisfied the theoretical assumptions, the fact that one needs to impose curvature that is not supported by empirical data should be a sign that something is mis-specified (Weininger).

Ball imposed convexity on the translog specification locally, as a point of approximation, by the Cholesky LDL’ method (Ball, p. 815). Unfortunately, however, with the translog, the curvature condition may be violated at other points of the regressor space (Wolff). This is why some impose the curvature globally. In the case of the translog, global imposition can simply be

implemented with the “Jorgenson and Fraumeni” method (Diewert and Wales, p. 48). We are writing software code to implement the Cholesky factorization in SAS, following some recent work by Moschini (1998a, 1999). Finally, Barnett (2002) notes that although econometricians often impose curvature globally, they typically impose monotonicity locally if at all. But without satisfaction of both curvature and monotonicity, the second-order conditions for optimizing behavior fail, and supply functions become invalid (Barnett, p. 199).

Extension of the Restricted Profit Function Model to U.S. Farm Production Regions

The estimation of the restricted profit function and of the factor demand and output supply response equations is based on the assumption that in long-run equilibrium and perfect competition, factor returns are exhausted (Euler’s Theorem). Using U.S.-level time series data, the residual return to land (the fixed factor) is always positive. However, using state-level data, this is often not true. This is partly because measurement of farm income and expenses and their proper allocation across states is more complicated than it is at the U.S. level. This clearly complicates the development and estimation of a regional supply response model. Therefore, we will postpone development of regional supply response models until we have successfully completed development and estimation of the U.S.-level model.

Quasi-fixed Factors

Furthermore, the presence of multiple quasi-fixed factors affects the measurement of residual rents. The estimation of the restricted profit function and of the shadow prices of variable and quasi-fixed inputs is dependent on the proper classification of variable and quasi-fixed inputs. If a quasi-fixed input is treated as variable by using a market price in place of a shadow value, then the imputed value of the input in question is mis-stated (Mishra, Moss, and Erickson). Therefore,

the presence of one or more quasi-fixed factors can cause mis-estimation of residual returns, and thus of supply response.

Cointegration of Time Series Data and Its Effects on Parameter Estimates

Lim and Shumway (1997, 1999) note that it is common practice to implicitly assume that all data are generated from stationary processes and to include time in the regression as a proxy for technical change and/or omitted variables. However, Engle and Granger et al. have shown that many economic time series have characteristics of a random walk. That is, they are not stationary around a function of time but are stationary in differences. If the data are nonstationary, then regressing one nonstationary series on others and/or on a time trend could yield spurious results and adversely influence hypothesis test conclusions because tests based on standard asymptotic results will have the wrong size. Therefore, we propose to perform unit root and cointegration tests to investigate whether economic time series are stationary and whether their linear combinations representing the cost share equations are cointegrated. Based on these test results, a new dual model might be specified and estimated to reflect these cointegrating relationships.

References

Antle, John M. "The New Economics of Agriculture." *Amer. J. Agr. Econ.* 81 (November 1999):993-1010.

Antle, J.M. "The Structure of U.S. Agricultural Technology, 1910-1978." *Amer. J. Agr. Econ.* 66 (November 1984): 414-21.

Askari, Hossein, and John Thomas Cummings. "Estimating Agricultural Supply Response with the Nerlove Model: A Survey." *International Economic Review*.18 (June 1977): 257-92.

Askari, Hossein G. *Agricultural Supply Response: A Survey of the Econometric Evidence*, with John Cummings. New York: Praeger, 1976.

Ball, V. Eldon. "Productivity and Growth in Postwar Agriculture." Paper presented at the Joint OECD/UNECE/Eurostat/FAO Seminar on Agricultural Statistics, Paris, France, 21-22 November, 2002.

Ball, V. Eldon. "Modeling Supply Response in a Multiproduct Framework." *Amer. J. Agr. Econ.* 70 (November 1988):813-25.

Ball, V. Eldon, Jean-Christophe Bureau, Kelly Eakin, and Agapi Somwaru. "Cap reform: modelling supply response subject to the land set-aside." *Agricultural Economics* 17 (1997): 277-288.

Barnett, William A. and Yul W. Lee. "The Global Properties of the Minflex Laurent, Generalized Leontief, and Translog Flexible Functional Forms." *Econometrica*, 53 (November 1985):1421-37.

Barnett, William A. "Tastes and Technology: Curvature is Not Sufficient for Regularity." *Journal of Econometrics*. 108(2002):199-202.

Berndt, E., and L. Christensen. "The Translog Function and the Substitution of Equipment, Structures, and Labor in U.S. Manufacturing, 1929-1968." *Journal of Econometrics*. 1 (March 1973):81-114.

Berndt, Ernst. *The Practice of Econometrics: Classic and Contemporary*. Addison-Wesley Publishing Company, Reading, MA, 1991.

Binswanger, Hans, Maw-Cheng Yang and Alan Bowers. "On the Determinants of Cross-Country Aggregate Agricultural Supply." *Journal of Econometrics* 36(1987):111-131.

Blackorby, Charles, Daniel Primont, and R. Robert Russell. "On Testing Separability Restrictions with Flexible Functional Forms." *Journal of Econometrics* 5(1977):195-209.

Chambers, Robert G. and Richard E. Just. "Estimating Multioutput Technologies." *Amer. J. Agr. Econ.* 71(November 1989):980-995.

Chambers, Robert G. *Applied Production Analysis: A Dual Approach*. Cambridge University Press: Cambridge, 1994.

Chavas, Jean-Paul and Matthew T. Holt. "Acreage Decisions under Risk: The Case of Corn and Soybeans." *Amer. J. Agr. Econ.* 72(August 1990):529-38.

Diebold, Francis X. and Russell L. Lamb. "Why Are Estimates of Agricultural Supply Response so Variable?" Finance and Economics Discussion Series 96-8, Board of Governors of the Federal Reserve System.

Diewert, W.E. and T.J. Wales. "Flexible Functional Forms and Global Curvature Conditions." *Econometrica*. 55(January 1987): 43-68.

Fawson, Chris and C. Richard Shumway. "A Nonparametric Investigation of Agricultural Production Behavior for U.S. Subregions." *Amer. J. Agr. Econ.* 70(May 1988):311-317.

Fernandez-Cornjo, Jorge. "Short- and Long-Run Demand and Substitution of Agricultural Inputs." *Agricultural and Resource Economics Review*. (April 1992):36-49.

Fulginiti, Lilyan, and Richard Perrin. "Argentine Agricultural Policy in a Multiple-Input, Multiple-Output Framework." *Amer. J. Agr. Econ.* 72(May 1990):279-88.

Just, Richard E. and Rulon D. Pope. "Production Function Estimation and Related Risk Considerations." *Amer. J. Agr. Econ.* 72(May 1979):276- 84.

Kumbhakar, Subal C. "Modeling Allocative Inefficiency in a Translog Cost Function and Cost Share Equations: An Exact Relationship." *Journal of Econometrics* 76(1997):351-56.

Kumbhakar, Subal C. "A Parametric Approach to Efficiency Measurement Using a Flexible Profit Function." *Southern Economic Journal*. 63(October 1996):473-87.

Lamb, Russell L. and Francis X. Diebold. "Why are Estimates of Agricultural Supply Response So Variable?" *Journal of Econometrics*. 76(Jan.-Feb. 1997):357-73.

Lau, Lawrence J. "A Characterization of the Normalized Restricted Profit Function." *Journal of Economic Theory*. (1976):131-63.

Lau, Lawrence J. "Testing and Imposing Monotonicity, Convexity, and Quasi-Convexity Constraints." Appendix A.4 in *Production Economics: A Dual Approach to Theory and Applications*. Volume I: The Theory of Production. Amsterdam: North-Holland, 1978.

Lim, Hongil, and C. Richard Shumway. "Technical Change and Model Specification: U.S. Agricultural Production." *Amer. J.Agr.Econ.* 79(May 1997): 543-554.

Lim, H. and C.R. Shumway. "Modeling Mexican Agricultural Production: Time Series Implications." *Empirical Economics*. (1999):509-28.

Lin, William, Paul C. Westcott, Robert Skinner, Scott Sanford, and Daniel G. De La Torre Ugarte, *Supply Response Under the 1996 Farm Act and Implications for the U.S. Fields Crops Sector*. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture. Technical Bulletin No. 1888.

Lopez, R. E. 1985. *Structural Implications of a Class of Flexible Functional Forms for Profit Functions*, *International Economic Review*. 26(1985): 26:593-601.

McClelland, John W. "Stationarity Assumptions and Technical Change in Supply Response Analysis." *Journal of Agricultural Economics Research*. 40(Fall 1988): 20-24.

McFadden, Daniel. "Convexity Analysis," Appendix A.3 in *Production Economics: A Dual Approach to Theory and Applications*. Volume I: The Theory of Production. Amsterdam: North-Holland, 1978.

Mielke, Karl D. "Acreage Response to Policy Variables in the Prairie Provinces." *Amer. J.Agr.Econ.* 58(August 1976): 572-77.

Mishra, Ashok K., Charles B. Moss and Kenneth W. Erickson. "Valuing Farmland with Multiple Quasi-Fixed Inputs." Unpublished manuscript. USDA-ERS and Department of Food and Resource Economics, University of Florida.

Moschini, Giancarlo. "The Semiflexible Almost Ideal Demand System." *European Economic Review* 42(1998):349-364.

Moschini, Giancarlo. "A Non-Nested Test of Separability for Flexible Functional Forms." *The Review of Economics and Statistics*, Vol. LXXIV (May 1992):365-69.

Moschini, Giancarlo. "A Model of Production with Supply Management for the Canadian Agricultural Sector." *Amer. J.Agr.Econ.* 70(May 1988):318-329.

Moschini, Ciancarlo. "Imposing Local Curvature Conditions in Flexible Demand Systems." *Journal of Business and Economic Statistics*. 17(October 1999):487-490.

Mundlak, Yair. *Agriculture and Economic Growth: Theory and Measurement*. Harvard University Press: Cambridge, MA, 2000, p 327.

Mundlak, Yair. "Production and Supply." Chapter 1, in *Handbook of Agricultural Economics*. Vol. 1A: Agricultural Production, ed. by Bruce L. Gardner and Gordon C. Rausser. (Amsterdam: Elsevier, 2001), pp. 3-85.

Mundlak, Yair. "Specification and Estimation of Multiproduct Production Functions." *Journal of Farm Economics.* 45(May 1963):433-444.

Nerlove, Marc. "Estimates of Supply of Selected Agricultural Commodities." *Journal of Farm Economics.* 38(1956):496-509.

Paris, Quirino, and Richard E. Howitt. "An Analysis of Ill-Posed Production Problems Using Maximum Entropy." *Amer. J.Agr.Econ.* 80(February 1998):124-138.

Paris, Quirino and Michael R. Caputo. "The Rhetoric of Duality." *Journal of Agricultural and Resource Economics,* 20(July 1995):195-214.

Pope, Rulon D. and Arne Hallam. "Separability Testing in Production Economics." *Amer. J.Agr.Econ.* 70(February 1988):42-152.

Ray, Subhash C. "A Translog Cost Function Analysis of U.S. Agriculture, 1939-1977." *Amer. J.Agr.Econ.* 64(August 1982): 490-98.

Schmitz, John D. "Dynamics of Beef Cow Herd Size: An Inventory Approach." *Amer. J.Agr.Econ.* 79(May 1997):532-542.

Shumway, C. Richard. "Recent Duality Contributions in Production Economics." *Journal of Agricultural and Resource Economics.* 20(July 1995):178-194.

Shumway, C. Richard, Rulon D. Pope, and Elizabeth K. Nash. "Allocatable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling." *Amer. J.Agr.Econ.* 66(February 1984):72-78.

Shumway, C. Richard and William P. Alexander. "Agricultural Product Supplies and Input Demands: Regional Comparisons." *Amer. J.Agr. Econ.* 70(February 1988):53-161.

Shumway, C. Richard and George C. Davis. "Does consistent aggregation really matter?" *Australian Journal of Agricultural and Resource Economics.* 45 (June 2001): 161-194.

Tweeten, Luther G. and C. Leroy Quance. "Positivistic Measures of Aggregate Supply Elasticities: Some New Approaches." *The American Economic Review.* 59(May 1969): 175-183.

Vasavada, U. and R.G. Chambers. "Investment in U.S. Agriculture." *Amer.J.Agr.Econ.* 68(November 1986): 950-60.

Weaver, Robert D. "Multiple Input, Multiple Output Production Choices and Technology in the U.S. Wheat Region." *Amer.J.Agr.Econ.* 65(February 1983):45-56.

Whipple, Glen D. and Dale J. Menkhaus. "Supply Response in the U.S. Sheep Industry." *Amer.J.Agr.Econ.* 71(February 1989):126-135.

Whittaker, James K. and Robert L. Bancroft. "Corn Acreage Response-Function Estimation with Pooled Time-Series and Cross-Sectional Data." *Amer.J.Agr.Econ.* 61(August 1979):551-53.

Table 1. Iterative Seemingly Unrelated Regression: R-Square, Adjusted R-Square, Durbin-Watson, and Parameter Estimates

Equation	R-Square	Durbin-Watson
LnProfit	0.383188	1.72838
RS1	0.00979448	1.35435
RS2	0.00242645	1.31434
RS3	0.536316	1.67423
CS1	0.00947139	1.28138
CS2	0.141610	1.35108

Restricted profit function:

$$\begin{aligned}
 \text{LPROFIT} = & A0 + A1 * \text{LOG}(P1/P6) + A2 * \text{LOG}(P2/P6) + A3 * \text{LOG}(P3/P6) \\
 & + A4 * \text{LOG}(P4/P6) + A5 * \text{LOG}(P5/P6) \\
 & + \text{LOG}(P1/P6) * (0.5 * A11 * \text{LOG}(P1/P6) + A12 * \text{LOG}(P2/P6) + A13 * \text{LOG}(P3/P6) \\
 & + A14 * \text{LOG}(P4/P6) + A15 * \text{LOG}(P5/P6)) \\
 & + \text{LOG}(P2/P6) * (0.5 * A22 * \text{LOG}(P2/P6) + A23 * \text{LOG}(P3/P6) * A24 * \text{LOG}(P4/P6) \\
 & + A25 * \text{LOG}(P5/P6)) \\
 & + \text{LOG}(P3/P6) * (0.5 * A33 * \text{LOG}(P3/P6) + A34 * \text{LOG}(P4/P6) + A35 * \text{LOG}(P5/P6)) \\
 & + \text{LOG}(P4/P6) * (0.5 * A44 * \text{LOG}(P4/P6) + A45 * \text{LOG}(P5/P6)) \\
 & + \text{LOG}(P5/P6) * (0.5 * A55 * \text{LOG}(P5/P6)) \\
 & + B15 * \text{LOG}(P5/P6) \\
 & + T * (C11 * \text{LOG}(P1/P6) + C12 * \text{LOG}(P2/P6) + C13 * \text{LOG}(P3/P6) + C14 * \text{LOG}(P4/P6) \\
 & + C15 * \text{LOG}(P5/P6)) \\
 & + D1 * T + 0.5 * D11 * T^{**2};
 \end{aligned}$$

Revenue share equations:

$$\begin{aligned}
 \text{RS1} = & A1 + A11 * \text{LOG}(P1/P6) * A12 * \text{LOG}(P2/P6) + A13 * \text{LOG}(P3/P6) + A14 * \text{LOG}(P4/P6) \\
 & + A15 * \text{LOG}(P5/P6) + B11 * \text{LOG}(A) + C11 * T;
 \end{aligned}$$

$$\begin{aligned}
 \text{RS2} = & A2 + A12 * \text{LOG}(P1/P6) * A22 * \text{LOG}(P2/P6) + A23 * \text{LOG}(P3/P6) + A24 * \text{LOG}(P4/P6) \\
 & + A25 * \text{LOG}(P5/P6) + B12 * \text{LOG}(A) + C12 * T;
 \end{aligned}$$

$$\begin{aligned}
 \text{RS3} = & A3 + A13 * \text{LOG}(P1/P6) * A23 * \text{LOG}(P2/P6) + A33 * \text{LOG}(P3/P6) + A34 * \text{LOG}(P4/P6) \\
 & + A35 * \text{LOG}(P5/P6) + B13 * \text{LOG}(A) + C13 * T;
 \end{aligned}$$

Cost share equations:

$$\begin{aligned}
 \text{CS1} = & A4 + A14 * \text{LOG}(P1/P6) + A24 * \text{LOG}(P2/P6) + A34 * \text{LOG}(P3/P6) + A44 * \text{LOG}(P4/P6) \\
 & + A45 * \text{LOG}(P5/P6) + B14 * \text{LOG}(A) + C14 * T;
 \end{aligned}$$

$$\begin{aligned}
 \text{CS2} = & A5 + A15 * \text{LOG}(P1/P6) + A25 * \text{LOG}(P2/P6) + A35 * \text{LOG}(P3/P6) + A45 * \text{LOG}(P4/P6) \\
 & + A55 * \text{LOG}(P5/P6) + B15 * \text{LOG}(A) + C15 * T;
 \end{aligned}$$

Table 1. Iterative Seemingly Unrelated Regression: R-Square, Adjusted R-Square, Durbin-Watson, and Parameter Estimates (continued)

Parameter	Estimate	Std Err	t Value	Pr > t
A0	-126.044	111.058	-1.13495	[.256]
A1	32.9047	13.2950	2.47497	[.013]
A2	18.4334	18.7054	0.985458	[.324]
A3	28.2298	3.88832	7.26014	[.000]
A4	30.4231	3.44727	8.82527	[.000]
A5	-29.0275	9.02481	-3.21641	[.001]
A11	1.35065	1.04435	1.29329	[.196]
A12	-2.51202	1.11312	-2.25673	[.024]
A13	-1.12820	0.270944	-4.16397	[.000]
A14	-1.42678	0.359205	-3.97204	[.000]
A15	1.31314	0.542192	2.42192	[.015]
A22	-1.16751	1.57679	-0.740437	[.459]
A23	-2.34860	0.331097	-7.09337	[.000]
A24	-2.71787	0.286191	-9.49672	[.000]
A25	2.34743	0.762199	3.07981	[.002]
A33	-1.10571	0.372088	-2.97163	[.003]
A34	0.077348	0.312757	0.247312	[.805]
A35	0.719135	0.257759	2.78995	[.005]
A44	-0.199534	0.164661	-1.21179	[.226]
A45	0.089846	0.227187	0.395473	[.692]
A55	-2.15313	0.43793	-4.91590	[.000]
B11	3.12454	3.80795	0.820530	[.412]
B12	-1.04024	0.366519	-2.83815	[.005]
B13	-0.178540	1.92124	-0.092930	[.926]
B14	-23.3206	4.51537	-5.16471	[.000]
B15	14.1977	2.42537	5.85380	[.000]
C11	0.012405	0.043685	0.283971	[.776]
C12	0.026226	0.044419	0.590421	[.555]
C13	-0.046053	0.016733	-2.75220	[.006]
C14	-0.191673	0.031097	-6.163371	[.000]
C15	0.116491	0.029691	3.92342	[.000]
D1	-0.181866	0.511708	-0.355410	[.722]
D11	0.0053918	0.00173474	3.10813	[.002]

Note: 1 is livestock, 2 is crops, 3 is secondary outputs, 4 is labor, 5 is non-land capital, and 6 is materials.

Table 2. Output Supply and Demand Elasticities 1/

Commodity	Elasticity with Respect to Price of Secondary output					
	Livestock	Crops		Labor	Capital	Materials
Livestock	2.275	3.269	0.216	-2.278	1.702	-5.184
Crops	2.293	2.748	0.049	-2.400	1.941	-4.631
Secondary output	1.252	0.403	-2.261	-1.849	-0.022	2.477
Labor	3.859	5.795	0.540	-2.898	-2.033	-5.263
Capital	1.702	1.941	-0.022	-2.033	1.075	-2.663
Materials	-11.381	-14.156	1.478	11.458	-2.663	15.264

1/ Uses USDA-ERS data, 1948-1999. Curvature restrictions are not imposed on the model.

Table 3. Output Supply and Input Demand Elasticities 1/

Elasticity with Respect to Price of

Commodity	Live-stock	Fluid Milk	Grains	Oil-seeds	Other Crops	Durable Equipment	Real Estate	Farm-Produced Durables	Hired Labor	Energy	Other Purchased Inputs
Livestock	1.089	0.494	0.476	0.399	1.012	-0.534	-0.275	-0.369	-0.419	-0.286	-1.586
Fluid milk	1.266	0.642	0.604	0.477	1.173	-0.556	-0.319	-0.325	-0.554	-0.409	-1.998
Grains	0.991	0.491	0.838	0.411	0.947	-0.192	-0.425	-0.470	-0.307	-0.166	-2.117
Oilseeds	1.115	0.502	0.552	0.432	1.023	-0.519	-0.342	-0.409	-0.358	-0.321	-1.692
Other crops	1.091	0.493	0.491	0.394	1.110	-0.613	-0.277	-0.319	-0.472	-0.219	-1.681
Durable equipment	1.359	0.552	0.235	0.473	1.446	-1.271	-0.192	-0.228	-0.443	-0.321	-1.611
Real estate	0.864	0.391	0.641	0.384	0.806	-0.237	-0.584	-0.622	-0.252	-0.206	-1.186
Farm produced durables	1.331	0.457	0.814	0.528	1.066	-0.323	-0.713	-1.162	-0.242	-0.219	-1.537
Hired labor	1.625	0.837	0.571	0.496	1.694	-0.674	-0.310	-0.260	-1.500	-0.379	-2.099
Energy	1.467	0.820	0.409	0.500	1.042	-0.647	-0.336	-0.312	-0.503	-0.941	-1.588
Other purchased inputs	1.412	0.694	0.906	0.538	1.388	-0.564	-0.336	-0.379	-0.483	-0.276	-2.900

1/ V. Eldon Ball, Table 6, p. 823, "Modeling Supply Response in a Multiproduct Framework," *American Journal of Agricultural Economics*, November, 1988. Curvature restrictions were imposed on the model using the Cholesky decomposition (pp. 816-817).