Exploring Agricultural Production Systems: Interactions between the Crop and Livestock Sectors

Dong Hee Suh, Ph.D. Candidate
Food and Resource Economics Department
University of Florida
Email: do1ghsuh@ufl.edu

Charles B. Moss, Professor
Food and Resource Economics Department
University of Florida
Email: cbmoss@ufl.edu

Selected Paper prepared for presentation at the Agricultural & Applied Economics Associations 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

Exploring Agricultural Production Systems: Interactions between the Crop and Livestock Sectors

Dong Hee Suh and Charles B. Moss

1 Introduction

The surge in food prices over the last few decades has raised concerns about the issues of food security and hunger, as high food prices are considered to negatively affect low-income consumers in developing and developed countries. According to the Food and Agriculture Organization (FAO), the Food Price Index increased by about 130%, from 91.1 in 2000 to 209.8 in 2013. For example, the Cereal Price Index increased from 85.8 in 2000 to 219.2 in 2013, while the Meat Price Index increased from 96.5 in 2000 to 184.2 in 2013. Given that a rise in agricultural commodity prices translates to an increase in food prices, the current high food prices are attributable to a combination of shocks to the supply and demand systems in the agricultural sector. Specifically, the demand factors such as growing demand for agricultural commodities in developing countries and rising demand for biofuels are reinforcing high agricultural commodity prices, while the supply factors such as increasing production costs and slowing growth in agricultural production under adverse weather conditions are driving high agricultural commodity prices (McCalla, 2009; Abbott et al., 2011). Moreover, the inelasticity of agricultural supply and demand contributes to higher and more volatile agricultural commodity prices in response to supply and demand shocks (Chambers and Vasavada, 1983; Leblanc and Hrubovcak, 1986; Shumway et al., 1988; Vasavada and Ball, 1988; Lansink and Stefanou, 1997; Warjiyo and Huffman, 1997).

The agricultural sector in the United States has also faced the pressure of meeting the increased demand for agricultural commodities under poor weather conditions, which has facilitated the adjustment of agricultural supply. In the crop sector, there have been significant shifts from food and feed crops to fuel crops to meet the increased demand for biofuels. An increase in the demand for biofuel feedstocks has motivated the adjustment of crop supply, thereby influencing the production of other field crops due to the competition for land and other resources between biofuel crops and non-biofuel crops. For instance, the increased demand for corn has caused higher corn prices and in turn, has motivated crop producers to plant corn on fields otherwise used for other crops (Hertel et al., 1996; Ruttan, 2002; Hertel, 2011). In addition to the adjustment of the crop sector, the livestock sector has responded to rising feed prices due to its dependence on crops such as corn and soybeans for livestock feed. For example, since corn is a primary component of livestock feed, a surge in corn prices has translated into an increase in the feed cost of livestock production (Tokgoz et al., 2008; Miljkovic et al., 2012). That is, due to the competition for corn between livestock and ethanol producers, an insufficient corn supply to the feed market has raised corn prices and in turn, has made livestock producers undoubtedly adjust their systems of input demand and output supply.

Given the adjustment of agricultural supply in the United States, it is necessary to explore the U.S. agricultural production systems, focusing on the interactions between the crop and livestock sectors. As the responses of the demand for inputs to their respective prices are of importance to the production of agricultural products, this paper evaluates the relationships among hired labor, self-employed labor, intermediate goods, capital, and land. In addition, as a change in an output price may affect the supply of other outputs if the output supply is correlated with one another, this paper identifies the relationships among crop, livestock, and farm-related outputs. This paper is organized as follows. Section 2 introduces the differential approach to the theory of the multiproduct firm. In Section 3, data are described, and estimation issues are discussed to propose a two-step estimation procedure that guarantees the theoretical validity of the input demand and output supply systems and improves their suitability to the data. In this section, estimation results are also presented to examine the input demand and output supply of the agricultural sector. The results contribute to identifying how changes in the prices of inputs and outputs are associated with the compositions of input demand and output supply, respectively. Finally, concluding remarks are provided in Section 4.

2 Differential Input Demand and Output Supply

Examining a multiproduct firm contributes to our understanding of output relationships in supply. This, in turn, can help the government promote price prediction when formulating policy measures (Shumway et al., 1988). In general, the dual approach to the theory of the multiproduct firm is used to estimate the systems of input demand and output supply, which usually requires specific flexible functional forms to directly approximate cost or profit functions. On the other hand, the differential approach has some advantages over the dual approach. The differential approach not only describes technology without any specific flexible functional forms but also reflects the differentiation of the optimizing conditions for the cost-minimizing inputs and profit-maximizing outputs of the multiproduct firm (Laitinen and Theil, 1978; Laitinen, 1980; Theil, 1980; Davis, 1997; Rossi, 1984; Fousekis and Pantzios, 1999; Livanis and Moss, 2006).

Following Laitinen and Theil (1978), we assume that a multiproduct firm employs n inputs, $x = (x_1, \cdots, x_n)'$, to make m products, $y = (y_1, \cdots, y_m)'$. For the differential system of input demand, the firm minimizes the cost, $C = w'x$ where $w = (w_1, \cdots, w_n)'$ is the vector of input prices, subject to a production constraint, $h(x, y) = 0$. The application of the differential approach to cost minimization yields the differential system of input demand, which is written as follows (for detailed derivation, refer to Laitinen and Theil (1978)):

$$f_i d\ln x_i = \gamma \sum_{r\in m} \theta_i^r g_r d\ln y_r - \psi \sum_{j\in n} (\theta_{ij} - \theta_i\theta_j)\, d\ln w_j \tag{1}$$

where γ is the total revenue-cost ratio, f_i is the cost share of input i, and g_r is the revenue share of output r. Each d represents infinitesimal changes in the natural logarithm of each variable. Moreover, θ_i^r reflects the share of input i in the marginal cost of output r, while $\psi(\theta_{ij} - \theta_i\theta_j)$ captures the price responsiveness of input demand.

For an empirical application, we add the error term (ϵ_i) to Equation (1) so that it follows a multivariate normal distribution with zero means and covariance matrix of $cov(\epsilon_i, \epsilon_j) = \sigma^2\psi(\theta_{ij} - \theta_i\theta_j)$ for $i, j = 1, \cdots, n$. In addition, the parameterization of this system requires converting infinitesimal changes to finite changes assuming that the parameters are constant over the periods. When each d is changed to Δ in order to represent finite changes in the natural logarithm of each variable, the finite version of the differential input demand is expressed as

$$\tilde{x}_{it} = \bar{\gamma}_t \sum_{r\in m} \theta_i^r \bar{g}_{rt} \Delta\ln y_{rt} + \sum_{j\in n} \pi_{ij}\Delta\ln w_{jt} + \epsilon_{it} \tag{2}$$

where $\bar{\gamma}_t = \sqrt{R_t R_{t-1}/C_t C_{t-1}}$ indicates the average revenue-cost ratio in which the revenue is $R = p'y$ given the output prices, $p = (p_1, \cdots, p_m)'$, and $\bar{g}_{rt} = (g_{rt} + g_{rt-1})/2$ represents the average revenue share of output r. In this formulation, we assume that both θ_i^r and $\pi_{ij} = -\psi(\theta_{ij} - \theta_i\theta_j)$ are constant coefficients so that the contemporaneous covariance matrix of error term remains the same in each period (Laitinen, 1980; Theil, 1980).

In addition, the total input decision of the multiproduct firm implies that the Divisia volume index of inputs is proportional to that of outputs. When we define the Divisia volume indices of inputs and outputs as $\Delta\ln X_t = \sum_{i\in n} \bar{f}_{it}\Delta\ln x_{it}$ and $\Delta\ln Y_t = \sum_{r\in m} \bar{g}_{rt}\Delta\ln y_{rt}$, respectively, the total input decision is $\Delta\ln X_t = \bar{\gamma}_t\Delta\ln Y_t$. Computing the residual quantity, $E_t = \Delta \ln X_t - \bar{\gamma}_t \Delta \ln Y_t$, we impose the condition of total input decision in the system by defining $\tilde{x}_{it} = \bar{f}_{it} (\Delta \ln x_{it} - E_t)$ where $\bar{f}_{it} = (f_{it} + f_{it-1})/2$ is the average share of input i. When we divide both sides of Equation (2) by $\bar{f}_{it}$, we obtain $\theta_i^r \bar{\gamma}_t \bar{g}_{rt} / \bar{f}_{it}$ for the output elasticity of input demand and $\pi_{ij}/\bar{f}_{it}$ for the price elasticity of input demand. Along with this parameterization of the differential system, we impose all theoretical restrictions on the input demand system: adding-up $\left(\sum_{i \in n} \theta_i^r = 1\right)$, homogeneity $\left(\sum_{j \in n} \pi_{ij} = 0\right)$, symmetry $(\pi_{ij} = \pi_{ji})$, and negative semi-definite π_{ij} matrix for concavity.

For the differential system of output supply, the multiproduct firm is assumed to maximize the profit, $R - C$, subject to the same production constraint, $h(x, y) = 0$. Similar to the case of input demand, the differential approach to profit maximization yields the differential system of output supply, which is written as follows (for detailed derivation, refer to Laitinen and Theil (1978)):

$$g_r d \ln y_r = \sum_{s \in m} \psi^* \theta_{rs}^* \left(d \ln p_s - \sum_{i \in n} \theta_i^s d \ln w_i \right) \tag{3}$$

where g_r is the revenue share of output r, and θ_i^s is the additional expense on input i for additional production of output s. In addition, $\psi^* \theta_{rs}^*$ reflects the price responsiveness of output supply.

When we add the error term (ϵ_r^*) to Equation (3), it follows a multivariate normal distribution with zero means and covariance matrix of $cov(\epsilon_r^*, \epsilon_s^*) = \sigma^2 \psi^* \theta_{rs}^* / \gamma$ for $r, s = 1, \cdots, m$. For the parameterization of this system, we multiply this system by γ since the contemporaneous covariance matrix of the error term depends on γ which varies over time; this multiplication yields the homoskedastic error term (Laitinen, 1980; Theil, 1980). The finite version of the differential output supply is written as

$$\tilde{y}_{rt} = \sum_{s \in m} \alpha_{rs} \left(\Delta \ln p_{st} - \sum_{i \in n} \theta_i^s \Delta \ln w_{it} \right) + \epsilon_{rt}^{**} \tag{4}$$

where $\tilde{y}_{rt} = \bar{\gamma}_t \bar{g}_{rt} \Delta \ln y_{rt}$, and $\epsilon_{rt}^{**} = \bar{\gamma}_t \epsilon_{rt}^*$. In addition, $\alpha_{rs} = \bar{\gamma}_t \psi^* \theta_{rs}^*$ are treated as constant coefficients. Dividing both sides of Equation (4) by $\bar{\gamma}_t \bar{g}_{rt}$, we obtain $\alpha_{rs}/\bar{\gamma}_t \bar{g}_{rt}$ for the price elasticity of output supply. For the theoretical restrictions of the output supply system, we impose homogeneity $\left(\sum_{s \in m} \alpha_{rs} = 0\right)$, symmetry $(\alpha_{rs} = \alpha_{sr})$, and positive definite α_{rs} matrix for convexity.

3 Empirical Analysis

3.1 Data and Estimation Issues

Data are mainly obtained from the Economic Research Service (ERS) of the United States Department of Agriculture (USDA), which provides a statistical database for agricultural productivity (Table 1). The selected primary inputs are hired labor, self-employed labor, intermediate goods, capital, and land, while the major types of agricultural products are crop, livestock, and farm-related outputs.[1] The data used in this analysis include annual quantities and prices from 1948 to 2011. Figure 1 presents historical changes in the composition of agricultural products. Specifically, the quantity share of crop outputs increased from 46% in 1948 to 48% in 2011, whereas the quantity share of livestock outputs decreased from 51% in 1948 to 47% in 2011. The graphical descriptions show the possibility

[1] According to the USDA-ERS, the data for livestock outputs include meat animals, dairy, poultry and eggs, and miscellaneous livestock products not separately identified, while the data for crop outputs include food grains, feed grains, oil crops, vegetables and melons, fruits and nuts, sugar crops, maple, seed crops, miscellaneous field crops, hops, mint, greenhouse and nursery, and mushrooms. In addition, farm-related outputs represent the outputs of goods and services from certain non-agricultural or secondary activities which are closely related to agricultural production for which information on output and input uses cannot be separately observed. On the other hand, capital represents durable equipment, while intermediate goods include farm origin, energy, fertilizer and lime, pesticides, purchased services, and other intermediate goods.

that the output relationships among agricultural products drive changes in the fractions of crop, livestock, and farm-related outputs. Given the data, the U.S. agricultural sector, which produces three major outputs using five primary inputs, is considered the multiproduct firm. One difficulty may arise when the technologies of producing crop, livestock, and farm-related outputs are incorporated into the framework of the multiproduct firm. However, this difficulty will not affect the theory of the multiproduct firm because only the first-order and second-order derivatives of the production functions are necessary in the differential systems (Laitinen, 1980). As the differential systems do not require specific production technologies, it is possible for the differential systems to combine the production of crop, livestock, and farm-related outputs.

On the basis of the data, a two-step estimation procedure is proposed to estimate the differential systems using the maximum likelihood technique. Laitinen (1980) adopted the maximum likelihood technique to jointly estimate the coefficients of both input demand and output supply. With homogeneity and symmetry, he imposed the condition of nonlinear symmetry in order to estimate θ_i^s which exists in the equations of input demand and output supply. However, the joint estimation often fails to satisfy the regulatory conditions such as the concavity of input demand and the convexity of output supply, simultaneously. In order to address this issue, a two-step estimation is implemented by assuming that the multiproduct firm chooses profit-maximizing output levels on the basis of cost-minimizing input levels; this is generally known as the two-step profit maximization.[2] That is, the equations of input demand are estimated in the first step, and the estimated values of $\hat{\theta}_i^s$ are substituted into the equations of output supply in the second

[2]Theil (1980) emphasized that the differential systems reflect the implied hierarchy within the multiproduct firm. In the two-step profit maximization, the hierarchy reflects that the output supplier can be separated from the input demander by viewing the output supplier as the superior of the input demander. For the multiproduct firm producing crop, livestock, and farm-related outputs, the output supplier may be an output manager or a subdivision that makes the decisions regarding supplying crop, livestock, and farm-related outputs, while the input demander may be an input manager or a subdivision that deals with the decisions about demanding hired labor, self-employed labor, intermediate goods, capital, and land.

step. In each step of estimating the systems, the theoretical restrictions are imposed on the systems. Considering the possibility that the restrictions can be often rejected in a small sample (Laitinen, 1978; Meisner, 1979; Moss and Theil, 2003; Cameron and Trivedi, 2005), the bootstrapping method is applied to obtain the estimates that satisfy the theoretical conditions. Following the method of Terrell (1996), the bootstrapped estimates are tested for the regulatory restrictions so that the procedure contributes to the theoretical validity of input demand and output supply and improves their fits to the sample data (Wolff et al., 2010).

3.2 Estimation Results

Table 2 reveals the estimation results of the differential input demand system in terms of the output elasticities of input demand. The estimated output elasticities of input demand show statistical evidence that an increase in the outputs leads to changes in the composition of input demand. An increase in crop outputs raises the demand for all inputs, which shows that a 1% increase in crop outputs raises the demand for hired labor, self-employed labor, intermediate goods, capital, and land by 0.52%, 0.70%, 0.47%, 0.85%, and 0.57%, respectively. With respect to a 1% increase in livestock outputs, the demand for self-employed labor decreases by 0.68%, but the demand for intermediate goods increases by 0.98%. A 1% increase in farm-related output raises only the demand for intermediate goods by 0.05%. The results show that an increase in crop, livestock, and farm-related outputs is accompanied with an increase in the demand for intermediate goods. In addition, as the demand for all inputs increases with respect to an increase in crop outputs, the U.S. agricultural sector seems to allocate more inputs to the production of crop outputs rather than the other outputs.

Table 3 shows the estimation results of the differential input demand system in terms of the price elasticities of input demand. In the estimated price elasticities of input demand, all own-price elasticities are negative and statistically significant. Except for the demand for hired labor, the own-price elasticities are very inelastic, demonstrating that the demand for self-employed labor, intermediate goods, capital, and land responds little to changes in their own prices. Specifically, a 1% increase in the own prices reduces the demand for hired labor, self-employed labor, intermediate goods, capital, and land by 1.25%, 0.67%, 0.16%, 0.14%, and 0.03%, respectively. In addition, there exist substitutable and complementary relationships among the inputs. For instance, a 1% increase in the price of hired labor leads to approximately a 0.43% increase in the demand for self-employed labor, while a 1% increase in the price of self-employed labor causes about a 0.82% increase in the demand for hired labor. This implies that agricultural producers have flexibility in adjusting labor to changes in wage rates, which is more attributable to the adjustment of hired labor rather than that of self-employed labor. In addition, the estimated cross-price elasticities suggest that intermediate goods are substituted by the other inputs. For instance, a 1% increase in the prices of intermediate goods raises the demand for hired labor, self-employed labor, capital, and land by 0.25%, 0.35%, 0.11%, and 0.08%, respectively. Regarding the demand for capital and land, statistical evidence shows a complementary relationship, representing that a 1% increase in the capital price reduces the demand for land by 0.02%, while a 1% increase in the land price reduces the demand for capital by 0.04%. This relationship suggests that an increase in agricultural areas is accompanied with an investment in durable equipment.

Table 4 presents the estimation results of the differential output supply system, showing the price elasticities of output supply. Statistical evidence reveals that the supply of agricultural products is very inelastic. A 1% increase in the own prices of crop and livestock products is likely to raise the supply of crop and livestock products by 0.024% and 0.016%, respectively. The results show that there is little flexibility in supplying crop and livestock products in response to changes in their own prices. In addition, the cross-price elasticities show the output relationship between crop and livestock products, suggesting that the U.S. agricultural sector substitutes crop products for livestock products, or vice versa. A 1% increase in the prices of crop products reduces livestock supply by 0.016%. Similarly, a 1% increase in the prices of livestock products reduces crop supply by 0.013%. This output relationship between crop and livestock products is of important to agricultural policy in the United States. If a policy measure stimulates the demand for crops, thereby increasing crop prices, the increased crop prices may reduce the supply of livestock products. Similarly, a policy measure raising livestock prices may contribute to a reduction in the supply of crop products. Without considering the output relationship, the implementation of a policy that focuses on one agricultural commodity will create unintended consequences in the supply of other agricultural commodities, and, in turn, affect their prices.

4 Conclusions

The inspiration for this paper comes from the current high and volatile food prices which are the results of mixed shocks to agricultural supply and demand. In response to a surge in the demand for agricultural commodities, the U.S. agricultural sector seems to be adjusting its agricultural supply to meet the increased demand. Given the contributions of the U.S. agricultural sector to the supply of food, feed, fiber, and fuel, it is important to explore the U.S. agricultural sector's input demand and output supply, focusing on the interrelationships among inputs and outputs in the production systems. As Shumway et al. (1988) emphasized the importance of understanding output relationships when implementing policy measures, identifying the output relationships would help the government predict agricultural supply and achieve stable agricultural and food prices. From this perspective, not only does this paper contribute to examining the responses of input demand and output supply to changes in their respective prices, it also identifies the interrelationships among inputs and outputs in the agricultural production systems.

The empirical analysis was performed by using the differential approach to the theory of the multiproduct firm, which offered the critical values in terms of elasticities. The estimation results of the input demand system suggest that the demand for hired labor, self-employed labor, intermediate goods, capital, and land significantly increases as crop outputs increase. In addition, the results show that the demand for inputs (except for hired labor) is very inelastic, suggesting that agricultural producers have little flexibility in adjusting the demand for inputs in response to rapid changes in input prices. The substitutable relationships among hired labor, self-employed labor, intermediate goods, and capital contribute to alleviating the pressure on production cost in response to a surge in input prices. Statistical evidence also reveals the complementary relationship between capital and land, suggesting that an investment in durable equipment increases proportionally to the expansion of agricultural areas. Furthermore, the estimation results of the output supply system suggest that agricultural supply is not very responsive to the respective price changes. There also exists statistical evidence that relative changes in the prices of crop and livestock products alter the composition of crop and livestock supply due to the substitutable relationship in supply.

The results reflect the interrelationships among inputs and outputs in the agricultural production systems. The findings are important because the results offer evidence that increased input prices may put high pressure on production cost due to the inelasticity of input demand. That is, the higher the input prices, the lower the supply of agricultural products. The reduced supply, in turn, may contribute to a rise in the prices of agricultural products. More importantly, the findings represent that the potential for policy measures to raise the demand for crop (livestock) products will raise their prices, thereby reducing the supply of livestock (crop) products. That is, the increased crop (livestock) prices will directly reduce the supply of livestock (crop) products due to the substitutable relationship between crop and livestock products in supply, which will also contribute to an increase in the prices of agricultural products. For example, as the U.S. biofuel policy raises the demand for biofuel crops, thereby increasing crop prices, livestock producers may face high feed cost due to their considerable dependence on crops such as corn and soybeans for livestock feed. Moreover, the increased cost of feed will contribute to a reduction in the supply of livestock products, thereby altering livestock prices. Therefore, the findings provide additional insight into the current agricultural and food policies. Given the importance of the interrelationships among inputs and outputs in the agricultural production systems, the findings suggest that an agricultural policy has to be justified by considering the potential impacts of the linkages and interactions between crop and livestock products.

References

Abbott, P., Hurt, C., Tyner, W., 2011. What's Driving Agricultural Prices in 2011? Farm Foundation.

Cameron, A., Trivedi, P., 2005. Microeconometrics: Methods and Applications. Cambridge University Press.

Chambers, R., Vasavada, U., 1983. Testing Asset Fixity for U.S. Agriculture. American Journal of Agricultural Economics 65(4), 761–769.

Davis, G., 1997. Product Aggregation Bias as a Specification Error in Demand Systems. American Journal of Agricultural Economics 79(1), 100–109.

Fousekis, P., Pantzios, C., 1999. A Family of Differential Input Demand Systems with Application to Greek Agriculture. Journal of Agricultural Economics 50(3), 549–563.

Hertel, T., 2011. The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making? American Journal of Agricultural Economics 93(2), 259–296.

Hertel, T., Stiegert, K., Vroomen, H., 1996. Nitrogen-Land Substitution in Corn Production: A Reconciliation of Aggregate and Firm-Level Evidence. American Journal of Agricultural Economics 78(1), 30–40.

Laitinen, K., 1978. Why Is Demand Homogeneity So Often Rejected? Economics Letters 1(3), 187–191.

Laitinen, K., 1980. A Theory of the Multiproduct Firm. North Holland Publishing Company.

Laitinen, K., Theil, H., 1978. Supply and Demand of the Multiproduct Firm. European Economic Review 11(2), 107–154.

Lansink, A., Stefanou, S., 1997. Asymmetric Adjustment of Dynamic Factors at the Firm Level. American Journal of Agricultural Economics 79(4), 1340–1351.

Leblanc, M., Hrubovcak, J., 1986. Dynamic Input Demand: An Application to Agriculture. Applied Economics 18(7), 807–818.

Livanis, G., Moss, C., 2006. Quasi-Fixity and Multiproduct Firm. Economics Letters 93(2), 228–234.

McCalla, A., 2009. World Food Prices: Causes and Consequences. Canadian Journal of Agricultural Economics 57(1), 23–34.

Meisner, J., 1979. The Sad Fate of Asymptotic Slutsky Symmetry Tests for Large Systems. Economics Letters 2(3), 228–234.

Miljkovic, D., Shaik, S., Braun, D., 2012. Impact of Biofuel Policies on Livestock Production in the United States. Journal of Policy Modeling 34(6), 817–831.

Moss, C., Theil, H., 2003. Homogeneity Testing Revisited. Journal of Agricultural and Applied Economics 35(Supplement), 3–4.

Rossi, N., 1984. The Estimation of Product Supply and Input Demand by the Differential Approach. American Journal of Agricultural Economics 66(3), 368–375.

Ruttan, V., 2002. Productivity Growth in World Agriculture: Sources and Constraints. Journal of Economic Perspectives 16(4), 161–184.

Shumway, R., Saez, R., Gottret, P., 1988. Multiproduct Supply and Input Demand in U.S. agriculture. American Journal of Agricultural Economics 70(2), 330–337.

Terrell, D., 1996. Incorporating Monotonicity and Concavity Conditions in Flexible Functional Forms. Journal of Applied Econometrics 11(2), 179–194.

Theil, H., 1980. The System-Wide Approach to Microeconomics. The University of Chicago Press.

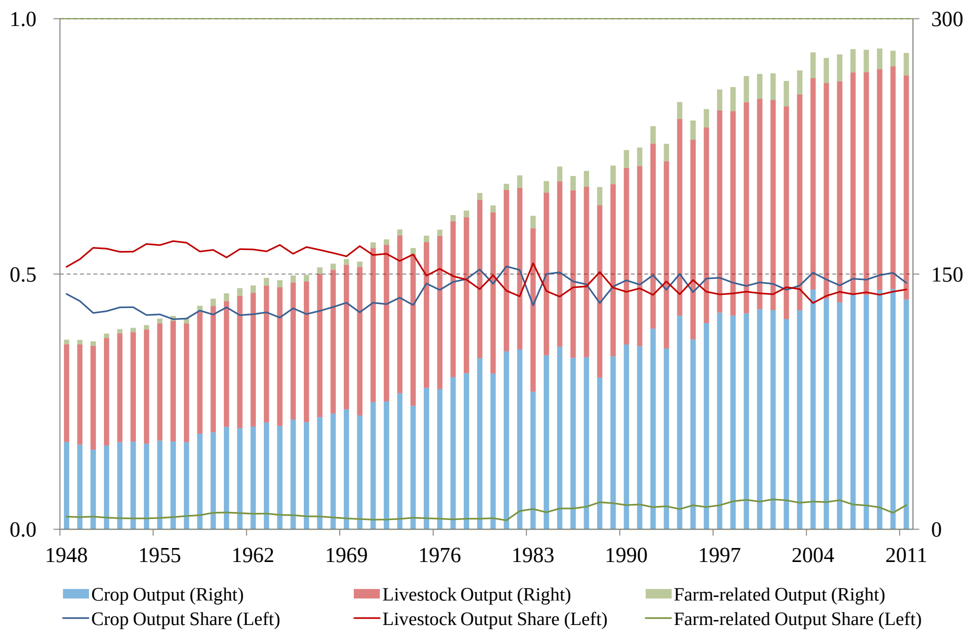
Tokgoz, S., Elobeid, A., Fabiosa, J., Hayes, D., Bobcock, B., Yu, T., Dong, F., Hart, C., 2008. Bottlenecks, Drought, and Oil Price Spikes: Impact on U.S. Ethanol and Agricultural Sector. Applied Economic Perspectives and Policy 30(4), 604–622.

Vasavada, U., Ball, V., 1988. A Dynamic Adjustment Model for U.S. Agriculture: 1948-79. Agricultural Economics 2(2), 123–137.

Warjiyo, P., Huffman, W., 1997. Dynamic Input Demand Functions and Resource Adjustment for U.S. Agriculture: State Evidence. Agricultural Economics 17(2), 223–237.

Wolff, H., Heckelei, T., Mittelhammer, R., 2010. Imposing Curvature and Monotonicity on Flexible Functional Forms: An Efficient Regional Approach. Computational Economics 36(4), 309–339.

Figure 1: Annual Changes in Supply of Agricultural Products, 1948-2011



Note: Quantities are in billion $ 2005, and their shares are measured as fractions.
Source: Agricultural Productivity in the Unites States, ERS, USDA

Table 1: Descriptive Statistics of Variables, 1948-2011

Variables	Mean	Std. Dev.	Minimum	Maximum
Hired Labor Price	0.3671	0.3479	0.0404	1.2328
Hired Labor Quantity	37,890	13,858	21,629	72,323
Self-Employed Labor Price	0.3655	0.3434	0.0411	1.2109
Self-Employed Labor Quantity	74,947	39,549	31,107	176,036
Intermediate Goods Price	0.5982	0.3485	0.2158	1.5375
Intermediate Goods Quantity	122,224	26,541	68,896	164,551
Capital Price	0.5865	0.3917	0.1200	1.2178
Capital Quantity	19,682	4,231	10,302	29,215
Land Price	0.5489	0.4362	0.1304	2.5635
Land Quantity	43,143	4,489	37,265	50,998
Crop Output Price	0.7719	0.3321	0.3611	1.7407
Crop Output Quantity	91,372	30,948	46,812	141,274
Livestock Output Price	0.6021	0.2766	0.2458	1.2514
Livestock Output Quantity	96,073	21,751	57,309	131,567
Farm-Related Output Price	0.6406	0.3804	0.1809	1.5371
Farm-Related Output Quantity	7,371	4,540	2,532	15,944

Note: Price indices are relative to 2005 = 1, and quantities are in million $ 2005
Source: Agricultural Productivity in the Unites States, ERS, USDA

Table 2: Output Elasticities of Input Demand

	Crop Output	Livestock Output	Farm-Related Output
Hired Labor Demand	0.5202***	-0.2936	0.0463
	(0.0663)	(0.1817)	(0.0325)
Self-Employed Labor Demand	0.7002***	-0.6753**	-0.0100
	(0.1406)	(0.2638)	(0.0344)
Intermediate Goods Demand	0.4671***	0.9828***	0.0548***
	(0.0374)	(0.0889)	(0.0143)
Capital Demand	0.8517***	0.2247	-0.0170
	(0.1109)	(0.3087)	(0.0293)
Land Demand	0.5670***	0.0907	0.0187
	(0.0389)	(0.1321)	(0.0219)

Note: Bootstrap standard errors are in parentheses.
***Denotes statistical significance at the 0.01 confidence level.
**Denotes statistical significance at the 0.05 confidence level.
*Denotes statistical significance at the 0.10 confidence level.

Table 3: Price Elasticities of Input Demand

	Hired Labor Price	Self-Employed Labor Price	Intermediate Goods Price	Capital Price	Land Price
Hired Labor Demand	-1.2566***	0.8166**	0.2497***	0.2161***	-0.0259*
	(0.3302)	(0.3287)	(0.0689)	(0.0785)	(0.0137)
Self-Employed Labor Demand	0.4340**	-0.6705***	0.3486***	-0.0745	-0.0376
	(0.1747)	(0.2118)	(0.1123)	(0.0496)	(0.0241)
Intermediate Goods Demand	0.0325***	0.0853***	-0.1599***	0.0159*	0.0261***
	(0.0089)	(0.0274)	(0.0340)	(0.0095)	(0.0080)
Capital Demand	0.1909***	-0.1238	0.1082*	-0.1377**	-0.0375*
	(0.0693)	(0.0824)	(0.0646)	(0.0595)	(0.0200)
Land Demand	-0.0107*	-0.0293	0.0831***	-0.0176*	-0.0254***
	(0.0057)	(0.0188)	(0.0255)	(0.0094)	(0.0092)

Note: Bootstrap standard errors are in parentheses.
***Denotes statistical significance at the 0.01 confidence level.
**Denotes statistical significance at the 0.05 confidence level.
*Denotes statistical significance at the 0.10 confidence level.

Table 4: Price Elasticities of Output Supply

	Crop Output Price	Livestock Output Price	Farm-Related Output Price
Crop Output Supply	0.0237** (0.0109)	-0.0131* (0.0078)	-0.0106 (0.0085)
Livestock Output Supply	-0.0157* (0.0094)	0.0156** (0.0091)	0.0001 (0.0050)
Farm-Related Output Supply	-0.1741 (0.1404)	0.0021 (0.0690)	0.1720 (0.1362)

Note: Bootstrap standard errors are in parentheses.
***Denotes statistical significance at the 0.01 confidence level.
**Denotes statistical significance at the 0.05 confidence level.
*Denotes statistical significance at the 0.10 confidence level.