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Cross-Sector Relationships Between the Corn Feed Grains and Livestock and Poultry Economies

John M. Marsh

A systems econometric model of the livestock (beef and pork), poultry (broiler), and corn sectors was estimated to evaluate cross-sector relationships. The equilibrium multipliers and comparative statics indicate unequal cross-effects of market disturbances, e.g., shocks in the livestock and poultry markets impact corn demand and supply more than shocks in the corn market impact livestock and poultry demands and supplies. Recent 2003 mad cow disease (BSE) problems in Canada and the United States display nontrivial cross-effects. For example, the BSE occurrences reduce real corn revenue in the United States by \$0.62 billion, or 5.0% of its 2003 revenue.

Key words: autoregressive distributed lags, comparative statics, equilibrium multipliers, revenue adjustments

Introduction

United States livestock, poultry, and grain producers are joint stakeholders regarding policies and economic changes in their industries. For example, U.S. Department of Agriculture (USDA) farm commodity programs and international grain trade agreements that impact grain production and prices can affect expected profits in livestock and poultry production. Likewise, structural changes in red meat and poultry demands or occurrences of livestock and poultry diseases can affect grain industry returns through the demand for feed. The USDA indicates about 55% of total feed grain disappearance (corn, oats, barley, and sorghum) was allocated to livestock and poultry feed use in 2003, and corn accounted for about 94% of total feed use in that year [USDA/National Agricultural Statistics Service (NASS), 2004].

The purpose of this study is to estimate joint farm-level demands and supplies in the corn feed grains, beef, pork, and poultry sectors and to evaluate the comparative statics of cross-sector relationships. A systems econometric model is developed that integrates the four sectors through mutual dependency of structural demands and supplies. Results indicate the comparative statics of cross-sector shocks depend upon system dynamics of the structural relationships. These factors are important in estimating cross-sector impacts such as the effects of corn loan rates, corn export demand, and fertilizer costs on demand and supply of livestock and poultry, or the effects of livestock and poultry

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meat demand on the demand and supply of feed corn. Producers have a vested interest in this information because of economic factors affecting their industries such as agricultural subsidies, agricultural trade, energy costs, animal health problems, and food safety issues.

Theoretical and empirical research involving the livestock, poultry, and feed grains sectors have received considerable attention (e.g., Anderson and Trapp, 1997; Aradhyula and Holt, 1989; Arzac and Wilkinson, 1979; Brandt, Kruse, and Todd, 1992; Chavas and Johnson, 1982; Freebairn and Rausser, 1975; Kulshreshtha and Reimer, 1975; Marsh, 1988, 1994; Rucker, Burt, and LaFrance, 1984; Shumway, Saez, and Gottret, 1988). These studies have varied according to model theory and development, methodology, and empirical/simulation results. A common feature of the research, however, has been testing of market hypotheses and measurement of supply and demand responses to exogenous policy and nonpolicy factors.

The current study differs from the literature cited above in that specific market variables, such as fertilizer costs, corn export demand, and USDA corn loan rates, are cross-correlated to livestock and poultry demand and supply responses. Likewise, variables such as beef, pork, and poultry meat demands are cross-correlated to corn demand and supply responses. Comparative statics are used to estimate revenue impacts of current market events. Included are revenue impacts on corn producers from mad cow disease (bovine spongiform encephalopathy, or BSE) occurrences in Canada and the United States, revenue impacts on corn producers from recent increases in consumer beef demand, and revenue impacts on livestock and poultry producers from recent increases in grain fertilizer costs.

Model Development

The livestock-poultry and corn model is specific to the farm level, consisting of supply and demand behavior of primary producers and marketing firms. However, the "farm level" as designated in the model reflects different degrees of vertical integration/coordination in the sectors. For example, the feeder pig market is not separately specified due to an industry dominated by integrated farrow-to-finish operations (i.e., packer-producer contracting). Similarly, the farm broiler market is not separately specified since the industry is highly integrated from hatching to wholesale processing. However, the feeder cattle, slaughter cattle, and corn sectors are less vertically coordinated and more conventionally defined. Thus, the sectors defined in the model are: (a) feeder cattle, (b) slaughter cattle, (c) slaughter hogs, (d) wholesale broilers, and (e) corn production.

The extent of vertical integration and the heterogeneity of buyers and sellers define the marketing agents in the model. In the feeder cattle sector, the sellers are cow-calf producers and the buyers are feedlot operators. In the slaughter cattle sector (over 85% consisting of fed steers and heifers), the sellers are feedlot operators and the buyers are meat packers. In the slaughter hog sector, the sellers are farrow-to-finish operators and the buyers are meat packers. In the broiler sector, the sellers are integrated operators producing processed poultry and the buyers are retail food establishments. In the corn sector, the sellers are farm producers and the buyers are finishers of livestock and poultry.

The model demands and supplies are theoretically based on first-order conditions of firm profit maximization. Firms using several inputs may produce multiple outputs with a given state of technology. First principles of the optimization problem give input demands as a function of own input prices, substitute input prices, output prices, and technology (see Henderson and Quandt, 1971, pp. 93–96, for details). For example, a farrow-to-finisher's input demand for corn depends upon the price of corn, the substitute price of sorghum, output price of slaughter hogs, and technology (genetics affecting slaughter weights). Output supply functions from first principles depend upon own prices, substitute prices in production, input prices, and technology. For instance, a corn grower's output supply depends upon the price of corn, the substitute price of soybeans, the input price of fertilizer, and technology (corn hybrids affecting yields).

For the market demand and supply equations that follow, vertical integration and firm heterogeneity pose problems for imposing micro theory parameter restrictions. Moreover, the use of rational distributed lags (following) complicates the imposition of theoretical parameter restrictions. Thus, parameter restrictions are not imposed, but rather, the theory of the firm serves as the basis for model identification of exogenous arguments. It is recognized that lack of parametric restrictions such as cross-equation symmetry could be inconsistent with theoretical profit functions.

Model Specification

The following equations represent the structural demands and supplies in the livestock-poultry and corn sectors. The maintained hypothesis includes competition and equilibrium conditions at the market levels (Brester and Marsh, 2001; Wohlgenant, 1989).

Corn Sector

$$(1) \quad Q_{CN}^S = \psi_1(P_{CN}^S, P_{LN}, P_{FT}, P_{SY}, D_P, T) + \mu_1 \quad (\text{supply}),$$

$$(2) \quad Q_{CN}^D = \psi_2(P_{CN}^D, P_E, P_{SS}, P_{SH}, P_{BW}, P_{SG}, T) + \mu_2 \quad (\text{demand}),$$

$$(3) \quad Q_{CN}^S = Q_{CN}^D \quad (\text{quantity market clearing}),$$

$$(4) \quad P_{CN}^S = P_{CN}^D \quad (\text{price market clearing}).$$

Feeder Calf Sector

$$(5) \quad Q_F^S = \psi_3(P_F^S, P_{CW}, P_H, T) + \mu_3 \quad (\text{supply}),$$

$$(6) \quad Q_F^D = \psi_4(P_F^D, P_{CN}, P_I, P_{SS}, T) + \mu_4 \quad (\text{demand}),$$

$$(7) \quad Q_F^S = Q_F^D \quad (\text{quantity market clearing}),$$

$$(8) \quad P_F^S = P_F^D \quad (\text{price market clearing}).$$

Slaughter Cattle Sector

$$(9) \quad Q_{SS}^S = \Psi_5(P_{SS}^S, P_{CW}, P_F, P_{CN}, T) + \mu_5 \quad (\text{supply}),$$

$$(10) \quad Q_{SS}^D = \Psi_6(P_{SS}^D, P_{BV}, P_{BX}, P_L, T) + \mu_6 \quad (\text{demand}),$$

$$(11) \quad Q_{SS}^S = Q_{SS}^D \quad (\text{quantity market clearing}),$$

$$(12) \quad P_{SS}^S = P_{SS}^D \quad (\text{price market clearing}).$$

Slaughter Hog Sector

$$(13) \quad Q_{SH}^S = \Psi_7(P_{SH}^S, P_{CN}, T) + \mu_7 \quad (\text{supply}),$$

$$(14) \quad Q_{SH}^D = \Psi_8(P_{SH}^D, P_{PV}, P_{PX}, P_L, T) + \mu_8 \quad (\text{demand}),$$

$$(15) \quad Q_{SH}^S = Q_{SH}^D \quad (\text{quantity market clearing}),$$

$$(16) \quad P_{SH}^S = P_{SH}^D \quad (\text{price market clearing}).$$

Broiler Sector

$$(17) \quad Q_{BW}^S = \Psi_9(P_{BW}^S, P_{CN}, P_{BL}, T) + \mu_9 \quad (\text{supply}),$$

$$(18) \quad Q_{BW}^D = \Psi_{10}(P_{BW}^D, P_{BX}, P_{PX}, P_{BR}, P_L, T) + \mu_{10} \quad (\text{demand}),$$

$$(19) \quad Q_{BW}^S = Q_{BW}^D \quad (\text{quantity market clearing}),$$

$$(20) \quad P_{BW}^S = P_{BW}^D \quad (\text{price market clearing}).$$

The definitions of variables are given in table 1. Equations (1) and (2) describe primary supply and derived demand for corn, respectively. Primary supply is based on the profit functions of corn growers. Derived corn demand is based on the profit functions of the beef, pork, and poultry users as well as by importing firms. The supply of corn (acreage \times yield) is a function of output corn market price (P_{CN}^S), output corn loan rate (P_{LN}), input fertilizer cost (P_{FT}), substitute price of soybeans (P_{SY}), a flexible cropping dummy variable (D_p), and technology (T , or trend reflecting genetics and mechanization). The USDA nonrecourse loan rate sets a floor price for program participating producers (Knutson, Penn, and Boehm, 1990). Specifying D_p accounts for the 1996 farm program (FAIR Act), which increased planting flexibility and reduced previous base acreage restrictions (Chambers, 2004).

Estimation of supply functions for feed grains is a complex issue due to historical changes in farm program provisions (Morzuch, Weaver, and Helmberger, 1980). With econometric estimation of grain supplies, the investigator normally attempts to balance specificity of program features with a more parsimonious set of regressors (Burt and Worthington, 1988). The approach here is to simplify farm program specifics by reducing program provisions to nonrecourse loan rates (price guarantees) and basic production (acreage) restrictions (Chambers, 2004; Westcott, Young, and Price, 2003).

Table 1. Variable Definitions of Livestock-Poultry and Corn Model

Variable	Definition
Endogenous Variables:	
Q_{CN}	Quantity corn produced (billion bushels)
Q_F	Quantity feeder calves, calf crop (million head)
Q_{SS}	Quantity slaughter cattle, live weight (billion pounds)
Q_{SH}	Quantity slaughter hogs, live weight (billion pounds)
Q_{BW}	Quantity broilers processed, ready-to-cook weight (billion pounds)
P_{BW}	Wholesale price of broilers ($\text{\$/pound}$)
P_{CN}	Price of No. 2 yellow corn, Central U.S. ($\text{\$/bushel}$)
P_F	Price of Medium No. 1, 600–700 pound feeder steers, Oklahoma City ($\text{\$/cwt}$)
P_{SS}	Price of Choice, Yield 2–4, 1,100–1,300 pound steers, Nebraska Direct ($\text{\$/cwt}$)
P_{SH}	Price of No. 1–3 barrows and gilts, Iowa/Southern Minnesota ($\text{\$/cwt}$)
Exogenous Variables	
P_{LN}	USDA nonrecourse corn loan rate ($\text{\$/bushel}$)
P_E	Export price of yellow corn ($\text{\$/bushel}$)
P_{SY}	Price of No. 1 yellow soybeans, Chicago ($\text{\$/bushel}$)
P_{SG}	Price of grain sorghum ($\text{\$/bushel}$)
P_{FT}	Price of nitrogen fertilizer ($\text{\$/ton}$)
P_{CW}	Price of slaughter cows, boning utility, Sioux Falls ($\text{\$/cwt}$)
P_{BR}	Retail price of broilers (young chicken) ($\text{\$/pound}$)
P_{BL}	Live price of broilers ($\text{\$/pound}$)
P_{BX}	Cut-out (wholesale) value of beef, Central U.S. ($\text{\$/cwt}$)
P_{PX}	Cut-out (wholesale) value of pork, Central U.S. ($\text{\$/cwt}$)
P_H	Price of mixed alfalfa-grass hay ($\text{\$/ton}$)
P_I	U.S. prime interest rate (%)
P_{BV}	Farm by-product value of cattle ($\text{\$/pound}$)
P_{PV}	Farm by-product value of hogs ($\text{\$/pound}$)
P_L	Index of food marketing labor costs (1987 = 100)
D_P	Binary variable for production flexibility under the 1996 FAIR Act (1970–1995 = 0.0; 1996–2003 = 1.0)
BSE	Binary variable for mad cow disease (2003 = 1.0; 0.0 otherwise)
T	Trend (representing technology)

The demand for corn (Q_{CN}^D) depends upon input demand price of corn (P_{CN}^D), output export demand price of corn (P_E), output demand prices of livestock and poultry (P_{SS} , P_{SH} , P_{BW}), input substitute price of sorghum (P_{SG}), and technology (T). The livestock and poultry prices consist of slaughter steer price (P_{SS}), slaughter hog price (P_{SH}), and wholesale poultry price (P_{BW}), and are specified to represent demand conditions in beef and hog finishing and poultry processing. Ceteris paribus, increases in these demand prices would increase the demand for corn because of expectations of increased profits from additional animal units fed. Corn export demand price captures the effects of foreign demand for U.S. corn. In 2003, the United States exported about 19% of its domestic production. Equations (3) and (4) are market-clearing conditions for corn quantities and prices, respectively.

Equations (5) and (6) represent feeder calf supply and demand, respectively. Feeder supply is based on the profit functions of cow-calf producers, while derived feeder cattle demand is based on the profit functions of cattle finishing firms. Feeder calf supply is a function of output feeder calf price (P_F^S), output price of cull cows (P_{CW}), input price of hay (P_H), and technology (T , or trend). Technology in feeder calf production includes increased weaning weights (genetics) and health and nutrition management. Domestic calf crop, the major source of feeder calf supplies, reflects behavior of breeding herd inventories. Thus, feeder calf price in equation (5) is the output price specific to the *capital* good, breeding cows (Jarvis, 1974). Slaughter cow price represents the opportunity cost of breeding cattle. That is, breeding cows can be culled (slaughtered) for *consumption* good purposes (Jarvis). *Ceteris paribus*, higher slaughter cow prices would encourage additional culling, thereby decreasing the calf crop. Hay price represents cost of maintaining breeding herds, but it may also reflect weather conditions.

Equation (6) represents feedlot demand for feeder calf placements. Quantity demanded of feeder calves is a function of input demand price of feeder calves (P_F^D), the input price of feed corn (P_{CN}), input cost of interest rate (P_I), the output price of slaughter steers (P_{SS}), and technology (T). Equations (7) and (8) are the quantity and price market-clearing equations, respectively.

Equations (9) and (10) represent slaughter cattle supply and demand. Slaughter cattle supply is based on profit functions of cattle finishing firms, while slaughter cattle demand is based on profit functions of meat packing firms. Slaughter cattle supply is a function of output slaughter steer price (P_{SS}^S), output slaughter cow price (P_{CW}) (a small proportion of total slaughter is cull cows), input price of feeder calves (P_F), input price of corn (P_{CN}), and technology (T). Technology includes factors such as genetics and health and feed nutrition that affect average slaughter weights. Quantity demanded of slaughter cattle depends upon input slaughter steer price (P_{SS}^D), output prices of by-products (P_{BV}) and boxed beef (P_{BX}), input price of labor (P_L), and technology (T). Equations (11) and (12) give the market-clearing conditions for slaughter cattle quantities and prices, respectively.

Equations (13) and (14) represent slaughter hog supply and demand, respectively. Slaughter hog supply is based on profit functions of farrow-finish production firms, and slaughter demand is based on profit functions of meat packing firms. Slaughter hog supply is a function of output slaughter price of barrows and gilts (P_{SH}^S), input price of feed corn (P_{CN}), and technology (T). The latter includes breeding genetics, health and nutrition, and mechanization, all of which have increased pig litter size and slaughter weights.

Equation (14) represents meat packer demand for slaughter hogs. Slaughter quantity demanded is a function of input slaughter demand price (P_{SH}^D), output prices of hog by-products (P_{PV}) and boxed pork (P_{PX}), input labor cost (P_L), and technology (T). Technology is specific to meat packer technological cost savings that can affect the derived demand for livestock (Brester and Marsh, 2001). Equations (15) and (16) give the market-clearing conditions for slaughter hog quantities and prices, respectively.

Equations (17) and (18) give the wholesale supply and demand for poultry (broilers). Wholesale supply is based on profit functions of poultry processors, while wholesale demand is based on profit functions of retail firms. Wholesale supply is a function of output wholesale price of broilers (P_{BW}^S), the input price of corn (P_{CN}), the input price of live broilers (P_{BL}), and technology (T). Technology in the integrated industry can

encompass genetics, disease control, feed management, capital stock, etc. The demand for wholesale poultry (by retailers) is a function of input wholesale broiler price (P_{BW}^D), input substitute prices of boxed beef (P_{BX}) and boxed pork (P_{PX}), output retail price of broilers (P_{BR}), input price of labor (P_L), and technology (T). Equations (19) and (20) give broiler quantity and price market-clearing conditions, respectively.

Dynamics

The demands and supplies of the livestock-poultry and corn (LPC) model may exhibit dynamic behavior due to biological growth, technology constraints, and expectations of sellers and buyers. A common representation of structural dynamics is autoregressive-distributed lags (ARDLs). In its conceptual form, the ARDL model represents a rational lag hypothesis with infinite distributed lags on the regressors (Greene, 2003). For example, agricultural supply would be a theoretical function of expected output and input prices, with expectations formed by parameter weights on lagged output and input price variables. The lag weights are represented by finite polynomial denominators and numerators specific to the dependent and independent variables, respectively (see Greene, pp. 571–576, for the polynomial lag functions).

Let an ARDL model consist of second-order lags. Represented in matrix form, we have:

$$(21) \quad \beta_0 \mathbf{Y}_t = \beta_1 \mathbf{Y}_{t-1} + \beta_2 \mathbf{Y}_{t-2} + \mathbf{v} \mathbf{Z}_{t-j} + \boldsymbol{\mu}_t, \quad j = 0, 1, 2.$$

The model consists of G equations. \mathbf{Y}_t is a $G \times 1$ vector of current endogenous variables, and \mathbf{Y}_{t-1} and \mathbf{Y}_{t-2} are $G \times 1$ vectors of lagged endogenous variables for one and two periods, respectively. β_0 is a $G \times G$ diagonal coefficient matrix, β_1 is a $G \times G$ coefficient matrix specific to the first-order lagged endogenous variables, and β_2 is a $G \times G$ coefficient matrix specific to the second-order lagged endogenous variables. The term \mathbf{Z}_{t-j} is a $K \times 1$ vector where K equals all current and lagged exogenous variables in the system, and the relevant coefficient matrix \mathbf{v} is $G \times K$. The $G \times 1$ error vector ($\boldsymbol{\mu}_t$) is assumed to be white noise but may be contemporaneously correlated (Greene, 2003). Chiang's (1984) transformation of the ARDL model gives (ignoring the error vector):

$$(22) \quad \beta'_0 \mathbf{y}_t = \beta'_1 \mathbf{y}_{t-1} + \mathbf{v}' \mathbf{z}_{t-j}, \quad j = 0, 1, 2,$$

where the \mathbf{y}_t and \mathbf{y}_{t-1} vectors are redefined through transforming second-order difference equations to a set of first-order difference equations (Chiang, 1984, pp. 605–613). The transformation of the two vectors results in adding G rows. The β'_0 and β'_1 coefficient matrices (order $2G \times 2G$) and the \mathbf{v}' coefficient matrix (order $2G \times K$) include submatrices consistent with Chiang's transformation process. Solving for \mathbf{y}_t , we obtain:

$$(23) \quad \mathbf{y}_t = (\beta_0'^{-1} \beta_1') \mathbf{y}_{t-1} + (\beta_0'^{-1} \mathbf{v}') \mathbf{z}_{t-j},$$

or simplifying,

$$(24) \quad \mathbf{y}_t = \bar{\beta} \mathbf{y}_{t-1} + \bar{\mathbf{v}} \mathbf{z}_{t-j},$$

where $\bar{\beta}$ and $\bar{\nu}$ are the corresponding matrix multiplications within the parentheses of equation (23).

Eigenvalues (or characteristic roots) are used to evaluate the dynamic stability of the system, and they are obtained from the coefficient matrix $\bar{\beta}$ of equation (24). The time paths of the multiplier coefficients (or rational distributed lag coefficients) are operationally derived from equation (24), and represent recursively estimated changes in \mathbf{y}_{t+j} ($j = 1, 2, \dots, k$ periods) subsequent to a *permanent* one-unit shock in \mathbf{z}_{t-j} ($j = 0$). Complex roots (if relevant) are still preserved using a transformation process by Chiang. Dynamic stability of the system occurs if every modulus of the eigenvalues is less than unity, in which case the distributed lag coefficients converge to long-run (equilibrium) multipliers. The solution or reduced form of the dynamic system of equation (24) is:

$$(25) \quad \bar{\mathbf{y}} = \left[(I - \bar{\beta})^{-1} \bar{\nu} \right] \bar{\mathbf{z}},$$

where $\bar{\mathbf{y}}$ is an equilibrium endogenous vector of $G \times 1$, and $\bar{\mathbf{z}}$ is an equilibrium exogenous vector of $(K - M) \times 1$. The bracketed term represents a $G \times (K - M)$ matrix of equilibrium multipliers, where M equals the total number of lagged exogenous variables. The multipliers of the LPC model are used for evaluating the nature of cross-sector effects and comparative statics of market shocks.

Data and Estimation

The sample period of estimation includes the years 1970 through 2003. Annual data specific to the corn sector are obtained from the USDA's *Feed Outlook* [USDA/Economic Research Service (ERS), 1972–2005] and *Agricultural Statistics* (USDA/NASS, 2004). Data relevant to the livestock and poultry sectors are obtained from various years of the USDA/ERS publications *Red Meats Yearbook*, *Poultry Yearbook*, and *Livestock, Dairy, and Poultry Situation and Outlook Reports*. All price/value data are deflated by the Consumer Price Index (CPI, 1982–84 = 100). The CPI and prime interest rate are taken from the *Economic Report of the President* (Congress of the U.S., Council of Economic Advisors, 2004), and the food marketing labor cost index is derived from the USDA/ERS *Agricultural Outlook* series (1972–2005). Corn export demand price was not available for the sample period; therefore, the variable was proxied by U.S. corn export demand quantities.¹

The demand equations of the LPC model are estimated as inverse demands, a common procedure for agricultural commodities where quantities may be predetermined (Eales, 1994; Wohlgenant, 1989). With prices expressed as dependent variables, the regressors include quantity demanded and the other theoretical variables specified in the structural demand equations. Thus, the \mathbf{y} vector of equation (24) consists of prices and quantities in the livestock, poultry, and corn sectors. Perturbations in \mathbf{z} of the solved system in equation (25) give the long-run changes in prices and quantities, and hence revenues in the market sectors.

¹ Other variables considered for export demand proxy were USDA trade-weighted dollar exchange rates for corn and an index of export quantity of feed grains, but data for these two variables were available for only latter years of the sample. The proxy variable used, U.S. corn export demand quantity, was lagged one period to avoid endogeneity problems in the corn inverse demand equation.

The rational distributed lag model includes joint dependency of prices and quantities. Contemporaneously correlated errors likely exist since stochastic processes may be common to the grain and livestock markets. Because of time-series properties, first-order autoregressive [AR(1)] error terms were also tested. Consequently, the model was estimated by three-stage least squares (3SLS) using a nonlinear least squares algorithm in the *EViews 3.1* software program. Nonstationarity and cointegrated relationships of the variables were not tested due to joint dependency in the model (Johnston and DiNardo, 1997, p. 317).

Empirical Results

Table 2 gives the 3SLS regression results of the structural equations, estimated in double logs. The ARDL equations were specified with $t - 1$ lags on the dependent variables and t and $t - 1$ lags on the exogenous variables. However, in the feeder calf supply equation, $t - 1$ and $t - 2$ lags were specified (on the dependent and independent variables) to allow for a protracted cattle inventory response (Rosen, Murphy, and Scheinkman, 1994). The empirical equations resulted in several insignificant lag coefficients. Because of a large number of system parameters, joint lags of the model were subjected to the Wald coefficient restriction test at the $\alpha = 0.05$ level. Test results for the feeder calf supply equation statistically supported joint lags of $t - 1$ and $t - 2$ for feeder calf price, but only $t - 2$ for hay price and only $t - 1$ for cull cow price. In the other equations, the Wald test supported only a single lag term (either t or $t - 1$) on the theoretical variables.²

Although the adjusted R^2 and standard errors of equation (SE) are presented in table 2, the equation fits must be interpreted with caution due to the generalized least squares (GLS) transformation of the product moment matrices in the systems estimation (Greene, 2003). The asymptotic t -ratios for the coefficients of the AR(1) errors were not statistically significant at the $\alpha = 0.05$ level. Excluding the intercepts, the asymptotic t -ratios indicated 46 of the 61 estimated coefficients were statistically significant at the $\alpha = 0.05$ level. Three coefficients were significant at the $\alpha = 0.10$ level.

Corn Market

Results of the corn supply equation are consistent with expected profit maximization. The corn market price coefficient indicates a 1% increase in corn price increases corn production by 0.47%. Results also reveal corn producers positively respond to the corn loan rate. A 1% increase (decrease) in the corn loan rate increases (decreases) corn production by 0.21%. The relatively smaller effect of the corn loan rate suggests producers regard the loan rate as a minimum price. From 1970–2003, USDA data indicate the corn loan rate exceeded the corn market price about 12% of the time, while the percentage of corn production placed under Commodity Credit Corporation (CCC) loan averaged about 17%. Arzac and Wilkinson (1979), Gallagher (1978), Ryan and Abel (1973), Westcott (2005), and Westcott, Young, and Price (2003) all reported positive effects of corn market prices and corn support prices (including loan rates) on corn *acreage*.

² Lags of $t - 2$ were not significant in supply equations outside of the feeder calf sector. Some variables in the structural equations contained no significant coefficients. Nevertheless, each of those variables containing the largest coefficient (t or $t - 1$) was still retained because of theoretical reasoning. Overall, the multiplier coefficients of the solved reduced form were less sensitive to omitting insignificant lags of the structural model compared to constraining the model to be static or omitting theoretical variables altogether.

Table 2. 3SLS Regression Results of Livestock-Poultry and Corn (LPC) Model, 1970–2003 (double logs)**Corn Production:**

$$Q_{CN} = 4.126 + 0.469P_{CN(-1)} + 0.212P_{LN} - 0.484P_{FT} - 0.412P_{SY} + 0.151D_P + 0.011T$$

(3.627) (2.804) (1.656) (-1.680) (-3.044) (1.923) (1.042)

$$R^2 = 0.641 \quad SE = 0.142 \quad Dep. = 2.015$$

Corn Price:

$$P_{CN} = -3.387 - 0.371Q_{CN} + 0.191P_E + 0.454P_{BW} + 0.440P_{SS(-1)} + 0.127P_{SH(-1)}$$

(-2.568) (-2.662) (2.823) (2.708) (2.551) (1.455)

$$+ 0.316P_{SG} + 0.015T + 0.244P_{CN(-1)}$$

(3.476) (1.892) (3.444)

$$R^2 = 0.962 \quad SE = 0.073 \quad Dep. = 0.834$$

Feeder Calf Supply:

$$Q_F = 0.060 + 0.204P_{F(-1)} + 0.047P_{F(-2)} - 0.034P_{H(-2)} - 0.154P_{CW(-1)} - 0.002T + 0.896Q_{F(-1)}$$

(0.218) (4.509) (2.781) (1.904) (-3.197) (-1.604) (13.223)

$$R^2 = 0.977 \quad SE = 0.013 \quad Dep. = 3.733$$

Feeder Calf Price:

$$P_F = 1.593 - 0.627Q_F + 1.297P_{SS} - 0.207P_{CN} - 0.098P_{I(-1)} - 0.226BSE + 0.001T$$

(1.075) (-1.991) (11.714) (-3.707) (-3.291) (-3.523) (0.220)

$$R^2 = 0.916 \quad SE = 0.073 \quad Dep. = 4.224$$

Slaughter Cattle Supply:

$$Q_{SS} = 1.518 + 0.188P_{SS(-1)} - 0.061P_{CW(-1)} - 0.064P_{CN(-1)} - 0.260P_F - 0.004T + 0.770Q_{SS(-1)}$$

(2.800) (2.211) (-1.292) (2.564) (-8.649) (-0.542) (7.610)

$$R^2 = 0.863 \quad SE = 0.024 \quad Dep. = 3.697$$

Slaughter Cattle Price:

$$P_{SS} = 1.304 - 0.565Q_{SS} + 0.754P_{BX} + 0.113P_{BV} + 0.194P_L - 0.001T$$

(2.810) (-9.354) (24.640) (5.622) (2.815) (-0.542)

$$R^2 = 0.996 \quad SE = 0.018 \quad Dep. = 4.064$$

Slaughter Hog Supply:

$$Q_{SH} = -0.457 + 0.241P_{SH(-1)} - 0.110P_{CN(-1)} + 0.008T + 0.845Q_{SH(-1)}$$

(-0.534) (2.852) (-2.723) (3.259) (4.550)

$$R^2 = 0.838 \quad SE = 0.052 \quad Dep. = 3.089$$

Slaughter Hog Price:

$$P_{SH} = 4.000 - 0.641Q_{SH} + 0.412P_{PX} + 0.225P_{PV} - 0.027P_L - 0.008T$$

(2.462) (-3.717) (3.853) (3.751) (-0.100) (-3.021)

$$R^2 = 0.988 \quad SE = 0.048 \quad Dep. = 3.713$$

[continued . . .]

Table 2. Continued**Broiler Supply:**

$$Q_{BW} = 0.167 + 0.091P_{BW(-1)} - 0.045P_{CN} - 0.055P_{BL} + 0.006T + 0.869Q_{BW(-1)}$$

$$(0.561) \quad (2.107) \quad (-1.839) \quad (-1.354) \quad (1.175) \quad (8.891)$$

$$R^2 = 0.997 \quad SE = 0.028 \quad Dep. = 2.782$$

Broiler Price:

$$P_{BW} = -0.723 - 0.133Q_{BW} + 1.045P_{BR} + 0.045P_{BX} - 0.003P_{PX} + 0.043P_L$$

$$(-0.480) \quad (-2.404) \quad (12.805) \quad (0.643) \quad (-0.059) \quad (0.181)$$

$$R^2 = 0.978 \quad SE = 0.048 \quad Dep. = 3.878$$

Notes: Asymptotic *t*-ratios are in parentheses below estimated coefficients. R^2 is adjusted *R*-squared, SE is standard error of equation, and Dep. is the log mean of the dependent variable. Critical *t*-values at $\alpha = 0.05$ and $\alpha = 0.10$ levels of significance are 1.960 and 1.645, respectively. Degrees of freedom (254) for the system are $MT^* - K$, where M = number of equations (10), T^* = adjusted sample size (full sample of 34 observations less two observations because of lag $t - 2$), and K = number of estimated parameters (66) in the system.

The effects of fertilizer cost and soybean price on corn supply were statistically significant. A 1% increase in fertilizer price decreases corn production by 0.48%. This input effect emphasizes the importance of energy costs in production, particularly since corn yields depend upon rates of fertilizer application. For soybeans (a substitute in corn production), a 1% increase in soybean price is found to decrease corn production by 0.41%. Arzac and Wilkinson (1979) found soybean price and prices of farm inputs to be insignificant in affecting corn acreage, while a University of Illinois Extension Service (2002) study indicated soybeans to be a strong production substitute for corn in planted acreage decisions.

The effect of the production dummy variable (1996 FAIR Act) on corn production was positive and significant. Its economic effect is relatively small, perhaps due to profit switching among alternative crops during the 1996–2003 period. Chambers (2004) concluded a significant structural change in the corn market after 1996 occurred because of more flexible cropping allowed in the 1996 farm bill.

The demand price for corn resulted in a Koyck distributed lag (first-order lag on the dependent variable) with most variables statistically significant. Market prices of slaughter steers, slaughter hogs, and wholesale broilers indicate that increases in demand prices for livestock and poultry increase the demand price of feed corn. Multicollinearity problems reduced the significance of slaughter hog price, but the Wald coefficient test yielded joint significance of the three price variables. Note the demand price effects of slaughter steers and broilers are nearly equal, with coefficients of 0.44 and 0.45 in the short run and 0.58 and 0.60 in the long run.³ Their equivalency reflects large growth in the broiler industry. In 1970, live weight broiler production was 10.8 billion pounds and by 2003, production had increased to 44 billion pounds. During the same period, live weight cattle slaughter increased from 36.7 billion pounds to 43.7 billion pounds and live weight hog slaughter increased from 20.7 billion pounds to 26.8 billion pounds. Arzac and Wilkinson (1979) found number of animal units on feed had

³ For any equation, the long-run elasticities are the pertinent slope coefficients divided by 1.0 minus the coefficient of the lagged dependent variable. In an equation where a lagged dependent variable was not statistically significant, the long-run and short-run elasticities are assumed to be the same.

a positive impact on the quantity demanded of feed corn. Chambers (2004) concluded increased livestock feed grain consumption had a positive influence on corn price.

Corn supply (production and stocks) demonstrates negative effects (coefficient of -0.37) on corn demand price. These results are consistent with Chambers' (2004) production and stock effects on corn inverse demand. Corn export demand exhibits the expected positive effect on domestic corn price, i.e., a 1% increase in foreign demand for U.S. corn increases domestic corn price by 0.19%. Sorghum price, representing a substitution effect in livestock feed demand, was statistically significant with a cross-elasticity of 0.32. Chambers did not model substitute prices in corn inverse demand, but reported a negative (competitive) effect of corn exports from Argentina and Brazil on U.S. corn price in the 1990s.

Feeder Calf Sector

Output and input prices in the feeder calf supply equation were statistically significant with theoretically correct coefficient signs. A Koyck lag structure characterized the equation with one- and two-period lags on feeder calf price (positive effects). A two-period lag occurred for hay price (negative effect) and a one-period lag for slaughter cow price (negative effect). These lags reflect the biological interval between decisions to retain young females for breeding purposes and marketing their offspring. The positive feeder calf price effect is consistent with feeder cattle price effects on breeding cattle inventories estimated by Buhr and Kimm (1997), Marsh (2003), and Rucker, Burt, and LaFrance (1984). The respective short-run and long-run supply elasticities of the LPC model are 0.25 and 2.41, which compare to feeder cattle supply elasticities of 0.22 and 2.82 reported by Marsh (2003). Hay prices reflect costs of maintaining breeding herds, and thus affect calf crop inventories. The short- and long-run hay price elasticities are -0.03 and -0.33 , respectively. The significance of the lagged slaughter cow price emphasizes the importance of selling breeding stock for consumption purposes. The coefficients show a 1% increase in slaughter cow price decreases calf crop by 0.15% in the short run and 1.48% in the long run.

The effect of trend on calf crop supply is negative, which is contrary to expected technology effects in the cow-calf sector. However, trend in this case is likely reflecting the substantial decline in calf crop due to the decline in U.S. breeding cow inventories. These breeding inventories declined by 28% from 1975 to 2003 (USDA/NASS, 2004).

Inverse demand for feeder calves is affected by cost of gain in cattle finishing, represented by corn price (Anderson and Trapp, 1997). The corn price effect is relatively inelastic, i.e., a 1% increase in corn price reduces feeder calf price by 0.21%. This corn price elasticity falls within the range of those reported by Buccola (1980), Marsh (2003), and Shonkwiler and Hinckley (1985). Slaughter steer price displays the greatest impact on feeder calf price (elasticity coefficient of 1.30) because of its major role in determining fed cattle revenues. Feeder calf supply negatively impacts feeder calf price; however, its elasticity of -0.63 is less than the -1.10 elasticity reported by Shonkwiler and Hinckley (1985). [In preliminary work, Mexican feeder calf imports were added as a separate regressor in feeder calf inverse demand. But the coefficient was not statistically significant, and when it was added to domestic feeder supplies (forming total feeder calf supplies), the coefficient was not different from the current estimate. For the sample period, Mexican feeder calf imports comprised about 1.9% of U.S. feeder cattle supplies.]

Note that a BSE (mad cow disease) binary variable for 2003 was added to the feeder price equation. Its significant and negative effect allowed for the unanticipated events of BSE in Canada and the United States in 2003.

Slaughter Cattle Sector

The empirical results of cattle slaughter supply and inverse demand are generally consistent with theoretical reasoning. Cattle slaughter supply (a Koyck distributed lag) is a positive function of output slaughter steer price and a negative function of input prices of corn and feeder calves. The respective long-run elasticities of 0.82, -0.28, and -1.13 differ somewhat from those reported in earlier studies, but are in agreement with the theoretical effects (Jarvis, 1974; Marsh, 1994; Nelson and Spreen, 1978; Ospina and Shumway, 1979). Slaughter cow price was not statistically significant. Inverse slaughter cattle demand is negatively affected by slaughter quantity demanded (-0.59) and positively impacted by beef by-product value (0.11) and boxed beef price (0.75). The positive effect of labor cost is contrary to a priori reasoning.

Slaughter Hog Sector

The hog supply equation resulted in a Koyck distributed lag with significant first-order lags on slaughter hog price (positive effect) and corn price (negative effect). These output and input price effects are consistent with farm hog supply relationships estimated by Heien (1975), and Prescott and Stengos (1987). The effect of corn price is relatively smaller than that of slaughter hog price, i.e., long-run supply elasticities of -0.71 and 1.56, respectively. The positive effect of trend on supply reflects technology developments that have reduced unit production costs in farrow-to-finish operations.

Inverse demand for slaughter hogs reveals significant coefficients of slaughter quantity demanded (-0.64), by-product value (0.23), and boxed pork price (0.41). However, food labor cost displayed an insignificant effect on slaughter hog price.

Broiler Sector

The empirical results of wholesale broiler supply and demand are theoretically consistent. Quantity supplied of broilers is a Koyck distributed lag and is a positive function of broiler price and a negative function of corn price, i.e., respective long-run elasticities of 0.70 and -0.34. The input price of live broilers was negative but not highly significant. Chavas and Johnson (1982) estimated production stage elasticities in the broiler sector and obtained long-run broiler price and feed price supply elasticities of 0.88 and -0.51, respectively. Aradhyula and Holt (1989) examined broiler supply relationships and obtained short-run own-price and feed price elasticities of 0.31 and -0.06, respectively. Inverse wholesale demand is a negative function of broiler quantity (coefficient of -0.13) and a positive function of retail broiler price (coefficient of 1.05). Labor cost was insignificant, as were the competitive input prices of boxed beef and boxed pork. Aradhyula and Holt (1989) estimated wholesale broiler inverse demand and obtained a significant negative quantity coefficient (-0.062), but significant competitive effects of retail beef and pork prices, with opposite signs.

Table 3. Selected Equilibrium Multipliers of the Livestock-Poultry and Corn (LPC) Model

Exogenous Variables	Endogenous Variables				
	Corn Price	Corn Quantity	Feeder Cattle Price	Feeder Cattle Quantity	Slaughter Hog Price
Boxed Beef Price	0.370	0.174	0.331	0.798	0.084
Boxed Pork Price	0.030	0.014	-0.001	-0.002	0.213
Retail Broiler Price	0.518	0.243	-0.018	-0.043	0.118
Sorghum Price	0.376	0.176	-0.013	-0.031	0.086
Fertilizer Cost	0.213	-0.384	-0.007	-0.018	0.049
Corn Loan Rate	-0.093	0.167	0.003	0.008	-0.021
Corn Export Demand	0.227	0.106	-0.008	-0.019	0.052
Soybean Price	0.182	-0.327	-0.006	-0.015	0.041

Notes: Values in the table are in percentage terms. A full set of multipliers is available from the author upon request.

[extended . . . →]

Overall, the unrestricted coefficient estimates of the ARDL model are consistent with the theoretical constructs of output supplies and input demands. These results provide a consistent framework for analyzing cross-sector relationships and comparative statics of market shocks.

Multiplier Characteristics

Table 3 presents the equilibrium multipliers (or total elasticities) specific to selected exogenous variables. Determining a priori signs for multipliers can be problematic since the model solution is a nonlinear function of the structural coefficients. The equilibrium multipliers are contingent upon the dynamic stability (eigenvalues) of the system. The eigenvalues of the LPC model resulted in one pair of conjugate complex roots, i.e., 0.761 plus and minus 0.158*i* (*i* = imaginary). The remaining eigenvalues were strictly real roots with values ranging from 0.003 to 0.86. (The full set of eigenvalues is available from the author upon request.) The moduli of the complex roots and real roots were all less than unity (Chiang, 1984, pp. 512–513); thus, the livestock-poultry and corn model is dynamically stable.

Figures 1 and 2 present 15-year time paths of the dependent variables (the variables are labeled as in table 1). The distributed lag effects (coefficients) converge to the equilibrium multipliers given in table 3. The time paths are calculated with respect to permanent one-unit shocks in two exogenous variables, fertilizer price and boxed beef price. Other shock variables could have been selected, but the long-term paths of the dependent variables are dominated by the polynomial denominators of the rational lag model. These denominators are manifested in the $(\beta_0^{-1}\beta_1')$ term of equation (23). Therefore, given the short-term characteristics of the polynomial numerators, the long-run paths of the dependent variables are similar regardless of the exogenous variable shocked (Greene, 2003; Rucker, Burt, and LaFrance, 1984).⁴

⁴ Thus, if the rational lag denominator in an equation is characterized by geometric distributed lags (one real root) or by cyclical distributed lags (complex roots), a shock in any exogenous variable will result in respective geometric or cyclical long-term paths of the dependent variable.

Table 3. Extended

Exogenous Variables	Endogenous Variables				
	<i>Slaughter Hog Quantity</i>	<i>Slaughter Cattle Price</i>	<i>Slaughter Cattle Quantity</i>	<i>Broiler Price</i>	<i>Broiler Quantity</i>
<i>Boxed Beef Price</i>	-0.132	0.095	0.700	-0.088	0.057
<i>Boxed Pork Price</i>	0.310	-0.005	0.003	-0.002	-0.011
<i>Retail Broiler Price</i>	-0.184	-0.085	0.048	0.982	0.504
<i>Sorghum Price</i>	-0.133	0.035	-0.061	0.016	-0.118
<i>Fertilizer Cost</i>	-0.076	0.020	-0.035	0.009	-0.067
<i>Corn Loan Rate</i>	0.033	-0.009	0.015	-0.004	0.029
<i>Corn Export Demand</i>	-0.081	0.021	-0.037	0.009	-0.071
<i>Soybean Price</i>	-0.065	0.017	-0.030	0.008	-0.057

The distributed lag paths in figures 1 and 2 are mildly influenced by a cyclical component, which emanates from the feeder calf supply equation with lagged feeder price of $t - 2$. Also, the relatively large eigenvalues of 0.86 (indicated above) and 0.71 (not indicated) reflect rigidities in livestock and poultry production which prevent rapid equilibrium adjustments to market shocks. Overall, the equilibrium multipliers of the livestock, poultry, and grain sectors (given in table 3) reflect the dynamic time paths of each sector. As shown by figures 1 and 2, within 7–9 years livestock (cattle and hogs) reach long-run equilibrium, the broiler sector reaches long-run equilibrium within 2–4 years, and the grain sector within 2–3 years. These equilibrium positions are a function of biological growth periods and dynamic interaction of demands and supplies among the sectors. For example, the biological production cycle of broilers is relatively short. However, the equilibrium adjustment of the broiler sector also reflects lengthy dynamic adjustments of the beef and pork sectors as well as the protracted expansion of poultry vertical integration since the 1970s.

Multiplier Cross-Effects

An important issue raised in this research is the nature of cross-sector relationships. Specifically, are the effects of exogenous shocks in the livestock-poultry sectors on corn prices and quantities similar to the effects of exogenous shocks in the corn sector on livestock-poultry prices and quantities? Because the cross-effect multipliers are elasticity measurements, they can be directly compared.

One important observation is the relatively large impact of the poultry sector on the corn sector. Assuming retail and wholesale meat prices reflect market demand conditions, poultry's impact on corn prices and quantities exceeds those of beef and pork—a 1% increase in retail poultry price increases corn price and quantity by 0.52% and 0.24%, respectively. In contrast, a 1% increase in beef wholesale price increases corn price and quantity by 0.37% and 0.17%, respectively. The 1% increase in pork wholesale price results in corresponding corn price and quantity increases of 0.03% and 0.01%.

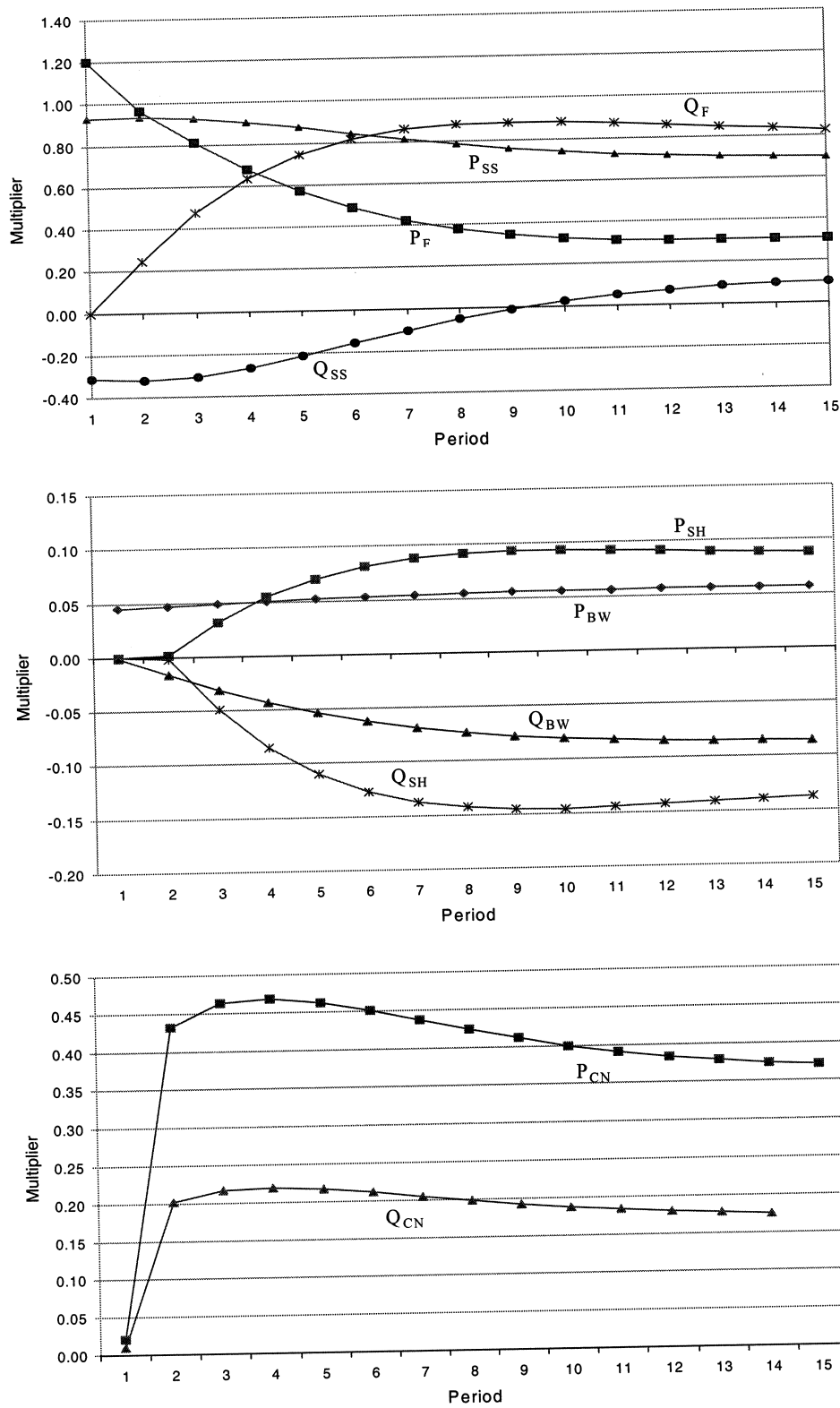


Figure 1. Multiplier time paths from one unit change in boxed beef price

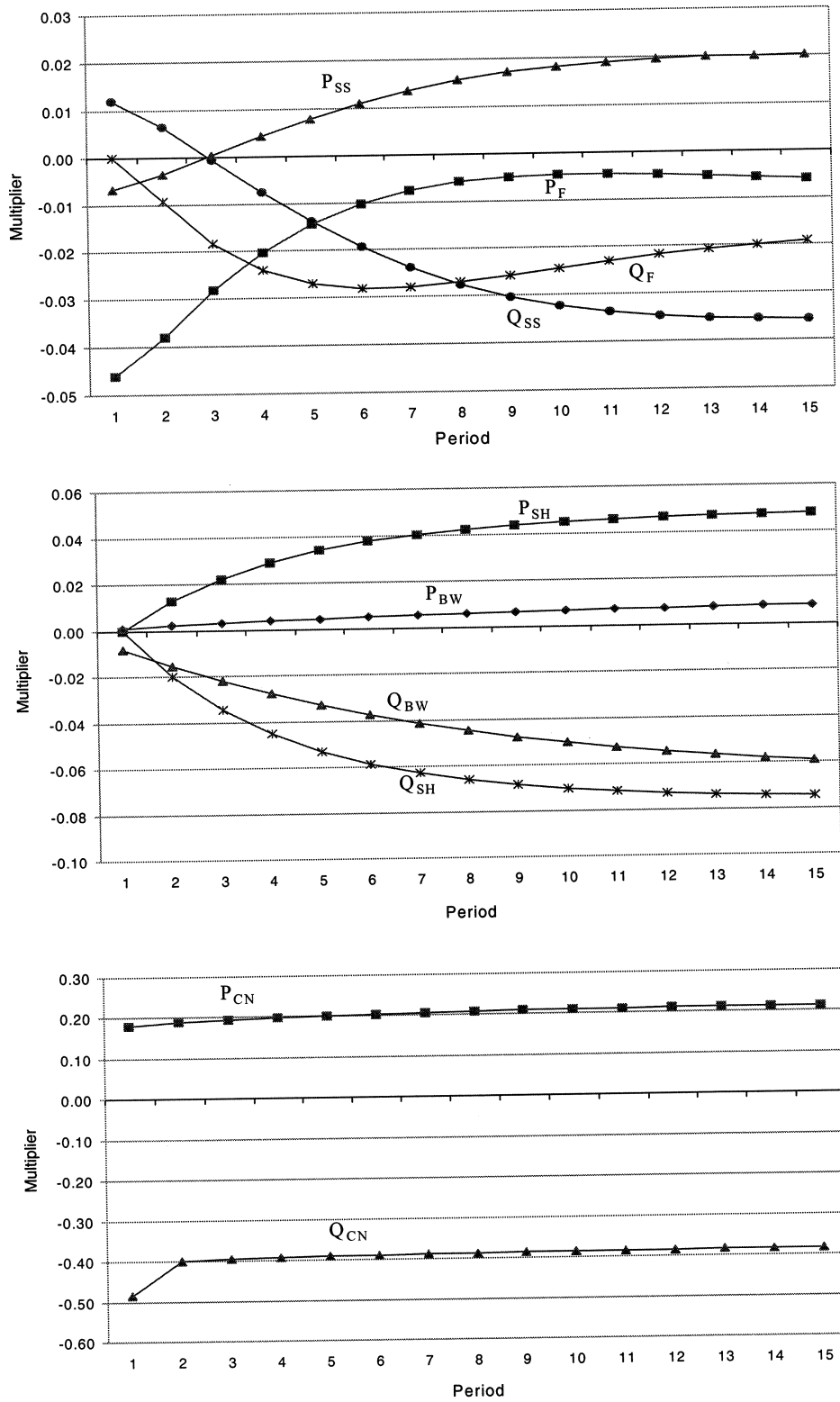


Figure 2. Multiplier time paths from one unit change in fertilizer cost

An examination of the multipliers reveals, on average, that economic changes in the livestock-poultry sectors impact the corn sector more than economic changes in the corn sector impact the livestock and poultry sectors. For example, a 1% increase in boxed beef price increases corn price by 0.37% and corn supply by 0.17%. However, a 1% increase in corn export demand decreases cattle slaughter supply by 0.04% and increases cattle price by 0.02%. Even smaller effects occur in the feeder cattle market. Or, a 1% increase in retail poultry price increases corn price and supply by 0.52% and 0.24%, respectively, but a 1% increase in fertilizer cost affects broiler price and quantity by 0.01% and -0.07%, respectively. Although comparative cross-effects differ with respect to exogenous variables shocked, these results emphasize that domestic demand conditions in livestock and poultry tend to outweigh (with respect to cross-effects) export demand and fertilizer cost conditions in the corn market.

Comparative Statics—Economic Events

Recent events in the beef and corn sectors are illustrative of producer vested interests in cross-sector relationships. These events result in pertinent shifts in demand or supplies that can be evaluated in the context of the current model. Specifically, from 1980 to 1998, consumer beef demand (as measured by a beef demand index) declined by about 50%; however, from 1998 to 2004, the beef demand index *increased* by about 26% due to improved quality, low-carbohydrate diets, and increased incomes (Livestock Marketing Information Center, 2005).

As noted earlier, outbreaks of BSE (mad cow disease) occurred in Canada and the United States in May and December of 2003. Recent work indicates that U.S. restrictions on imports of Canadian live cattle in May 2003 and reduced access of U.S. beef to foreign markets in 2004 (primarily Japan and South Korea) resulted in a net 7% decrease in real slaughter steer price (Marsh, Brester, and Smith, 2005). Also, the United States recently has experienced large increases in natural gas prices, a critical component of nitrogen (ammonia) fertilizer. From 2002 to 2004, nitrogen fertilizer prices (nominal) increased by about 50%, which would be about a 43% increase in real dollars (Washington Association of Wheat Growers, 2005).

The equilibrium multipliers are used to evaluate the comparative statics of these economic changes. Table 4 reports the long-term changes in equilibrium prices, quantities, and revenues relative to their 2003 values based on the assumption the above changes would be permanently held at the stated levels. Prices and revenues are in real terms. Based on the work of Marsh (2003) and the empirical results of the LPC model, the 26% beef demand increase translates into a 20.8% increase in real boxed beef price, and the 7% decrease in fed slaughter price translates into a 9.3% decrease in real boxed beef price.⁵ Real feeder calf revenues are based on an average feeder calf weight of 625 pounds.

⁵ For example, Marsh (2003) found a 1% increase in the beef demand index (D) increases slaughter cattle price (P_{SS}) by 0.604%. From the LDP model, a 1% increase in boxed beef price (P_{BX}) increases slaughter cattle price by 0.754%. If the beef demand index increases by 26%, then using partial derivatives we have:

$$\left(\frac{\partial P_{SS}}{\partial D}\right)\left(\frac{\partial P_{SS}}{\partial P_{BX}}\right)^{-1} \times 26.0 = (0.604)(0.754)^{-1} \times 26.0 = 20.8\%.$$

Table 4. Comparative Statics of Recent Economic Changes in Beef and Corn Sectors Relative to 2003 Values

Sector / Price, Quantity, Revenue		Economic Changes		
		Beef Demand (↑)	2003 BSE	Fertilizer Cost (↑)
Feeder Cattle:				
▶ Price (\$/cwt)	P_F	3.56	-1.60	-0.17
▶ Quantity (million head)	Q_F	6.29	-2.80	-0.29
▶ Revenue (\$ billions)	REV	3.01 (24.6%)	-1.26 (10.3%)	-0.13 (1.1%)
Slaughter Cattle:				
▶ Price (\$/cwt)	P_{SS}	6.70	-2.98	0.39
▶ Quantity (billion pounds)	Q_{SS}	0.87	-0.39	-0.66
▶ Revenue (\$ billions)	REV	3.38 (16.9%)	-1.48 (7.4%)	-0.14 (1.0%)
Corn:				
▶ Price (\$/bushel)	P_{CN}	0.04	-0.04	0.11
▶ Quantity (billion bushels)	Q_{CN}	0.17	-0.16	-1.67
▶ Revenue (\$ billions)	REV	0.66 (5.3%)	-0.62 (5.0%)	-1.10 (8.8%)
Slaughter Hogs:				
▶ Price (\$/cwt)	P_{SH}	0.36	-0.17	0.45
▶ Quantity (billion pounds)	Q_{SH}	-0.87	0.32	-0.88
▶ Revenue (\$ billions)	REV	-0.07 (1.2%)	0.01 (0.2%)	-0.08 (1.4%)
Broilers:				
▶ Price (\$/cwt)	P_{BW}	0.40	-0.16	0.13
▶ Quantity (billion pounds)	Q_{BW}	-0.59	0.26	-0.94
▶ Revenue (\$ billions)	REV	-0.07 (0.6%)	0.03 (0.3%)	-0.28 (2.5%)

Notes: Economic changes are: 26% increase (1998–2004) in retail beef demand; Canadian and U.S. mad cow disease occurrences in 2003; and 43% increase (2002–2004) in fertilizer price. Prices and revenues (REV) are in real terms, and numbers in parentheses are revenue changes as a percentage of 2003 revenues.

The impacts of these recent economic events, overall, are not trivial, though revenue impacts vary across sectors. For example, the 26% increase in beef demand increases feeder cattle and slaughter cattle revenues by \$3.01 billion and \$3.38 billion, respectively, or 24.6% and 16.9% of their 2003 revenues. The corn sector benefits from the retail beef demand increase through increased demand for feed, and along with increased corn production response, corn revenue increases by \$0.66 billion or 5.3% of its 2003 revenue. In the tradeoff, the pork and broiler sectors each realize slight revenue reductions of \$0.07 billion or 1.2% and 0.60% of their respective 2003 revenues.

The 43% increase in real fertilizer cost results in a greater impact on the corn sector than on the livestock and poultry sectors. (Energy costs also impact the livestock and poultry sectors in other ways, but those effects are not analyzed here.) The livestock and poultry sectors experience declining revenues. For example, as a percentage of 2003 revenues, the declines are 1.1% and 1%, respectively, for feeder and slaughter cattle, 1.4% for slaughter hogs, and 2.5% for broilers. Although the increase in fertilizer price

increases corn price by \$0.11 per bushel, the decline in corn production of 1.67 billion bushels causes corn revenues to decrease by \$1.10 billion, or 8.8% of its 2003 revenues.

The 2003 mad cow disease (BSE) outbreaks in North America yield negative revenue changes for the feeder cattle, slaughter cattle, and corn sectors with only slight revenue gains in the slaughter hog and broiler sectors. The declines in feeder cattle revenue (\$1.26 billion) and slaughter cattle revenue (\$1.48 billion) represent about 10.3% and 7.4% of their 2003 revenues. The reduction in corn revenue (from reduced feed demand) is \$0.62 billion, or about 5% of its 2003 revenue. The competitive pork and poultry sectors experience only slight revenue increases.

Conclusions

A systems econometric model of the livestock, poultry, and corn sectors was estimated to evaluate cross-sector relationships. The equilibrium multipliers and comparative statics reveal unequal cross-effects of sector market shocks, i.e., exogenous factors in livestock and poultry markets impact the corn sector more than exogenous factors in the corn market impact the livestock and poultry sectors. The demand and supply cross-effects are important to agricultural producers due to the dynamics of their industries. For example, the comparative statics indicate BSE problems in the beef industry reduce corn grower returns, and increasing fertilizer costs in grain production reduce returns to livestock and poultry producers.

The equilibrium multipliers suggest demand impacts of the integrated broiler industry on the corn sector exceed demand impacts of the beef and pork industries on the corn sector. These relative effects could have important economic implications for corn growers should a disruption such as avian bird flu infiltrate the domestic poultry industry. The dynamic model solution also emphasizes the importance of feedback relationships. For example, the equilibrium price and quantity time paths of broilers incorporate more than biological production periods of poultry, but the time paths also reflect longer term biological adjustments inherent in competitive beef and pork production.

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