Supply Dynamics in the U.S. Hog Industry

Matthew T. Holt and S. R. Johnson

Working Paper 86-WP 12
July 1986

Abstract

A quarterly econometric model of supply response in the U.S. hog industry is constructed. This model incorporates relevant biological features of hog production directly into the structural specification. Dynamic mean path elasticities of the model are analytically derived with the results indicating behavior which is consistent with economic intuition.

Analyzing the dynamic behavior of livestock supply response has long been of interest in agricultural economics. Indeed, many earlier contributions by agricultural economists represent attempts to identify and explain cyclical price-production patterns for various agricultural products (Hopkins 1926; Ezekiel 1938; Breimeyer 1958; Waugh 1964). Over the years, various theories and model specifications have been proposed to explain the dynamic nature of agricultural production. These include the adaptative expectations hypothesis (Nerlove 1958) and the partial adjustment model (Griliches 1967). Both procedures result in the same reduced form (except for the error process) and both imply a geometrically declining distributed lag structure. More flexible models of dynamic behavior have been proposed by Almon (1965) and Jorgenson (1966), although their methods require greater discretion and input by the investigator. Most recently, vector autoregressions (VARs) have been used to analyze the dynamic behavior of markets. The VAR approach assumes that all variables are endogenous to the system. In addition, no a priori relationships are imposed on the system (e.g., no exclusion restrictions are applied). Once constructed, the system can be shocked and the dynamic behavior inferred.

Numerous studies have used distributed lag specifications to model the dynamics of livestock production, including those by Harlow (1962); Heien (1975); Freebrain and Rausser (1975); Arzac and Wilkinson (1979); and Rucker, Burt, and LaFrance (1984). VAR models have been used by Bessler (1984), and Brandt and Bessler (1984) to explore the dynamics of the hog industry. Although these studies contribute to our knowledge of the livestock industry, a number of weaknesses remain. Problems arise because economic theory offers little guidance for actually specifying lag distributions or dynamic adjustment processes. While advances in the microfoundations of supply response have been made (Hansen and Sargent 1980; Eckstein 1985), researchers must still rely on their sample data, along with their subjective judgment, to choose the correct model specification.

Even though economists know little about the dynamics of expectation formation, there is often a rigid set of biological and technological interrelationships that govern supply response in livestock markets. As Chavas and Johnson (1982) show, it can be useful to view livestock production as a sequence of stages with particular functions performed at each stage. The decisions affecting output at any particular stage will limit the range of possible adjustments that can occur subsequently. Ignoring this potential source of prior information can result in models with poor statistical properties and inconsistent dynamic behavior.

In this paper, an approach similar to that employed by Chavas and Johnson (1982) is used to specify and estimate a dynamic supply response model for the U.S. hog industry. Special emphasis is placed on identifying and incorporating important biological relationships into the model specification. The dynamic properties of the model are then examined by analyzing the mean path elasticities resulting from changes in key exogenous variables.

The Biological Nature of Hog Production

Given the importance of biological lags, it is useful to review a few features of the hog industry. Production decisions in the hog industry can be examined on at least five different levels. The first level involves the size of the breeding herd, which is the primary engine of supply response. The available stock of breeding animals determines the potential number of sows that can farrow and places a physical limit on sow slaughter, the second level of production. The number of sows farrowing times litter size equals pig crop, the third production level. The current pig crop determines the subsequent magnitude of barrow and gilt slaughter, the fourth production level. The final level combines sow slaughter with barrow and gilt slaughter to determine total farm pork production.

Feedback occurs throughout the system as producers adjust the culling rate of sows and the level of gilt retention in response to changing price and profit expectations. Once the size of the breeding herd is determined (that is, once sow slaughter and gilt retention are known), short run hog production is essentially fixed. The size of the breeding herd determines the future size of the pig crop which, in turn, dictates the future level of barrow and gilt slaughter.

Knowledge of the biological nature of the production process can be useful in determining the lag lengths and dynamics involved in supply response. Sows and gilts farrow approximately four months after breeding. Pigs are usually weaned in a three-to-eight week period following farrowing and are then fed to a final market weight of 220 to 240 pounds. This "finishing process" takes between four and five months to complete. The above relationships imply that, on average, there will be a six-month lag between farrowing and slaughter and a ten-month lag between breeding and slaughter.

Model Specification

The aforementioned biological relationships constitute the prior information used in specifying the supply response model. In addition, all expected prices are assumed to be functions of observed lagged prices. Although these expectations are not rational in the sense implied by Muth (1961), they continue to do a reasonable job of explaining agricultural supply response. Other supply shifters include the price of corn and the short-term interest rate. The corn price was included because it is the most important component of the feed ration (cost of production studies [USDA] show that feed is the single most important expense in hog production) and interest rates were specified to reflect the cost and availability of credit.

Higher interest rates would tend to dampen the effects of breeding herd expansion. Throughout the model, seasonality is accounted for by using dummy variables for the second, third, and fourth quarters.

The model consists of four behavioral equations and one identity. In all cases, the behavioral equations were specified to be linear in the parameters and variables. In view of the biological lags in hog production, a quarterly observation period was chosen for analysis. The model was estimated by ordinary least squares over the 1967 to 1984 period. When necessary, corrections were made for first-order autocorrelation and the equations were reestimated in a generalized least squares framework. The data were obtained from various issues of the USDA's Hogs and Pigs, Livestock and Poultry Outlook and Situation Report, and annual supplements of Livestock and Meat Statistics. Interest rates were obtained from the Agricultural Finance Databook issued by the Federal Reserve System.

Breeding herd inventory (BHUS), equation (1) in table 1, is specified as a partial adjustment model. The coefficient on the lagged dependent variable indicates that only 12 percent of the desired adjustment in breeding herd inventory occurs from one quarter to the next. The two-quarter lags chosen for the hog price (FPPK) and corn price (PCO4) variables were a result of preliminary analysis. All economic variables have the expected sign and, with the exception of the interest rate (IFCL), are statistically significant. Breeding herd inventory is very price inelastic in the short-run, although price responsiveness does increase with time.

Lagged breeding herd inventory is a primary explanatory variable in the sow slaughter (SSUS) function, equation (2) in table 1. The breeding herd inventory from the previous quarter represents the available stock of sows that could be slaughtered. Sow slaughter should also increase with the average age of the breeding herd. To capture this effect, breeding herd inventory, lagged two quarters, was also included. The price of corn (PCO4) and the farm price of hogs (FPPK) were specified with one quarter lags. The current interest rate (IFCL) was also included. All economic variables have theoretically correct signs. The elasticities also indicate that sow slaughter was slightly more price responsive than breeding herd inventory in the short run.

Aside from litter size, the current pig crop (PCUS), equation (3) in table 1, must be proportional to the number of sows in the breeding herd. The hog price (FPPK), lagged two quarters, was also included, although the pig crop equation is very price inelastic. Preliminary estimations included other economic variables (i.e., interest rates and feed costs), but all were found to have low explanatory power and were excluded from the final version. This is in line with our a priori expectations, i.e., once sows are bred, there can be little short-run response to changing economic conditions.

Barrow and gilt slaughter (BGSUS) is the final behavioral equation. In view of the biological nature of hog production, pig crop, lagged one and two quarters, was included as the important explanatory variable (recall that it takes about six months to feed a pig to market weight). No economic variables were included in this equation. Again, the logic is that once pigs are put on feed little can be done to alter the number of market hogs that will result. A dummy variable (DMPC) was also included to account for changes in the way pig crop data were collected after 1973.

Equation (5) in table 1 is a domestic pork production (PPF) identity. Although this equation is a local approximation of the true identity, simulation results indicate that it predicted pork production with a high degree of accuracy. All equations do a reasonable job of explaining hog supply response over the fit period.

As an additional validation test, the model was simulated dynamically over the fit period. The root mean squared errors (RMSE) and the root mean squared percent errors (RMSPE) associated with each behavioral equation are presented in table 1. In general, the model did a good job of simulating actual response and the results were comparable with those of previous studies (e.g., Arzac and Wilkinson 1979; Martin 1982).

Dynamics of Hog Production

Once a linear model has been estimated, reduced form parameter estimates can be obtained. In the present study, the model is essentially recursive so that the reduced form can be readily obtained from the structural parameters. With the reduced form, the dynamic properties of the model can be investigated by examining mean path multipliers and elasticities. This approach is typically applied to a system of linear first-order stochastic difference equations. Consequently, in the present case the model must be transformed from a system of higher order stochastic difference equations into a first-order difference equation system. Following Chow (1975, pp. 107 and 233), the reduced form of the reparameterized system can be expressed as

$$\mathcal{Y}_t = A\mathcal{Y}_{t-1} + C\mathcal{X}_t + B_t + U_t$$

where $\mathcal{Y}_t$ is a redefined vector of endogenous and predetermined variables, $\mathcal{X}_t$ is a vector of redefined current exogenous variables, B_t is a vector containing constant terms, and U_t is the reduced form disturbance vector. The matrices A and C contain the reduced form parameters and the appropriate identities for reparameterization; these matrices determine the dynamic properties of the model. Intermediate run multipliers measure the combined effects of a change in an exogenous variable that has persisted for several periods. Intermediate run elasticities can be obtained from the relevant multipliers in the usual fashion.

Figure 1 shows the intermediate run elasticities for pork production due to a change in the farm price of hogs (FPPK), the corn price (PCO4), and the interest rate (IFCL). Of interest is that an increase in hog price actually results in decreased production for several periods. As the hog price increases farmers adjust their expectations, save more gilts for breeding, and reduce sow slaughter. Hence, it takes at least three or four periods before a higher price actually results in increased production. Considering the biological nature of hog production, these results seem entirely plausible and consistent. Increases in corn price or interest rates cause a similar response but in the opposite direction.

Table 1. Structural Parameter Estimates and Selected Fit Statistics

Equation (1) Breeding Herd Inventory(OLS)

$$BHUS = \underset{(2.29)^{a}}{1335.68} + \underset{\substack{(3.36)\\ [0.077]}}{18.21}\ FPPK_{-2} - \underset{\substack{(3.77)\\ [-0.091]}}{382.78}\ PCO4_{-2} - \underset{\substack{(0.63)\\ [-0.012]}}{9.91}\ IFCL + \underset{(15.26)}{.879}\ BHUS_{-1}$$

$$+ \underset{(.03)}{3.26}\ DV2 + \underset{(.75)}{79.72}\ DV3 - \underset{(3.85)}{415.55}\ DV4$$

$R^2 = 0.88$ $SE^{b} = 317.49$ RMSE = 559.97 RMSPE = 6.55

Equation (2) Sow Slaughter (GLS)

$$SSUS = \underset{(0.92)}{293.37} + \underset{(4.41)}{.178}\ BHUS_{-1} - \underset{(1.70)}{0.067}\ BHUS_{-2} - \underset{\substack{(2.86)\\ [-0.388]}}{12.80}\ FPPK_{-1} + \underset{\substack{(1.57)\\ [0.131]}}{76.62}\ PCO4_{-1}$$

$$+ \underset{\substack{(1.57)\\ [0.107]}}{12.81}\ IFCL + \underset{(1.43)}{50.48}\ DV2 + \underset{(6.67)}{257.15}\ DV3 + \underset{(6.75)}{253.19}\ DV4$$

$R^2 = 0.85$ SE = 106.69 $\rho = 0.407$ RMSE = 122.71 RMSPE = 6.55

Equation (3) Pig Crop (GLS)

$$PCUS = \underset{(0.25)}{-807.13} + \underset{(6.79)}{2.19}\ BHUS + \underset{\substack{(1.72)\\ [0.069]}}{37.82}\ FPPK_{-2} + \underset{(17.47)}{7335.20}\ DV2 + \underset{(5.53)}{2597.69}\ DV3$$

$$+ \underset{(6.77)}{2856.19}\ DV4$$

$R^2 = 0.84$ SE = 1467.34 $\rho = 0.336$ RMSE = 2185.26 RMSPE = 10.15

Equation (4) Barrow and Gilt Slaughter (GLS)

$$BGSUS = \underset{(3.11)}{5786.35} + \underset{(4.85)}{0.282}\ PCUS_{-1} + \underset{(5.94)}{0.337}\ PCUS_{-2} + \underset{(1.33)}{0.25}\ DMPC + \underset{(0.94)}{259.54}\ DV2$$

$$- \underset{(5.19)}{2146.41}\ DV3 - \underset{(2.44)}{822.86}\ DV4$$

$R^2 = 0.85$ SE = 824.25 $\rho = 0.533$ RMSE = 1833.58 RMSPE = 9.95

Equation (5) Pork Production Identity[c]

$$PPF = -5103964 + 19219.9\ LWBG + 236.763\ BGSUS + 1237.02\ LWS + 447.368\ SSUS$$

RMSE = 4614.26 RMSPE = 9.49

Notes: The variables are defined as follows: BHUS is breeding herd inventory (thousand); SSUS, commercial sow slaughter (thousand); BGSUS, barrow and gilt slaughter (thousand); PPF, farm pork production (million lbs); FPPK, price of barrows and gilts, seven market average (\$/cwt); PCO4, average corn price received by farmers (\$/bu); IFCL, common interest charged on feeder cattle loans (percent); LWBG, liveweight of barrows and gilts (lbs.); LWS, liveweight of sows (lbs); DMPC, pig crop dummy, DMPC = PCUS through 1973, zero thereafter; DVI, dummy variable for the Ith quarter

[a] Structural parameter estimates are accompanied by their asymptotic t-ratios in parentheses and corresponding elasticities, evaluated at sample mean values, in brackets.

[b] SE is the standard error of the estimated equation and RMSE and RMSPE are the root mean squared error and root mean squared percent error obtained from the dynamic simulation.

[c] The actual identity used to derive pork production was PPF = LWBG * BGSUS + LWS * SSUS. Equation (5) is the linearized version of the actual identity.

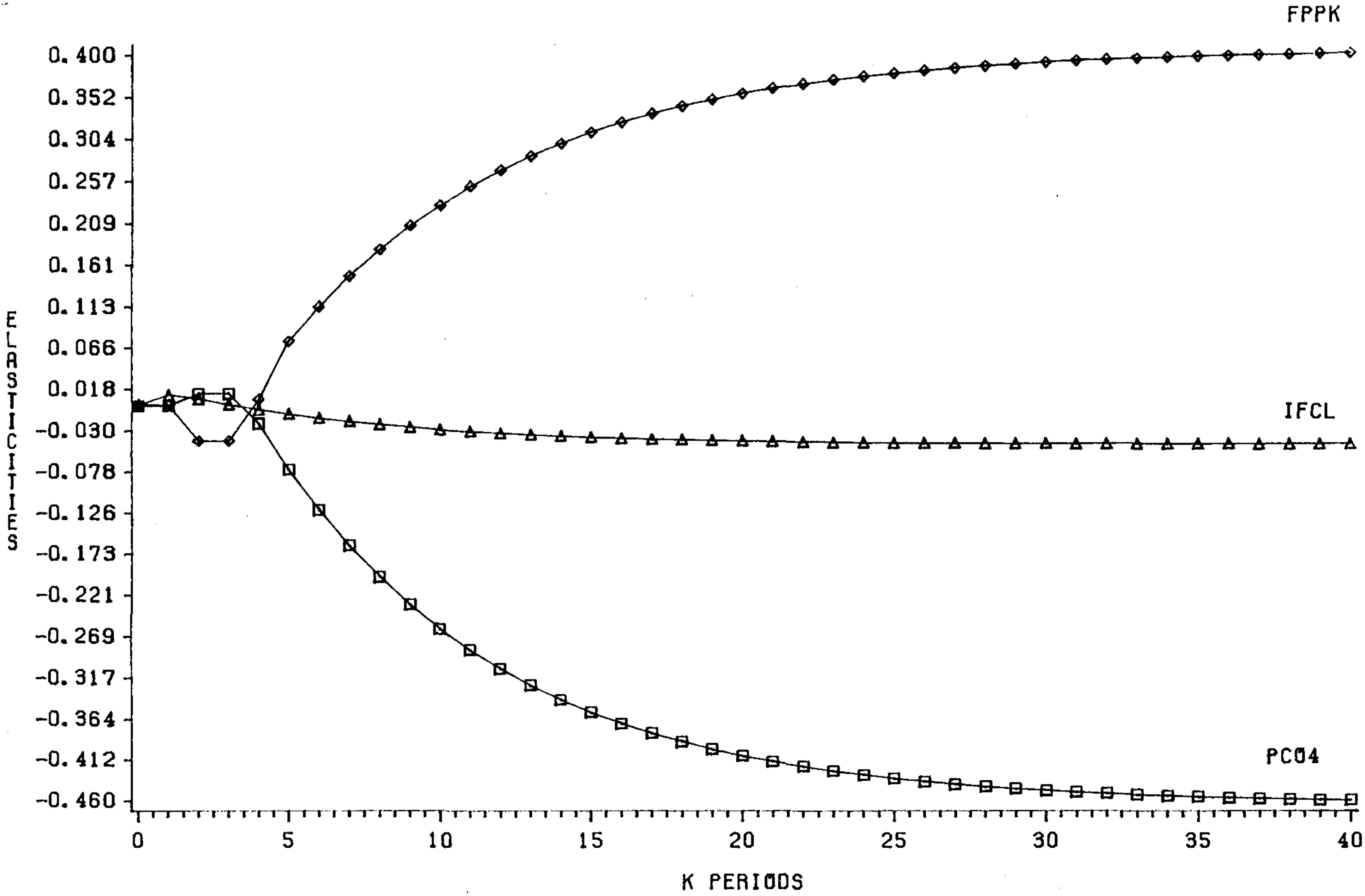

Figure 1. Intermediate Run Elasticities Of U.S. Pork Production.

6

The elasticities also indicate that pork production is slightly more responsive to corn price than hog price, while responsiveness to the interest rate is low. All elasticities increase in magnitude over time, eventually reaching a new steady state level. The long run elasticities with respect to hog price, corn price, and interest rate are 0.4025, -0.4632, and -0.0487, respectively. Seventy-five percent of the production adjustment resulting from a change in the hog price or interest rate occurs after 15 periods. The same level of response due to a change in corn price takes 16 periods.

Selected intermediate elasticities for all endogenous variables are reported in Table 2. Again, the patterns tend to conform to our *a priori* knowledge of the biological nature of hog production, i.e., an increase in hog price has no impact for several periods. After several periods sow slaughter declines and pork production falls. The adjustment process requires at least four periods for the higher hog price to result in higher levels of barrow and gilt slaughter and pork production. Furthermore, it takes several periods before the breeding herd increases enough to make sow slaughter positive. In all cases, the elasticities for pork production, barrow and gilt slaughter, and pig crop are lower than the respective elasticity for the breeding herd inventory. Clearly, the greatest flexibility to adjust to changing economic conditions occurs early in the production process.

The response caused by a change in corn price is similar. It takes two periods before sow slaughter increases and pork production increases. After four periods, barrow and gilt slaughter declines and pork production falls. Patterns caused by a change in the interest rate are similar to those for the corn price, the difference being that response is more immediate since interest rates are specified in the model at current levels.

Concluding Remarks

Much of the supply response analysis in agriculture is conducted with *ad hoc* model specifications. Until recently, economic theory has had little to say about the expectation formation and subsequent dynamic behavior of firms due to changing economic stimuli. This implies that until a complete theory of the firm is forthcoming, researchers must continue to rely on intuition, previous research, and preliminary analysis to guide them in model specification.

There is, however, a rich source of noneconomic prior information that is available in many instances, especially for livestock, timber, and perennial crop production where biological production lags are typically longer than the period of analysis. In general, models explicitly incorporating this information should result in improved forecasts, better dynamic properties, and sounder policy analysis.

The present study has demonstrated that incorporating biological information directly into the supply response equations of a quarterly hog model can result in estimates with structural integrity and acceptable dynamic behavior. Using a similar approach to model output response in other agricultural markets should prove to be beneficial.

Table 2. Selected Intermediate Run Elasticities

	K	BHUS	SSUS	PCUS	BGSUS	PPF
FPPK	0	0	0	0	0	0
	1	0	0	0	0	0
	2	0	-.392	0	0	-.041
	3	.079	-.392	.128	0	-.041
	4	.148	-.293	.186	.042	.007
	5	.209	-.243	.236	.111	.074
	10	.419	-.070	.412	.265	.230
	20	.587	.069	.552	.388	.355
	30	.634	.108	.591	.423	.389
	∞	.651	.122	.606	.436	.403
PCO4	0	0	0	0	0	0
	1	0	0	0	0	0
	2	0	.132	0	0	.014
	3	-.093	.132	-.078	0	.014
	4	-.175	.015	-.146	-.025	-.021
	5	-.246	-.046	-.206	-.078	-.074
	10	-.495	-.249	-.413	-.232	-.259
	20	-.693	-.405	-.570	-.398	-.407
	30	-.748	-.456	-.622	-.444	-.447
	∞	-.769	-.476	-.642	-.461	-.463
IFCL	0	-.012	.107	-.009	0	.011
	1	-.012	.107	-.009	0	.011
	2	-.022	.093	-.018	-.003	.007
	4	-.039	.079	-.032	-.016	-.006
	5	-.046	.073	-.038	-.021	-.011
	10	-.070	.053	-.058	-.038	-.029
	20	-.089	.037	-.075	-.053	-.043
	30	-.095	.032	-.079	-.057	-.047
	∞	-.096	.031	-.081	-.058	-.049

References

Almon, S. "The Distributed Lag Between Capital Appropriations and Expenditures." Econometrica 33(1965):178-96.

Arzac, Enrique R., and Maurice Wilkinson. "A Quarterly Econometric Model of United States Livestock and Feed Grain Markets and Some of Its Policy Implications." Amer. J. Agr. Econ. 61(1979):297-308.

Bessler, David A. "An Analysis of Dynamic Economic Relationships: An Application to the U.S. Hog Market." Can. J. Agr. Econ. 32(1984):109-24.

Board of Governors of the Federal Reserve System. Agricultural Finance Databook. Division of Research and Statistics, Washington, D.C., December 1984.

Brandt, Jon A. and David A. Bessler. "Forecasting with Vector Autoregressions Versus a Univariate ARIMA Process: An Empirical Example with U.S. Hog Prices." No. Cent. J. Agr. Econ. 6(1984):29-36.

Breimeyer, Harold F. "Emerging Phenomenon: A Cycle in Hogs." J. Farm Econ. 43(1958):760-68.

Chavas, Jean-Paul, and Stanley R. Johnson. "Supply Dynamics: The Case of U.S. Broilers and Turkeys." Amer. J. Agr. Econ. 64(1982):558-67.

Chow, Gregory C. Analysis and Control of Dynamic Economic Systems. New York: John Wiley and Sons, 1975.

Eckstein, Zui. "The Dynamics of Agricultural Supply: A Reconsideration." American J. Agr. Econ. 67(1985):204-14.

Ezekiel, Mordecai. "The Cobweb Theorem." Quart. J. Econ. 52(1938):225-80.

Freebairn, J. W. and Gordon C. Rausser. Effects of Changes in the Level of U.S. Beef Imports." Amer. J. Agr. Econ. 57(1975):676-88.

Griliches, Zui. "Distributed Lags: A Survey." Econometrica 35(1967):16-49.

Hansen, Lars P. and T.J. Sargent. "Formulating and Estimating Dynamic Linear Rational Expectations Models." J. Econ. Dynamics and Control 2(1980):7-46.

Harlow, Arthur A. "A Recursive Model of the Hog Industry." Agr. Econ. Res. 14(1962):1-12.

Heien, Dale. "An Econometric Model of the U.S. Pork Economy." Rev. Econ. and Statist. 57(1975):370-75.

Hopkins, John A., Jr. "A Statistical Study of the Prices and Production of Beef Cattle." Iowa State College of Agricultural and Mechanical Arts Res. Bull. 101, Dec. 1926.

Jorgenson, Dale W. "Rational Distributed Lag Functions." Econometrica 32(1966):135-49.

Martin, William J. U.S. Agricultural Policy and the Demand for Imported Beef. Ph.D. thesis, Iowa State University, 1982.

Muth, John. "Rational Expectations and the Theory of Price Movements." Econometrica 29(1961):315-35.

Nerlove, Marc. "Distributed Lags and the Estimation of Long Run Supply and Demand Elasticities: Theoretical Considerations." J. Farm Econ. 40(1958):301-11.

Rucker, Randal R., Oscar R. Burt, and Jeffrey T. LaFrance. "An Econometric Model of Cattle Inventories." Amer. J. Agr. Econ. 66(1984):131-44.

U.S. Department of Agriculture. Hogs and Pigs. ERS, Washington, D.C., various issues 1967-84.

________________. Livestock and Poultry Outlook and Situation Report. ERS, Washington, D.C., various issues 1967-84.

________________. Livestock and Meat Statistics. Statistical Bulletin 522 and Annual Supplements, ERS, Washington, D.C., various issues 1973-83.

Waugh, Frederick V. "Cobweb Models." J. Farm Econ. 46(1964):732-50.