A MARKOV CHAIN ANALYSIS OF PORK FARM SIZE DISTRIBUTIONS IN THE SOUTH

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Abstract

Concerns over declining farm numbers, shifts in farm size distribution, and associated infrastructural problems have led to a heightened awareness of structural considerations within policy making circles. Future policy decisions will have substantial structural consequences for the agricultural industry. Often, however, the indirect effects of grain pricing policies on the livestock sector have been overlooked in these policy decisions. The incorporation of price effects into a Markov chain analysis of pork farm size distributions and the simulation of those projections to the year 2000 under various price scenarios should provide some insight into the future structure of livestock farming in the South.

Key words: Markov chain, farm size distribution, pork farms.

Many changes have taken place in the structure of livestock production in the United States over the last 20 years. The total number of livestock farms has been declining steadily, and the size distribution of those farms remaining in production has undergone significant change. In Table 1, information concerning the historical number and structure of pork farms in the South Atlantic census division is presented. From 1969 to 1982, farm numbers declined by nearly 50% and considerable shifts occurred in the size distribution of the remaining farms.

Recently, concerns about the declining number of farms and the "industrialization" of agriculture has led to a new awareness of structural issues among farm policy makers. Although pork production is not covered directly under the farm bills, corn, a major farm program commodity, is an important input into hog production. Because farm program provisions have had important direct and indirect effects on corn prices, they may have had unanticipated structural effects on the pork industry. For example, recent proposals such as the Harkin-Gephardt proposal to use high fixed support prices for grain rather than direct payments could seriously affect livestock producers.

It is the objective of this paper to analyze the process of structural change in the pork industry, with particular emphasis on how the hog-to-corn price ratio affects structural change. This information should be of interest to policy makers when evaluating alternative farm programs that would have differential effects on corn prices.

THEORETICAL CONSIDERATIONS

Although farm numbers and agricultural structure are often of great interest to policy makers, standard economic theory does not directly address structural issues. Friedman has said that "a thoroughly satisfactory theory explaining the determinants of the number or structure of firms does not exist" (p. 103). Although theory does not provide much guidance in formulating net entry equations, there have been some studies in this area (Mansfield; Peltzman; Telser et al.; Veloce and Zellner). A net entry equation, however, provides no information concerning the structure of surviving firms and is thus a very limited tool for analyzing structural change.

The Markov process has been the most frequently used technique for analyzing structural changes in an industry (Daly et al.; Stanton and Kettenun; Ethridge et al.). In the Markov process, movements of firms from one size category to another are associated with discrete probabilities. The standard first-order Markov process involves the assump-

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tion that the probability of a firm moving from one size category in period t to another size category in period t+1 is independent of size movements in previous periods. Another necessary assumption for using Markov models is that the observed movements of firms among size categories provide satisfactory measures of the underlying probabilities.

The probability, P_{ij}, of moving from size category i to size category j is called a transition probability. The transition probabilities can be represented in matrix form.

$$(1) \quad P = \begin{bmatrix} P_{ii} & \cdots & P_{in} \\ \vdots & \ddots & \vdots \\ P_{ni} & \cdots & P_{nn} \end{bmatrix}$$

$$\text{where } P_{ij} \geq 0 \text{ and } \sum_j P_{ij} = 1.$$

Each element P_{ij} represents the probability of moving from state i to state j. When the P_{ij}'s are constant over time, they are called stationary transition probabilities. If the P_{ij}'s are changing over time, they are called nonstationary probabilities. Those interested in a more rigorous discussion of Markov chain analysis should consult Judge and Swanson.

Padberg has described the conditions under which a Markov process is appropriate for modeling structural change in an industry. If environmental factors dictate a general type of structural development in an industry, the Markov model may be useful in approximating the development pattern. This type of industry development is characterized by low entry barriers when the industry is young and a correspondingly high rate of entry. After establishment, barriers exist in that prospective entrants may be handicapped by scale economies, lack of experience, and inadequate financing. Hence, few firms enter after the "start-up" period. Instead, competition among existing firms, typically in the form of rivalry in technical progress, results in declining firm numbers. Successful innovators expand, while firms which are unsuccessful in adopting new technology become weak and drop out. Thus, if firm growth is at least partly due to technical innovation, Padberg concludes that the Markov model may be appropriate.

It seems highly probable that the conditions described by Padberg are applicable to the pork industry because pork farming, in general, has become more capital intensive over the last few decades. Often, pork production is a part-time farming activity for small and medium-sized farms. These farms are often characterized by low capital investment. However, because of the specialized management skills (and acquired tastes) required to successfully raise hogs, there is almost no new entry at the large and extra-large size levels. Additionally, the capital investment typically increases substantially as pork farms increase in size, due to the substitution of capital for the farmer's fixed supply of labor.

METHODS

In this research a Markov chain analysis was used to develop estimated coefficients of transition between pork farm sizes under various assumptions about the influence of the hog/corn price ratio and the nature of farm disappearance from the industry. These estimated coefficients were used to predict changes in farm size distribution over the historical period shown in Table 1. These predicted changes were then tested for correlation with the actual changes in farm size distribution (shown in Table 1), and a correlation coefficient was determined for each model. Finally, the model producing the estimated coefficients showing the highest correlation between predicted and actual values was used to develop a simulation of future pork farm size distributions to the year 2000 assuming high (35), medium (25), and low (15) hog/corn price ratios. In recent years, the hog/corn price ratio has flunctuated between 20 and 25. Farm programs affecting corn prices could alter this price ratio considerably, however.

Data Used

Data used in this analysis were acquired from pooled U.S. Census data (1969, 1974, 1978, and 1982) across five Census divisions. Those five Census divisions were the West North Central, the East North Central, the West South Central, the East South Central, and the South Atlantic. Cumulatively, this accounted for 96% of U.S. pork production in 1982. Data on the number of pork farms in each of four different size categories were collected and converted to percentage of farms by size.[1]

Percentages by size and total number of

[1]Size categories were: small (10–49 mkt. hogs sold/yr.), medium (50–199 mkt. hogs sold/yr.), large (200–500 mkt. hogs sold/yr.), and X-large (>500 mkt. hogs sold/yr.).

farms over the historical period are shown for the South Atlantic Census Division in Table 1. The South Atlantic Census division accounted for slightly less than 10% of national pork production in 1982 and was chosen for presentation here because the authors felt that this region typified pork production throughout the South.

Estimating the Probability Matrices

When information concerning the movement of individual firms among size categories is available, the method of maximum likelihood (Anderson and Goodman) can be used to calculate the stationary transition probabilities of the Markov process. If the transition probabilities are believed to be changing over time due to the influence of certain factors, a non-stationary Markov model can be developed using least squares techniques (Hallberg; Ethridge et al.). In this case, the observed movements from one size category to another are regressed on the factors assumed to account for the movements.

In many cases, however, detailed data tracing the movement of individual firms among size categories are unavailable. Frequently, only the total number of firms in each size category is available. Fortunately, Telser (1963) presented a methodology for using a least squares technique to estimate stationary transition probabilities from aggregate data. A system of N equations of the following form can be estimated:

$$(2)\ S_j^t = \sum_i P_{ij} S_j^{t-1} \qquad i,j=1,\ldots,N,$$

where N is the number of states, S is the percentage of observations occurring in each state, P is the transition probability to be estimated, and t represents time. Telser demonstrated that, when using unrestricted least squares, the constraint:

$$(3)\ \sum_j P_{ij} = 1$$

is automatically satisfied. Unrestricted least squares does not, however, rule out the possibility of negativity in the transition probabilities or of estimates of P_{ij} being greater than 1.

To avoid the negativity problem, quadratic programming and minimum absolute deviation (MAD) have been used to estimate the transition probabilities (Smith and Dardis). In the case of MAD, linear programming is used to minimize the sum of the absolute value of the deviations. Each error, e_j^t, is expressed as:

$$(4)\ e_j^t = f_j^t - g_j^t,$$

where f_j^t and g_j^t are the positive and negative vertical deviations above and below the regression line for the set of observations. The traditional MAD estimation, therefore, would be:

$$(5)\ \text{Min} \sum_j \sum_t |f_j^t| + \sum_j \sum_t |g_j^t|,$$

subject to the constraints:

$$(6)\ S_j^t = \sum_i P_{ij} S_j^{t-1} + f_j^t - g_j^t,$$

and

$$(7)\ \sum_j P_{ij} = 1.$$

In this study, the MAD technique was used to estimate the transition probabilities for pork farm size distributions because ordinary

TABLE 1. HISTORICAL PORK FARM SIZE DISTRIBUTION IN THE SOUTH ATLANTIC CENSUS DIVISION

Census Year	Total # of Farms Reported	Small[a]	Medium[b]	Large[c]	X-Large[d]
		%			
1969	66,508	57.907	30.996	8.170	2.926
1974	44,070	52.272	32.878	9.530	5.318
1978	51,352	53.092	31.261	9.454	6.193
1982	27,277	47.766	29.358	11.328	11.548

[a] Farms selling 10-49 market hogs/year.
[b] Farms selling 50-199 market hogs/year.
[c] Farms selling 200-500 market hogs/year
[d] Farms selling > 500 market hogs/year.

least squares yielded unacceptable results (negative probabilities, probabilities greater than 1) and because the quadratic programming software available would not accept a problem of this size. The properties of MAD estimators have been discussed by Karst; Ashar and Wallace; and Lee et al. Lee et al. concluded that the MAD estimators have the property of consistency and appear to provide a satisfactory basis for estimating transition probabilities.

There are two major drawbacks to the estimation procedure described above. First, as Telser (1962) demonstrated, when disappearance to (or appearance from) the outside is not explicitly modeled, an assumption of proportional disappearance is implicity enforced. If this assumption is unacceptable, a "null" category can be developed as an alternative state. Thus, for an industry structure problem under the assumption of non-proportional disappearance, the states should include size categories as well as an "exit" category. This allows firms in period t+1 to move not only between size categories, but also into or out of the industry, regardless of the industry position that they occupied at time t. In our study, the effect of inclusion of a null category is examined by developing two sets of estimates, one with and one without a null or "exit" category.[2]

The second major drawback of the traditional Markov chain analysis is that it ignores the effect of outside variables on changes in the distribution percentages. For example, it is not unreasonable to expect that the hog/corn price ratio (HC) could have an effect on the probabilities of movement among the size categories. Thus, the appropriate expression for the (non-stationary) transition probabilities would be:

(8) $P_{ij}{}^{t} = a_{ij} + b_{ij}HC^{t}$.

Equation (8) can be estimated directly if firm level data are available (Ethridge et al.) or can be incorporated into the share equations if only aggregate data are available. Substituting equation (8) into equation (2) yields:

(9) $S_j{}^{t} = \sum_i (a_{ij} + b_{ij}HC^{t})S_j{}^{t-1}$,

which can easily be estimated using linear techniques. Unfortunately, estimation of equation (9) would double the number of regressors in each equation. This is infeasible with small numbers of observations. However, if it is assumed that:

(10) $b_{1j} = b_{2j} = b_{3j} \ldots = b_{nj} = b_j$,

then equation (9) reduces to:

(11) $S_j{}^{t} = (\sum_i a_{ij}HC^{t}S_j{}^{t-1}) + b_jHC^{t}$.

This is the method suggested by Telser (1962) for incorporating the effects of exogenous factors. To keep the shares summing to 1, the sum across j of the b_j terms must be zero.

Substitution of equation (11) for equation (6) in the traditional MAD model yields:

(12) $\text{Min} \sum_j \sum_t |f_j{}^{t}| + \sum_j \sum_t |g_j{}^{t}|$,

subject to the constraints:

(13) $S_j{}^{t} = (\sum_i a_{ij}HC^{t}S_j{}^{t-1}) + b_jHC^{t}$,

(14) $\sum_j P_{ij} = 1$, and

(15) $\sum_j b_j = 0$.

The above alternative model in equations (12)–(15) was used to estimate transition coefficients with and without the "exit" category. In addition, the traditional Markov approach was modeled for both proportional and non-proportional exit. Thus, four models in total were estimated using the MAD technique. Model 1 (M1) involved the estimation of transition probabilities for pork farms assuming proportional disappearance among the four size categories and no price influence. Model 2 (M2) again assumed that the HC price ratio does not influence the transition probabilities. But non-proportional disappearance among the farm size categories was permitted through the use of a fifth category called the "exit" category. In model 3 (M3), the HC price ratio was included as an explanatory variable in distributional shifts, under the assumption of proportional disappearance of farms among

[2]In the model without an exit category, the % distribution of surviving farms forms the share variables. In the model with exit, shares are developed using a base year, and defunct farms make up a fifth share category.

size categories. Finally, in model 4 (M4), the HC price ratio was included as an explanatory variable under the assumption of non-proportional disappearance.

RESULTS

Estimation results for the two models, assuming no influence of the HC price ratio (M1 and M2), are shown in Tables 2 and 3. The diagonal elements of the matrices shown in Tables 2 and 3 indicate the probabilities of farms remaining in the same size category from period t to period t+1 for models M1 and M2, respectively. For example, in Table 2 estimation results for the model without an exit category (M1) reveal that a small farm in period t has an 88.9% probability of remaining small in period t+1 and a 10% probability of moving to a medium-sized farm. However under the assumption of non-proportional disappearance (M2), estimation results shown in Table 3 indicate that the probability of remaining small drops to 40%. The drop occurs because there is a high estimated probability (59.9%) that small farms will exit the pork industry given the assumptions of M2. In model M2, there is an estimated zero possibility of growth for the small farm, an unsatisfactory result. Both models indicate that the most likely shifts upward in size occur as large farms become extra-large (M1—15% prob., M2—14% prob.).

Correlation coefficients of predicted versus actual size distributions of the remaining farms were developed for the two models. The overall correlation coefficient for model M1 is slightly higher than that for M2, indicating that M1 is a slightly better estimator of historical transition between pork farm size categories. Therefore, when the HC price ratio is not included, the assumption of proportional disappearance seems to provide better predictions of the size distribution of the remaining farms.

The estimated coefficients for models M3 and M4 are presented in Tables 4 and 5, respectively. Since the HC price ratio is included as an explanatory variable in both of these models, the estimated coefficients cannot be interpreted as traditional transition probabilities. Instead, non-stationary probabilities can be developed from these coefficients following equation (8).

As was the case for models without price influence (M1 and M2), the estimated correlation coefficients for models M3 and M4 again indicate that the model assuming proportional exit (M3) is a better predictor of changes in pork farm size distributions. Interestingly, in model M3, the estimated coefficients of HC are positive for the small and medium size categories, indicating that an increased HC price ratio encourages the retention of family-sized farms. In model M4, where exit is explicitly included, the coefficient of HC is positive in all but the exit and extra large

TABLE 2. MINIMUM ABSOLUTE DEVIATION ESTIMATES FOR MODEL 1 (NO EXIT CATEGORY, NO HC PRICE RATIO INFLUENCE)

Dependent Variable	Probabilities of Transition $SMALL_t$	MED_t	LGE_t	$XLGE_t$
$SMALL_{t+1}$	0.8897	0.0438	0	0
MED_{t+1}	0.0955	0.8624	0	0
LGE_{t+1}	0	0.0773	0.8482	0.0692
$XLGE_{t+1}$	0.0146	0.0163	0.1517	0.9307
CORRELATION COEFFICIENT = 0.96789				

TABLE 3. MINIMUM ABSOLUTE DEVIATION ESTIMATES FOR MODEL 2 (WITH EXIT CATEGORY, NO INFLUENCE OF HC PRICE RATIO)

Dependent Variable	Probabilities of Transition $EXIT_t$	$SMALL_t$	MED_t	LGE_t	$XLGE_t$
$EXIT_{t+1}$	0.6856	0.5992	0.1227	0.2213	0.2675
$SMALL_{t+1}$	0.1427	0.4007	0.1939	0	0
MED_{t+1}	0.0869	0	0.6495	0	0
LGE_{t+1}	0.0455	0	0.0337	0.6383	0
$XLGE_{t+1}$	0.0389	0	0	0.1402	0.7324
CORRELATION COEFFICIENT = 0.95810					

TABLE 4. MINIMUM ABSOLUTE DEVIATION ESTIMATES FOR MODEL 3 (WITHOUT EXIT CATEGORY, WITH INFLUENCE OF HC PRICE RATIO)

Dependent Variable	Estimated Coefficients of Transition[a] SMALL$_t$	MED$_t$	LGE$_t$	XLGE$_t$	HC ratio$_t$
SMALL$_{t+1}$	0.8701	0	0	0	+0.001127092
MED$_{t+1}$	0.0384	0.5508	0.0777	0	+0.006284045
LGE$_{t+1}$	0.0339	0.1449	0.9165	0	−0.002462543
XLGE$_{t+1}$	0.0575	0.3042	0.0056	1.0	−0.004948594
CORRELATION COEFFICIENT = 0.96875					

[a]The non-stationary probabilities are found using:

$P_{ji} = a_{ji} + b_j{}^*HC,$

where P_{ji} is the probability of moving from state i to state j, a_{ji} is the coefficient in the jth row and the ith column, and b_j is the coefficient of the HC ratio in row j.

TABLE 5. MINIMUM ABSOLUTE DEVIATION ESTIMATES FOR MODEL 4 (WITH EXIT CATEGORY, WITH INFLUENCE OF HC PRICE RATIO)

Dependent Variable	EXIT$_t$	SMALL$_t$	MEDt	Estimated Coefficients of Transition[a] LGE$_t$	XLGE$_t$	HC ratio$_t$
EXIT$_{t+1}$	0.9123	0.7795	0.8137	0	0.1771	−0.014092
SMALL$_{t+1}$	0	0.2204	0	0	0	+0.00738042
MED$_{t+1}$	0	0	0.1862	0.2592	0	+0.006206393
LGE$_{t+1}$	0.0574	0	0	0.6191	0	+0.0005789113
XLGE$_{t+1}$	0.0301	0	0	0.1215	0.8228	−0.00007371069
CORRELATION COEFFICIENT = 0.94372						

[a]The non-stationary probabilities are found using:

$P_{ji} = a_{ji} + b_j{}^*HC,$

where P_{ji} is the probability of moving from state i to state j, a_{ji} is the coefficient in the jth row and the ith column, and b_j is the coefficient of the HC ratio in row j.

categories. This indicates that high HC price ratios reduce both farm exits and transitions to the largest size category. A lower HC price ratio would, therefore, not only increase farm failures but push the industry towards a more concentrated structure.

The future structure of the pork industry in the South Atlantic Census division was simulated in a two-step procedure. First, the percentage of farms exiting agriculture was estimated using the two models (M2 and M4) that included exit as an explanatory variable (Table 6). When the HC price ratio was not included (M2), it was estimated that 52% of the farms in the South Atlantic Census division that were producing in 1982 will exit the industry by the year 2000. When the HC price ratio was included (M4), it is clear that it has substantial effects on the number of farms exiting pork production. Very little change occurs in the number of farms exiting the South Atlantic Census division under the low price ratio (HC=15) scenario. This should provide additional validity to M3, since the average HC price ratio over the historical period 1960–1982 was 18. Therefore, it should not be surprising that models M2 and M4L (i.e., M4 with HC=15) give similar results. However, when the average HC price ratio is increased to 25, exits fall to 36.5% of those farms in business in 1982. If the average price ratio is 35, only 21.4% of pork farms in the South Atlantic Census division will have exited the industry by the year 2000. Therefore, the fate of 30% of all pork farms in the South Atlantic Census division could depend on the HC price ratio over the next 15 years.

Because the models without exit (M1 and M3) provide slightly better predictions of the size distribution of the remaining farms, these models were used to simulate the future size distribution of pork farms in the South Atlantic Census division (Table 7). The projected distributions for the various price ratio scenarios are shown in Table 7. A simulation of the transition probabilities estimated in M1 shows that 31.8% of all pork farms in the South Atlantic Census division will be small and 22% will be extra large by the year 2000. If an average HC price ratio of 15 is assumed, that distribution changes very little. However, as the assumed average HC price ratio is increased, the percentage of small and medium-sized pork farms increases while the

TABLE 6. PERCENTAGE OF PORK FARMS IN THE SOUTH ATLANTIC DIVISION EXITING AGRICULTURE BY THE YEAR 2000 UNDER DIFFERENT PRICE SCENARIOS

Model	Hog/Corn Price Ratio Assumption	Exiting Percentage[a]
Model 2	Price has no effect	52.14
Model 4L	HC = 15	51.70
Model 4M	HC = 25	36.56
Model 4H	HC = 35	21.42

[a] Base year = 1982.

percentage of large and extra large pork farms declines sharply.

It is clear from these results that the HC price ratio can greatly affect pork farm size distributions. There are several possible related reasons for this. First, the increase in economic rents caused by an increasing HC price ratio enables farms (with existing facilities) that might otherwise be forced out of the industry because of management or production inefficiencies to remain in operation. It is reasonable to expect that this could result in the above changes in size distribution. Second, as the HC price ratio rises, it seems reasonable to expect farms primarily concerned with grain production, but with existing capacity for raising pork, to enter the industry. The higher HC ratio allows them an alternative means of marketing a portion of their product for a greater value added, thus, better utilizing their labor and increasing returns to their total farm enterprise. Traditionally these farms have been small and medium-sized operations. Finally, increasing profitability in the pork industry makes it more attractive for novices to enter hog farming for the first time. As mentioned previously, these unproven managers typically enter the industry only with the smaller-sized operations.

CONCLUSIONS

In this study, a Markov chain analysis of the structure of the pork production industry in the South Atlantic Census division was performed. This study builds upon past research using Markov chains by explicitly modeling farm exits and by implementing a procedure to derive non-stationary probabilities using aggregate data. Results of this study indicate that both total farm numbers and the size distribution of pork farms are highly sensitive to the assumption about what the future HC price ratio will be.

Policy makers need to be aware of the interactions between grain policy and the survival and structure of livestock farms. Current grain policies, involving direct subsidies and low support prices, have a significant influence upon the survival of pork farms of all sizes. Also, low grain prices will allow the continuance of small and medium-sized farms. According to the Goldschmidt hypothesis, the continuance of family-sized farm operations is an important component of the quality of life in rural communities. Hence, a move back towards high fixed support prices for grain could have unanticipated results on the structure of the pork industry and eventually on the entire rural community.

The set of models presented in this paper provides a tool that can be used to evaluate the effects of reductions in corn price support programs on pork farm size distributions, assuming that a falling corn price would cause HC price ratios to increase in the long run. Clearly, in the short run, as corn price supports are lowered the price of corn will fall and the HC price ratio will rise. As both corn and hog producers are allowed time to adjust production, however, the long-term relationship is more difficult to determine. Further research in this area is outside the context of this paper but could facilitate analysis of the long-term implications of the removal of corn price support programs on the market price of corn.

TABLE 7. SOUTH ATLANTIC PORK FARM SIZE DISTRIBUTION IN 2000—SIMULATION RESULTS UNDER LOW, MEDIUM, AND HIGH PRICE SCENARIOS

Model	Hog/Corn Price Ratio	Distribution % Small[a]	Medium[b]	Large[c]	X-Large[d]
Model 1	N/A	31.845	28.430	17.641	22.083
Model 3L	15	32.938	26.880	14.232	25.948
Model 3M	25	36.642	39.187	9.432	14.736
Model 3H	35	40.346	51.495	4.633	3.525

[a] Farms selling 10–49 market hogs/year.

[b] Farms selling 50–199 market hogs/year.

[c] Farms selling 200–500 market hogs/year.

[d] Farms selling > 500 market hogs/year.

REFERENCES

Anderson, T. W., and L. A. Goodman. "Statistical Inference About Markov Chains." *Annals Math. Stat.*, 28(1957):89–110.

Ashar, V. G., and T. D. Wallace. "A Sampling Study of Minimum Absolute Deviations Estimators." *Oper. Res.*, 11(Sept.-Oct. 1963):747–58.

Daly, R. F., J. A. Dempsey, and C. W. Cobb. "Farm Numbers and Sizes in the Future." In *Size, Structure, and Future of Farms*. Ed. A. G. Ball and Earl O. Heady. Ames, Iowa: Iowa State University Press, 1972.

Ethridge, D. E., S. K. Roy, and D. W. Myers. "A Markov Chain Analysis of Structural Changes in the Texas High Plains Cotton Ginning Industry." *So. J. Agr. Econ.*, 17, 2(1985):11–19.

Friedman, M. *Price Theory*. Chicago, Illinois: Aldine Publishing Company, 1976.

Goldshmidt, W. *As You Sow*. New York: Harcourt/Brace, 1978.

Hallberg, M. C. "Projecting the Size Distribution of Agriculture Firms—An Application of a Markov Process with Non-Stationary Transition Probabilities." *Amer. J. Agr. Econ.*, 51(1969):289–302.

Judge, G. C., and E. R. Swanson. "Markov Chains: Basic Concepts and Suggested Uses in Agricultural Economics." Dept. Agr. Econ., University of Illinois, AERR 49, 1961.

Karst, O. J. "Linear Curve Fitting Using Least Deviations." *J. Amer. Stat. Assoc.*, 53(March 1958):118–32.

Lee, T. C., G. G. Judge, and T. Takayama. "On Estimating the Transition Probabilities of a Markov Process." *J. Farm Econ.*, 47(Aug. 1965):742–62.

Mansfield, E. "Entry. Gibrat's Law, Innovation, and the Growth of Firms." *Amer. Econ. Review*, 52(1962):1023–51.

Padberg, D.I. "The Use of Markov Processes in Measuring Changes in Market Structure." *Amer. J. Agr. Econ.*, 44(1962):189–99.

Peltzman, S., "Entry in Commercial Banking." *J. of Law and Econ.*, 8(1965):11–50.

Smith, B., and R. Dardis. "Inter-Fiber Competition and the Future of the United States Cotton Industry." *Amer. J. Agr. Econ.*, 54(1972):207–16.

Stanton, B. F., and L. Kettunen. "Potential Entrants and Projections in Markov Process Analysis." *J. Farm Econ.*, 49(1967):633–42.

Telser, L. G. "The Demand for Branded Goods as Estimated From Consumer Panel Data." *Rev. of Economics and Statistics*, 44(Aug. 1962):300–24.

Telser, L. G. "Least-Squares Estimates of Transition Probabilities." In *Measurement in Economics; Studies in Mathematical Economics and Econometrics in Memory of Yehuda Grunfeld*. Ed. C. F. Christ et al. Stanford: Stanford University Press, 1963. 270–92.

Telser, L. G., W. Best, H. Egan, and H. Higginbotham. "The Theory of Supply With Applications to the Ethical Pharmaceutical Industry." *J. of Law and Economics*, 18(1975):449–78.

U.S. Department of Commerce. *U.S. Census of Agriculture, (various reporting years)*. Volume I. Bureau of the Census. Washington, D.C.: Government Printing Office, 1972–85.

Veloce, W., and A. Zellner. "Entry and Empirical Demand and Supply Analysis For Competitive Industries." *J. of Econometrics*, 30(1985):459–71.