AN ECONOMETRIC FARM STRUCTURE MODEL

Anthony L. Joseph, Fred C. White, and Thomas N. Barclay

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ABSTRACT

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While the magnitude of changes in farm structure have been well documented, little empirical work has been undertaken to explain what factors have caused these changes to occur. This study develops an analytical model to assess the impact of selected variables on farm structure.

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The structure of American agriculture has continually been in a state of change, with the rate of this change varying according to the economic situation present at the time. A great deal of concern has been focused on the changing structure of agriculture in the last decade, see for example (U.S. Department of Agriculture, ESS, 1979a, 1979b, and 1981). While it has been well documented that some classes of farms have expanded rapidly as others declined, little empirical work has been done on what factors have caused these changes to occur, i.e. what factors affect structure. The relative importance of the factors that are determinants of structure has been largely a matter of judgement in previous literature. Attention in this study is given to the factors that previous literature deemed important. The overall objective of this study is to analyze factors affecting the structure of production agriculture in the United States. Utilizing structural measurements, in particular the number and size distribution of farms, certain forces are empirically tested as to their effects on structure dimensions. These empirical estimates are used to determine the effect selected factors have and what role they play in the changing structure of agriculture.

Model and Estimation Procedure

To determine the effects of certain economic factors on the structure of production agriculture a measure of the size distribution of farm units

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*Graduate Assistant, Professor, and Former Graduate Assistant, Agricultural Economics Dept., University of Georgia, Athens, GA.

will be needed. To estimate farm distribution a negative exponential function is utilized. This step of estimation will be designated stage one of the analysis.

Representation of farm distribution by negative exponential functions have been used by Dovring (1962), Boxley (1971), Ching (1973), and Dixon and Sonka (1969). All the authors employed the function

$$(1)\ Y_i = A e^{-\beta X_i} + u_i$$

where

Y_i is the percentage of farms larger then X_i,

X_i is the lower limit of farm size for a given size class divided by the average farm size,

A and β are parameters to be estimated,

e is the base of the natural logarithms, and

u_i is a random disturbance term.

At $X_i = 0$, $e^{-X} = 1.0$ or 100 as interpreted in percentages. If one examines a plotted negative exponential function with various values of β the distribution tends to concentrate the area under the curve to the left as the parameter is reduced.

Dovring (1962) was one of the first to use an exponential function to represent farm size distribution. He along with Boxley utilized ordinary least squares (OLS) for estimation of the parameters. The distribution estimates of farm by size category were carried out by using a decumulative distribution of a negative exponential function with an intercept parameter (Boxley, p. 90).

Ching built upon Boxley's negative exponential by using restricted least squares (RLS) techniques, defining the dependent variable as the smallest farm size category (Ching, p. 502). Dixon and Sonka after reviewing the work by Dovring, Boxley, and Ching found room for improvement in the estimation of the parameters by replacing OLS and RLS with a maximum likelihood estimator (MLE).

The maximum likelihood estimator developed by Dixon and Sonka will be used to represent the distribution of farms by sales class in stage one of this study. Imposing the restriction developed by Ching on equation (1), i.e.,

$$(2)\ A = (100/e^{-\beta X_1})$$

where

X_1 = the smallest size farm class,

such that Y = 100% when X is the smallest size class (Ching, p. 500), and then taking the natural logarithm yields

$$(3)\ \ln (Y_i/100) = \beta(X_1 - X_i) + u_1$$

where the u_1 is an additive error term. A transformation used to avoid computational difficulties resulting from negative variables involves the switching of X_1 and X_i in equation (3). The regression results yield an estimate of the β parameter to be used in subsequent analysis. A problem with estimation of equation (3) is that in practice the error term u_1 is not normally distributed with zero mean and variance σ^2. The variance of the error term in this case is heteroscedastic. To correct the problem of heteroscedasticity the variance was assumed to be specified $\sigma_i^2 = \sigma^2 X_i^\delta$ where δ is some positive number (Dixon and Sonka).

Along with stage one of the analysis, two regression models (designated stages two and three) will be used to measure the effects of selected variables on the distributional (β) parameter. Stage two will estimate the parameters of a regression equation where farm numbers per state is the dependent variable. The predicted value of the dependent variable from stage two will be used as an explanatory variable in the stage three regression equation. This characterizes the model as a recursive regression model. The recursive system is used because some of the variables are determined interdependently, and the statistical properties necessary for minimum least squares bias in stage three are satisfied by the recursive approach (Tweeten and Nelson, p. 31).

The model used for stage two is

$$(4)\quad F = a_0 + a_1L + a_2E + a_3S + u_2$$

where

F is farm numbers,

L is aggregate land in farms,

E represents economies of size,

S is average farm size (from the previous period),

a's are parameters to be estimated (j = 0, 1, 2, and 3), and

u_2 is a random disturbance term.

The variable farm numbers is expected to be related to land in farms and average farm size. For a given average farm size, farm numbers are expected to be positively related to land in farms. However, average farm size in any given period would be endogenously related to farm numbers. For this reason lagged values of farm size and a variable reflecting economies of size are used in the model. The economies of size variable, which is the farm size for which average costs and average returns are equal, is expected to be negatively related to the number of farms. If the economies of size variable for a particular state is relatively high, farms would have to be larger than average to obtain lower costs per unit. This situation would cause consolidation of farms into larger more productive units which means a decrease in farm numbers, ceteris paribus.

To estimate the unknown parameters in equation (4) an estimated generalized least squares (EGLS) estimator is used. The EGLS estimator is used because heteroscedasticity is expected in the error terms. This would mean that the covariance matrix, $\sigma^2 I_t$ of the general linear model is to be specified $\sigma^2\Psi$, where Ψ is a known positive definite matrix. A difficulty that arises in practice is that neither σ^2 nor Ψ is usually known. The EGLS estimator deals with this problem by using estimates of σ^2 and Ψ. In order to do this some prior knowledge of the form of the heteroscedasticity must be employed. In the case of equation (4) the variance is hypothesized to be a function of the independent variables. This specification has the form $\sigma^2 = Z_k'\alpha$ where α is a vector of unknown parameters and Z_k is a matrix of k independent variables. To estimate the variance Harvey (1974) suggests a two step estimator which yields $\hat{\hat{\alpha}}$ a consistent estimate of α. Therefore, the EGLS estimate of Θ to be performed with the assumption of heteroscedasticity is

$$(5)\quad \hat{\Theta} = (X'(Z'\hat{\hat{\alpha}})^{-2}X)^{-1}X'(Z'\hat{\hat{\alpha}})^{-2}y$$

The final stage of the recursive estimation process (stage three), quantifies the effects of selected economic forces on the distribution of farms as measured by the β parameter from equation (3). While the number of economic factors affecting the distribution of farms is quite large, the major ones as indicated in the literature include technology, economies of size, agricultural policies, and prices (Babb; Ball and Heady; Gardner and Pope). In the present analysis a cross-sectional model is used for a time period in which agricultural policies and prices may be considered as constants. The model used to explain the distribution of farms is

$$(6)\quad \beta = b_0 + b_1\hat{F} + b_2E + b_3R + b_4S + u_3$$

where

β is the beta parameter of the size distribution model,

E represents economies of size,

R is public research plus extension expenditures,

S is average farm size (from the previous period),

$\hat{F}$ is predicted total farm numbers,

b_j are parameters to be estimated (j = 0, 1, ... 4), and

u_3 is a random disturbance term.

The average farm size is included as a control variable in the equation, because two distributions with different means might have the same parameter estimate of β. The total number of farms as predicted from equation (4) was also expected to influence the β parameter; states with a larger number of farms, ceteris paribus, would be expected to have more small farms. Research expenditures are also used as an independent variable but the relationship is unclear as to how it affects the distribution of farms. The relationship between economies of size and β is expected to be positive because as the variable economies of size increases the mean of the distribution is expected to increase thus increasing the β parameter. Estimation of equation (6) will utilize the traditional general linear model.

Data and Variable Specification

The data in this study are primarily from the Census of Agriculture (U.S. Bureau of Census). Public research and extension expenditures were derived from Davis (1979). All data were collected on a state basis for the 48 contiguous states and distributional parameters were estimated for each state. The census years used in the analysis are 1964, 1969, and 1974. All lagged variables are from the preceding census year, which includes 1959. The time period chosen was homogenous with respect to government programs and price levels. Drastic exogenous influences in this time period were not reflected in the data. Agricultural price levels as measured by the parity ratio were relatively stable through the 1960's and 1970's (U.S. Department of Agriculture, Agricultural Statistics). Also, government programs to support farm prices during the 1960's and early 1970's were fairly similar. The dramatic changes in output prices and government programs in 1973 were not expected to be reflected in changing structural dimensions in the 1974 census because farmers did not have enough time to make significant structural adjustments. In fact, there was almost no change in the number of farms during 1973 and 1974 (U.S. Department of Agriculture, Agricultural Statistics). Consequently, price levels and government programs are not considered in this study as factors in structural change.

Economies of size are expected to play a major role in shaping structure. The existence of economies of size pressure existing producers to expand operations to take advantage of lower per unit costs. The long-run average cost (LRAC) curve captures a variety of pecuniary, technical, and external economies (Babb, p. 55). The sum total of these economies, as reflected by the LRAC curve, affect the dimensions of farm structure.

Tweeten described the LRAC curve as an output-input ratio defined as gross income divided by the cost of all farm inputs (Tweeten, p. 178). An output-input ratio was calculated in the present study for each sales class. First an opportunity cost for investment is estimated by summing the values of land, buildings, machinery, and livestock--and multiplying an opportunity rate times the sum. This opportunity cost for investment is then added to production expenses and opportunity labor costs. The result of this calculation is assumed to be total costs. Total revenue is obtained by summing the value of production sold and the increase in land values (measured as an annual rate over each five year census period).

The LRAC curve is derived by dividing total costs by total revenue. The variable "economies of size" is determined, in dollar value, where LRAC is equal to 1. This is interpreted as the point where one dollar of cost yields one dollar of revenue.

Technology is expected to affect structure through cost decreasing and output increasing methods. The problem with empirical testing of its effects is a data difficulty. Technology is diverse in its effects and many variables make up its dimensions. One way of measuring its effects is to collect data on research and extension expenditures.

These variables will reflect capital committed to technological development in agriculture. The effect of this variable may tend to enlarge farm size because technology usually has a capital cost but not always (for example improved varieties of seed).

Other variables used in this study such as average farm size, land in farms, and total number of farms are themselves dimensions of structure. Although they are, changes in their values reflect and affect structure. For example the total number of farm acres in the U.S. are declining due to urban expansion. This forces producers to produce more from fewer acres thus increasing total sales per acre. Even though the land base is shrinking average farm size (measured in sales) seems to be increasing. Some of this increase is due to economies of size but the fact that large farms are in a better position to expand surely has its effect (Krause and Kyle, p. 748). This situation would point to a shift in the distribution of farms with the larger classes benefiting relatively more. The total number of farms in a state reflects some of the same concepts as described above. With average farm size increasing some producers must be leaving farming. This exit makes increases in farm size possible.

Estimation Results

Estimates of the distribution parameter β were made for each of the 48 contiguous states and for the three census years 1964, 1969, and 1974. Standard errors were calculated and tests for significance show all parameters were significant at the 5 percent level. While individual β parameters are not reported they were used in the regression analyses discussed below.

The results of the total farm number regression model, equation (4), are given in Table 1. As expected, the dependent variable farm number is positvely related to land in farms. Farm numbers are inversely related to economies of size which indicates that states with smaller economies of size would be expected to have a larger number of farms, other things equal. Large economies of size would force consolidation which would mean decreasing farm numbers. As expected, farm numbers are inversely related to average farm size in the previous period. All variables are significant at the 5 percent level except economies of size which is significant at the 10 percent level. R^2 indicated that 40 percent of the variation had been explained by this model.

Regression coefficients for equation (6) explaining the distribution parameter β are reported in Table 1. The goodness of fit statistic (R^2) in this stage appears to be quite high with the model explaining 87 percent of the variation. The F-statistic used to test the significance of the whole regression model is statistically significant at the 5 percent level. The only variable that is not significant at the 5 percent level is research and extension expenditures. The very low t-value indicates no relationship was found to exist between the variable and the distribution of farms among sales classes. This result indicates that public research and extension activities are not significantly biased toward large farm expansion. The predicted farm numbers variable from equation (4) was found to be significant and negatively related to the β parameter indicating that states with a larger number of farms will have more small farms, ceteris paribus. The coefficient on average farm size in the previous period was statistically significant.

Table 1. Pooled Regression Results for Farm Numbers and Distributional Parameters[a/]

Independent Variables	Units	Dependent Variables: Farm Numbers in Thousands	Dependent Variables: Exponential Distribution Parameter Beta
Intercept		30.2058 (6.7703)	-0.6143 (-17.4449)
Land in Farms	Million Acres	1.1155 (8.3832)	
Economies of Size	Thousand Dollars	-0.1108 (-1.3959)	0.0003 (3.0202)
Average Farm Size in the Previous Period	Thousand Dollars	-0.2717 (-5.0504)	-0.0113 (-30.7410)
Research and Extension Expenditures	Million Dollars		-0.0003 (-0.2493)
Predicted Total Farm Numbers	Thousand Farms		-0.0017 (-3.2553)
R^2		0.3979	0.8720
F-Statistic		30.8446	236.8060

[a/] Student t-values are in parentheses.

The coefficient on economies of size was found to be positive and statistically significant. The results indicate that economies of size do affect the distribution of farms. To find out exactly how much effect the first derivative of the β parameter is taken with respect to economies of size. The functions needed to accomplish this are equations (4) and (6).

$$(7)\ \frac{d\beta}{dE} = \frac{\partial\beta}{\partial E} + \frac{\partial\beta}{\partial F}\frac{\partial F}{\partial E}$$

With this formulation, the change in the β parameter resulting from a $1000 change in the economies of size variable is 0.000488, ceteris paribus.

The average beta parameter for the pooled cross-sectional data along with the average economies of size are -1.13296 and $40 thousand, respectively. If, for example, economies of size increased to $80,000 the β parameter would increase from -1.13296 to -1.11344 (see Figure 1). The change in distribution would also indicate a larger average farm size because the mean of the distribution moves to the right. This indicates that average farm size in the present time period also is affected by economies of size.

A change in the beta parameter causes a shift in the number of farms between size categories. Table 2 shows a shift in farm numbers among sales classes with two different beta parameters. The total number of farms is assumed to be 100,000 in both cases. A small change in the parameter value can cause a relatively large change in the number of farms in a particular sales class. One can see from the table that as the parameter shifts from -1.0 to -1.1 a large number of farms are accumulated in smaller size categories. Some of the changes may seem rather small but recall that the change in the parameter was only .1. Even though the

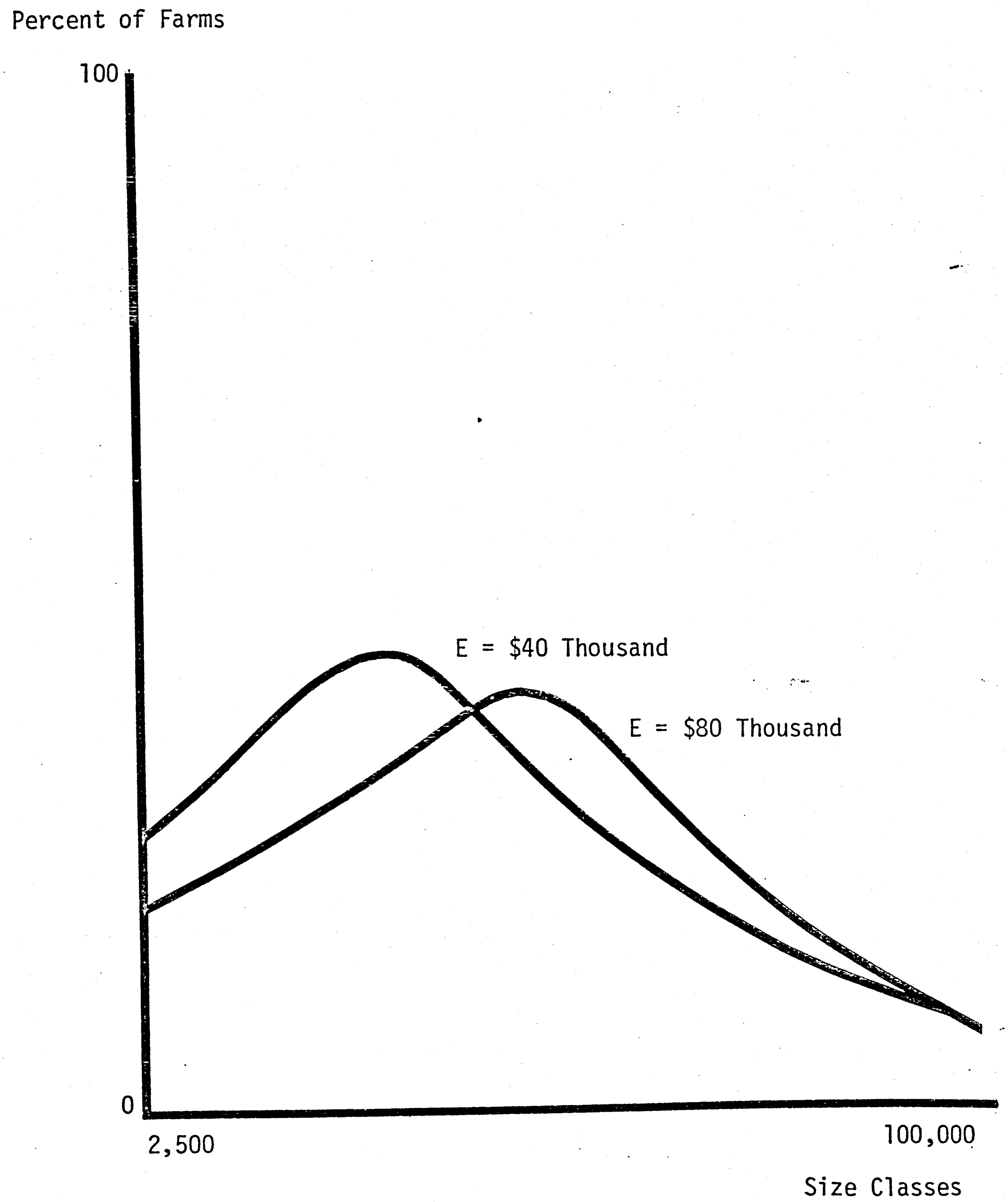

Figure 1. Distribution of Farms Under Two Alternative Economies of Size Conditions

Table 2. Farm Numbers by Sales Class Under Selected Beta Parameter Values[a/]

Sales Category	Beta Parameter -1.0	Beta Parameter -1.1	Difference in Farm Numbers
(Dollars)	(Farm Numbers)		
2,500-5,000	15,360	16,750	1,390
5,000-10,000	23,990	25,560	1,570
10,000-20,000	29,510	29,980	470
20,000-40,000	22,930	21,320	-1,610
40,000-100,000	8,060	6,312	-1,748
Over 100,000	150	78	-72

[a/] Assuming total farm number equals 100,000.

change in the parameter was small the largest sales class declined by almost 50 percent.

Conclusions

This study quantified the effect of selected variables on the distribution of farm sizes. The effect of public research and extension expenditures was found not to be statistically significant. Economies of size significantly affect the structure of farms by income class. This result indicates that farmers in states with larger economies of size are more likely to expand, other things equal. Government programs and price levels which obviously affect structure were not incorporated into this study because of their relative stability over the time period examined, the 1960's and early 1970's. If a time series study of this type was carried out it would be very important to include government programs and price levels. The cross-sectional nature of this study resulted in average, long-term relationships. There is no indication given as to the time required to make the adjustments described in this study.

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