RELATIONSHIP BETWEEN FARM SIZE AND TECHNICAL EFFICIENCY IN WEST TENNESSEE AGRICULTURE

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There has been persistent interest in the issues relating to farm size and survival of family farms since the beginning of agricultural economics as a discipline. Since the early 1950s, the number of farms has been decreasing and the average farm size has been increasing. Some poverty has always existed in the rural areas, but the difference in the level of incomes between small and large farms has been widening (Singh and Bagi). Consequently, some persons are concerned with the implications of concentration of farm production in the hands of fewer farms and the potential for industrialized organization of agriculture (Stanton, p. 727). Serious concern has been expressed about America's very large farms and what their growth signals for the rest of agriculture (Breimyer; Nikolitch, 1964, 1970, 1972). The changes in the structure of agriculture are suspected to be accelerated by government policies (Balobaum; Bravo-Ureta and Helmers; Carman; Coffman; Gardner and Pope; Jensen; Penn and Boehm; Raup, 1969, 1978; Upchurch).

In brief, agricultural economists are interested more than ever in the issues of equity and efficiency (Humphries, p. 879; Schuh; Schultz, p. 876; Stanton, p. 727; Tweeten, p. 863). Therefore, it is important to assemble and provide evidence about resource use on small and large farms in different settings, so that improved judgments can be made regarding the trade-offs between production efficiency and equity (Stanton, p. 735). However, most of the empirical work relevant to these issues is based on the economic engineering or synthetic firm analyses, rather than or actual firm-level data analyses (Carter and Dean; Dean and Carter; Faris and Armstrong; Moore). Few studies that used firm-level data (e.g. Aigner and Chu; Førsund and Jansen; Hall and LeVeen; Richmond; Seitz, 1970, 1971) have assumed the production frontier to be deterministic.

There are two main problems with this concept. First, the frontier is primarily stochastic, rather than deterministic. Second, no assumptions are made about the properties of the disturbance term (which in some cases is implicitly assumed). Consequently, the parameters of the fixed frontiers of these studies are not estimated in any statistical sense, but are simply "computed" via mathematical programming methods (Schmidt and Lovell, p. 344). In order to overcome these shortcomings, in this study, the comparative average technical efficiency of small and large farms has been estimated relative to the stochastic frontier production functions, using the maximum likelihood method.

STOCHASTIC PRODUCTION FRONTIER

Recently, Aigner et al., and Meeusen and van den Broeck have specified and estimated a stochastic production frontier which can be written as

$$(1) \qquad Y_t = F(X_t,B)e^{\epsilon_t} \qquad t = 1,---,N$$

where Y_t is the output of t-th farm, X_t is a vector of inputs, B is a vector of coefficients, and ϵ_t is a random disturbance. This error term is further decomposed into two error components as follows:

$$(2) \qquad \epsilon_t = v_t - u_t$$

where both u_t and v_t are distributed independent of each other. The disturbance v_t is assumed to be symmetrically distributed ($-\infty < v_t < \infty$), and it captures the random effects of random shocks outside the farm's control, observation and measurement errors on the dependent variable, and other statistical "noise" that every empirical relationship contains. This causes the placement of the deterministic frontier $F(X_t, B)$ to vary across farms, and, therefore, the production frontier $Y_t \leq F(X_t,B)e^{v_t}$ becomes stochastic now.

The error component u_t is assumed to be derived from a normal distribution truncated above at zero, i.e. a half-normal distribution. The technical efficiency[1] relative to the stochastic frontier is captured by the one-sided error component e^{-u_t}, and the condition $u_t \geq 0$ ensures that all observations lie on or below the stochastic pro-

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[1] Stigler (p. 213) argues that all perceived inefficiency is only allocative inefficiency. Even this is recognized as the result of a failure on the part of the researcher, that is a failure to measure all relevant inputs, or to specify correctly the rational behavior of the producers. Stigler may be correct, but his assertion still remains to be empirically tested (Førsund, et al., p. 23). Futhermore, even Stigler (p. 215) agrees that the observed output of two farmers with reasonably homogeneous inputs can still vary.

duction frontier. The appropriate technical efficiency for an individual farm is

$$(3) \qquad e^{-u_t} = Y_t/F(X_t,B)e^{v_t}$$

where $F(X_t,B)e^{v_t}$ represents a Cobb-Douglas stochastic production frontier. Hence, the random variable u_t reflects the degree of technical efficiency of the t−th farm. If a farm is able to produce the maximum output from a given set of X-inputs, the farm will achieve 100-percent technical efficiency, $e^{-u_t} = 1$.

The joint distribution function of the sum of the truncated normal random variable u_t and the symmetric normal random variable v_t has been derived by Aigner et al., to estimate the parameters by maximum likelihood method. Given a random sample of N observations, the log-likelihood function of the parameters can be written as[2]

$$(4) \quad \ln L(Y|B,\lambda,\sigma) = N \ln \frac{\sqrt{2}}{\sqrt{\Pi}} + N \ln \sigma^{-1} + \sum_{t=1}^{N} \ln [1 - F^*(\epsilon_t \lambda \sigma^{-1})] - \frac{1}{2\sigma^2} \sum_{t=1}^{N} \epsilon_t^2$$

where $\lambda = \sigma_u/\sigma_v, \sigma^2 = \sigma_u^2 + \sigma_v^2$, $F^*(.)$ is the standard normal distribution function, and B is the vector of coefficients.

The coefficient $\lambda = \sigma_u/\sigma_v$ indicates the relative variation in the two sources of random errors. As λ approaches zero, the relative variation implies that σ_u^2 approaches zero and/or σ_v^2 approaches infinity, and this indicates that the symmetric error v_t dominates in the determination of the sum of error $\epsilon_t = u_t - v_t$. This means that the discrepancy between the observed output y_t and the frontier one for a given set of input values is primarily the result of factors beyond the control of the farmer, such as measurement error in output observation. Similarly, when the coefficient $\lambda = \sigma_u/\sigma_v$ becomes large, it indicates that the one-sided error term u_t dominates the sources of random variation in the model. In other words, the discrepancy between the observed output Y_t and the frontier output is mainly the result of technical inefficiency.

The estimated stochastic frontier production function can be used to measure the average technical efficiency, first suggested by Afriat, and later empirically estimated by Aigner et al. and by Meeusen and van den Broeck. Unfortunately, the technical efficiency index e^{-ut} cannot be calculated for each individual farm, because v_t is unobservable. However, the average efficiency index for all farms in the sample can be estimated by the statistical expectation of u_t. Assuming, as we have in this study, that u_t is derived from a normal distribution truncated above at zero, that is, a half-normal distribution, the average technical efficiency index is

$$(5) \qquad E(e^{-u_t}) = 2 e^{\sigma_u^2/2} [1 - F^*(\sigma_u)]$$

where F* is the standard normal distribution function evaluated at σ_u.

DATA AND THE ESTIMATED MODELS

The farm-level data used in this study were obtained from a stratified random sample spread over two counties in west Tennessee, and are quite representative of the agricultural situation in that part of the state. There were 215 farm families in the sample, and these farms represented about 6 percent of all farm units in the two counties, according to 1974 Agricultural Census. The data were collected by trained enumerators who lived in these counties. Selected farm households were interviewed 26 times during 1978. The first and the last interviews consisted of opening and closing inventories, which collected data on a number of stock variables such as asset ownership, especially livestock. The 24 bi-monthly visits were made to every farm in the sample in order to collect reliable information on all inputs and outputs.

At the end of the survey, 22 farms were excluded from the sample because of incomplete information. The remaining 193 farms constitute about 5.6 percent of all the farm units in the selected counties. Among these 193 farms, 115 raised only crops, while the remaining 78 raised crops and livestock. In this study, the 115 crop farms and 78 mixed (crop and livestock) farms were divided into small and large farms. In the case of both types of farms, the farms with operating areas smaller than 175 acres are classified as small farms, and farms with 175 acres and more are classified as large farms. This figure of 175 acres was chosen as the dividing line because it is the average size of the 193 farms in the sample. Furthermore, this value is very close to the average farm size in the two selected counties, though it is somewhat higher than the average farm size in the state of Tennessee.

The sample of the 193 farms was separated into 115 pure crop farms and 78 mixed farms. Both crop and mixed farm subsamples were divided into small and large farm groups. Small and large farms have been classified according to acreage

[2] For a detailed derivation, see Aigner et al., (p. 27, 35, 36).

as well as the value of farm sales.[3] Table 1 shows that there is wide variation in the percentage of gross farm income derived from the livestock enterprises among the 78 mixed farms. Therefore, the optimal procedure would have been to estimate separate production functions for livestock and crop enterprises in the case of mixed farms, because it is possible that these two types of enterprises may not be accurately represented by a single production function. However, the necessary input data to estimate separate production functions were not available. During the survey, detailed output information was collected for every farm enterprise, but, unfortunately, corresponding input data for each enterprise were not recorded separately. For example, separate records for labor and capital inputs used for livestock and crop production on the same farm were not kept. Similarly, the amounts of fertilizer and other chemicals applied to crops and pasture were not recorded separately.

TABLE 1. Percentage of Gross Farm Income From Livestock Enterprises on Mixed Farms[a]

	FARM SIZE		
Percentage of Farm Income from Livestock	Small (< 175 Acres)	Large (≥ 175 Acres)	All
	........Number of Farms.............		
≤ 25	7 (14.29)	16 (55.17)	23 (29.49)
26 - 50	10 (20.41)	10 (34.48)	20 (25.64)
51 - 75	14 (28.57)	1 (3.45)	15 (19.23)
> 75	18 (36.73)	2 (6.90)	20 (25.64)
TOTAL	49 (100.00)	29 (100.00)	78 (100.00)

[a] Figures in the parentheses are the percentages.

Model Specification and Estimation

The Cobb-Douglas production function to be estimated in this study can be written as follows:

$$(6) \qquad \ln Y_t = \ln A + a_1 \ln T_t + a_2 \ln H_t + a_3 \ln K_t + a_4 \ln F_t + a_5 \ln LV_t + \epsilon_t$$

where A is a constant, a_i's are the parameters to be estimated, and

Y = value in dollars of farm output. In the case of mixed farms, it also includes the "value added" to livestock over the year, and the income from actual livestock sales during the year. The cost of livestock purchased for resale has been subtracted. Y is calculated on the basis of actual prices received by individual farms. Therefore, it incorporates any price efficiency differences across farms.

T = acreage of crop and pasture land per farm.[4] It does not include homestead and other non-tillable land.

H = number of hours of human labor actually used on individual farms during the year. It includes family as well as hired labor.[5]

K = annualized flow of capital services from agricultural machinery and equipment, farm buildings and fences. It includes depreciation,[6] interest, repair and maintenance, and operating expenses.

F = dollar value of fertilizer, lime, herbicides, and other chemicals, per farm.

LV = dollar value of feeds, veterinary care, etc., per farm.

It should be noted that $a_5 = 0$ in equation (6), for both small and large pure crop farms.

The maximization of the log-likelihood function is performed by a Newton-Raphson iteration procedure, with the ordinary least squares (OLS) estimates composing the initial estimates. The maximum likelihood estimates of the stochastic frontier production functions for small and large farms classified according to acreage and the value of farm sales are presented in Tables 2 and 3, respectively.

EMPIRICAL RESULTS AND DISCUSSION

There are a number of important results that emerge from Tables 2 and 3. First, the average technical efficiency is higher for the crop farms as compared to the mixed farms. Second, both small and large crop farms have almost equal technical efficiency. But the mixed large farms are technically more efficient as compared to the

[3] The value of farm assets may be a more relevant measure of the size of a farm enterprise than acreage and value of farm sales. But use of the value of farm assets as a measure of the size of a farm operation has its own limitations. Farm machinery and equipment is available only in few specifications. Therefore, it is likely that at least some small farms may have overinvested in such capital items. Furthermore, the age of machinery and equipment will have an effect on its current value, while, with proper maintenance, relatively older capital stock may be giving adequate service. However, we could not use this measure here because of the lack of adequate information about the value of land for all farms in the sample.

[4] No efforts have been made to account for land quality differences across farms: necessary data were not available. However, even if data were available, it would not be easy to construct land quality indices (Bardhan). For a detailed discussion of the issues involved see Bagi (p. 459).

[5] The quality of labor is quite likely to vary across farms. But the quality of labor provided by the members of a given family may not be homogeneous. However, there is no non-question-begging method to adjust for such qualitative differences.

[6] A uniform depreciation rate is charged over the economic life of machinery and equipment, farm buildings, and fences.

TABLE 2. Maximum Likelihood Estimates of Stochastic Frontier Production Functions For Small and Large Farms Classified According to the Acreage[a]

Variables	Crop Farms		Mixed (i.e. Crop and Livestock) Farms	
	Small (89)	Large (26)	Small (49)	Large (29)
Constant	2.6403 (5.7315)	5.7644 (5.0234)	3.8807 (4.2853)	3.6737 (2.3621)
ln T	.6374 (6.7095)	.5100 (4.0203)	.4159 (2.7858)	.1706 (1.8254)
ln H	.1975 (3.8552)	.1344 (2.6271)	.1352 (1.8500)	.2156 (2.2998)
ln K	.1981 (4.9067)	.1201 (2.0114)	.1231 (2.4026)	.1671 (2.4059)
ln F	.2436 (5.0240)	.2594 (2.6893)	.1354 (2.4669)	.1018 (1.6054)
ln LV			.2336 (3.7010)	.3507 (2.6142)
S	1.2766 (13.2625)	1.0239 (7.2309)	1.0432 (6.1377)	1.0058 (4.4850)
h = 1-S	.2766 (2.7526)	.0239 (0.1538)	.0432 (0.2505)	.0058 (0.0259)
R^2	.7059	.7735	.6703	.6575
$\lambda=\sigma_u/\sigma_v$	1.5947	2.2646	2.2265	1.7324
$\theta=\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	.7178	.8368	.8321	.7501
Average Technical Efficiency	.8521	.8499	.7547	.7651
Average Technical Inefficiency	.1479	.1501	.2453	.2349

[a] Figures in the parentheses are the asymptotic t-ratios.
Note: S = the returns to scale.

TABLE 3. Maximum Likelihood Estimates of Stochastic Frontier Production Functions For Small and Large Farms Classified According to the Value of Farm Sales[a]

Variables	Crop Farms		Mixed (i.e. Crop and Livestock) Farms	
	Small (84)	Large (31)	Small (46)	Large (32)
Constant	3.3838 (7.2017)	5.1359 (4.9539)	4.7549 (4.6866)	4.1884 (2.2588)
ln T	.6219 (6.6023)	.4710 (4.1867)	.2954 (2.7722)	.2513 (2.2820)
ln H	.1206 (2.2256)	.1362 (2.3634)	.2017 (1.8890)	.1965 (2.2770)
ln K	.1868 (4.4162)	.1661 (2.5522)	.1968 (2.2066)	.1331 (1.8707)
ln F	.2023 (4.1298)	.2621 (2.6545)	.1181 (2.1765)	.1028 (1.2903)
ln LV			.1966 (1.8125)	.3350 (2.5795)
S	1.1316 (11.9279)	1.0354 (7.3304)	1.0086 (5.8914)	1.0187 (4.2935)
h = 1-S	.1316 (1.3872)	.0354 (0.2506)	.0086 (0.0502)	.0187 (0.0788)
R^2	.6599	.6956	.6428	.6322
$\lambda=\sigma_u/\sigma_v$	1.8837	2.1268	1.6639	2.0588
$\theta=\sigma_u^2/(\sigma_u^2+\sigma_v^2)$	.7801	.8147	.7346	.8091
Average technical efficiency	.8494	.8503	.7477	.7702
Average technical inefficiency	.1506	.1497	.2523	.2298

[a] Figures in the parentheses are the asymptotic t-ratios.
Note: S = the returns to scale.

mixed small farms, according to both classifications. Technical efficiency of a given group of farms is only slightly different under the acreage and the value of farm sales classification criteria. The technical efficiency of large (small) farms is higher (lower) under the classification based on the value of farm sales as compared to those identified according to the acreage classification. This particular result is not surprising, since the value criteria classify farms with small acreage, but high level of farm output, as large farms, and farms with large acreage, but low income, as small farms. Consequently, a sample selected on the basis of the value of farm output is likely to underestimate (overestimate) the technical efficiency of small (large) farm group.

Third, all λ values are greater than unity. As indicated before, this means that the symmetric error (v_t) dominates the one-sided error (u_t) in all cases. Furthermore, the θ values range between 0.7178 and 0.8368. This means that between about 72 and 84 percent of the discrepancy between the observed and the maximum (frontier) output results from technical inefficiency. In other words, the shortfall of the observed output from the frontier output primarily reflects factors that are within the control of the farmers. Fourth, only small crop farms classified according to acreage exhibit siginficant increasing returns to scale.[7]

Technical inefficiency represents the degree of failure to produce the maximum output from a given level of inputs. One-percent technical inefficiency means that the farmers could have produced one-percent more output from the *existing* level of inputs. A group of farms is technically more efficient if this group produces more output from the same level of inputs as compared to another group of farms. Technical inefficiency varies between 0.1497 and 0.2523, as shown in Tables 2 and 3. Therefore, there is a potential to increase the farm output between about 15 and 25 percent from the existing level of inputs.

SUMMARY AND CONCLUDING REMARKS

A sample of 193 farms from west Tennessee is first divided into crop and mixed farm subsamples. Then these two types of farms are subdivided into small and large farm groups on the basis of the acreage and the value of gross farm sales. A stochastic frontier production function for each group of farms has been estimated, using a maximum likelihood method. The results show that both small and large crop farms have almost equal technical efficiency. But mixed large farms have somewhat higher technical efficiency, as compared to the mixed small farms.

However, both small and large farms classified according to acreage, as well as the value of farm sales, have substantial technical inefficiency—the degree of failure to produce the maximum output from a given level of inputs. One-percent

[7] Technical inefficiency is inversely related to the returns to scale (Førsund et al., p. 16; Schmidt and Lovell, pp. 346–51). However, the returns to scale is not a direct measure of technical efficiency. Therefore, a group of farms with relatively lower returns to scale can have higher technical efficiency, as compared to a group of farms with higher returns to scale.

technical inefficiency means that it is possible to produce one-percent more output from the existing level of inputs. Therefore, small and large farms have the potential to increase farm output between 14.79 to 25.23 percent from the existing level of inputs.

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