ECONOMIES OF SIZE AND OPERATING EFFICIENCY OF LIVESTOCK MARKETS: A FRONTIER FUNCTION APPROACH

W. H. Lesser and W. H. Greene

Abstract. A cost curve for livestock auction markets was estimated using a frontier function estimator. This estimator has the advantages of consistency and asymptotic efficiency (for certain disturbance specifications). The one-sided residuals satisfy theoretical requirements for cost curves and allow estimates of operational efficiency. Results indicate little size savings above 50,000 LMU, (12 percent of markets in 1976). Estimated operational inefficiencies ranged from 0 to 45 percent. Total technical efficiency (size diseconomies plus operational inefficiencies) are high for some markets and some size groups. Little consolidation is predicted for the industry because the estimated cost of technical inefficiency is small compared to distance related costs (e.g., transport and shrink).

Several attempts have been made over the last decade to estimate size economies of local livestock auction markets (Cf. Stoddard, Grinnell and Shuffett, Kuehn, Wilson and Kuehn, and Buccola and Polishuk). Two methodologies were used in these studies, economic engineering methods (Cf. Kuehn), statistical cost analysis (Cf. Stoddard), or a combination of the two (Cf. Buccola and Polishuk). Both procedures have limitations which make interpretation and application of the results difficult.

Economic engineering techniques are applicable to markets using current, not past, technology (Scherer, 1970, p. 83). The livestock auction industry has not seen notable changes in technology in recent years, but those technological advances which have occurred have usually been incorporated into the facility design. Many existing markets predate these design changes. In New York State, for example, "[the physical plants in which many of the auctions operate] were originally constructed for other purposes and had been converted to auction markets," (Marion, p. 6). Thus, the layout of many markets does not permit operating at maximum efficiency and economic engineering studies overestimate size economies if poor design leads to congestion. Economic engineering methods also are most appropriate if the enterprise is capital intensive and output determined by the rate of machine operation. Livestock auctions, however, are labor intensive with output critically dependent on labor management and coordination practices.

Statistical cost analysis may be inappropriate because traditional estimation procedures such as least squares lead to the measurement of an "average" cost function rather than the envelope or frontier curve specified by economic theory (French, pp. 55-58). Estimation using operating data filed with the Packers and Stockyards Administration of the Department of Agriculture (P&SA) does, however, avoid the problem of definitional differences in costs and accounting procedures since the P&SA requires livestock auction markets to compile annually extensive, fairly uniform accounting data (P&SA Form 130).

The purpose of this study is to estimate size economies in livestock auction markets using a national sample. The estimation is done using a recently developed frontier function estimator (Greene). This estimator, as discussed in more detail below, has several advantages over the methodologies noted earlier. It is theoretically consistent in that the results represent a true envelope curve. Depending on certain values of the underlying parameters, estimation using maximum likelihood procedures can lead to considerable gains in asymptotic efficiency compared to least squares estimators. And finally since the estimated curve approximates the minimal obtainable operating costs for a given level of output, deviations from this level (as measured by the estimated residuals) reflect the degree to which a particular observation fails to achieve the theoretical optimum level of cost minimization (or output for a given cost).

The results of this analysis should contribute to a better understanding of auction market costs and operational efficiencies as well as provide some insights into likely structural changes following almost complete deregulation of commission fees by the P&SA. In past years the livestock auction industry was regulated in much the same way as a public utility, a situation which might be expected to have reduced the competitive interactions of markets and the incentives for improving efficiency through consolidation or other means (Grinnell and Shuffett).

This paper is structured as follows. The following section outlines the properties of the frontier function estimator. Space does not permit the demonstration of these properties, and the interested reader is directed to the original source (Greene). The statistical estimates from a national sample of livestock auction markets are presented in the third section. To help with the interpretation of these results they are contrasted with those from a recent study by Buccola and Polishuk. This comparison is included for heuristic purposes only since the two estimates differ in sample area (National vs. Virginia), estimation techniques (frontier function vs. error component estimation) and data (sample vs. sample plus economic engineering).

FRONTIER FUNCTION ESTIMATOR

Early work on the estimation of full frontiers (e.g., Aigner and Chu) used linear and quadratic programming techniques to estimate the parameters. While this approach does solve the constrained estimation problem, the estimates so obtained have unknown statistical properties and therefore have limited usefulness (Schmidt). Recent research has produced operational statistical techniques which provide frontier estimates with known properties. Work has proceeded in two directions. Aigner, Lovell, and Schmidt *et al.* have relaxed the orthodox assumption of one sided residuals, and developed estimation techniques for what is known as the composed error model. Greene has examined, instead, the properties of maximum likelihood estimators of "full frontier" functions. He shows that certain specifications lead to maximum likelihood estimators with all of the familiar properties in spite of the rather unusual nature of the disturbance (i.e., its "one sidedness"). One particularly attractive stochastic specification is the Gamma family of distributions (of which the chi-squared distribution is a member). Each of the two types of frontier estimators has its features to recommend it. We have adopted the full frontier approach because in addition to the parameter estimates it provides, in the estimated residuals, direct estimates of relative operating efficiency for the individual sample observations.

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A few comments on estimation are in order. The production or cost function is specified in general form as

(1) $y_t = \alpha + \underline{\beta}'\underline{X}_t + \epsilon_t,\ t = 1,2,\ldots T$

where y_t is output or total cost

$\underline{X}_t$ is a vector of exogenous variables

ϵ_t is a random disturbance.

It is easy to show that when ϵ_t is one sided, as long as $E(\epsilon_t)$ is the same for all t, say μ, OLS provides unbiased and (given the usual assumptions about $\underline{X}_t$) consistent estimates of $\underline{\beta}$. The OLS intercept, α, however, is biased; it estimates $\alpha + \mu$ instead of α. But, it is shown in Greene that a consistent estimate of α can be obtained by the (intuitively appealing) procedure of simply shifting the OLS estimated intercept until all residuals save the one associated with the supporting point have the correct sign. Therefore, consistent estimates can be obtained by OLS. However, a more efficient estimate is obtained by using the technique of maximum likelihood. In the setting of the Gamma distribution for ϵ proposed by Greene considerable gains in asymptotic efficiency over OLS can be obtained, depending upon certain values of the underlying parameters. The precise form of the likelihood function and the form of the asymptotic covariance matrix for the estimates are presented elsewhere (Greene).

EMPIRICAL ESTIMATES

The models to be estimated are

(2) $\text{LnC} = \alpha_0 + \alpha_1 \text{LnY}$ and Model I

(3) $\text{LnC} = \alpha_0 + \alpha_1 \text{LnY} + \alpha_2 (\text{LnY})^2$ Model II

where C is total auction marketing expenses, and

Y is throughput measured in standardized units.

Model I assumes constantly decreasing (or increasing) costs while model II allows the function to have the traditional U-shape. The latter model is better suited to the livestock auctioning process, an assembly and sorting operation in which mixed lots are brought together in one place and sorted according to the needs of buyers. Average costs are expected to decline over an interval as fixed costs are distributed over a larger volume and as labor becomes more specialized, then turn up when crowding and the distance from pens to the ring reduce productivity. The use of the log linear form permits the estimation of scale economies. When $\alpha_2 = 0$, the Cobb Douglas function with economies of scale $1/\alpha_1$ is obtained. For the more general model, the measure of economies of scale is $\partial \text{lnc}/\partial \text{lnC} = \alpha_1 + 2\alpha_2 \text{lnY}$. A value greater than one indicates diseconomies, equal to one indicates constant returns to scale, and so on. (This method of measuring scale economies was first proposed by Nerlove in his classic paper on electricity generation.)

Cost and volume data from all 1,596 auctions reporting in 1976 are used to estimate the models (P&SA, unpublished data). Only items identified by the P&SA as pertaining directly to the marketing function are included with total costs (see Stoddard, pp. 27-32). Two adjustments to the data must be made before it is appropriate for the analysis. First, substantial differences in reported costs for similar size firms have been found by other authors to cause estimation problems (Cf. Wilson and Kuehn). To reduce this, dispersion means of groups established by the P&SA for 16 size ranges from less than 5,000 units to greater than 200,000 units are used. Second, the breeds and class of animals sold influence marketing costs. Pooling uniform lots of fed beef, for example, can reduce unit handling costs compared to individual sales while the unsteadiness of young calves makes them slow and therefore expensive to auction. The livestock marketing unit (LMU) is used to accommodate these cost differences. One LMU equals the marginal cost of selling each of the following groups of animals: 1 steer, heifer or cow, 1 calf, 1 horse, 3 hogs, and 4 sheep (Stoddard, pp. 25-28). The composition of a livestock marketing unit may vary from area to area but this breakdown which is currently used by the P&SA is adopted here.

Size Economies

The parameter estimates for the two models (Table 1) favors the acceptance of Model II although the multiple correlation coefficient (R^2) is not available to aid in the selection process. Defining "minimum efficient scale" (MES) as the point where all size economies are exhausted, this point can be estimated for Model II by equating $\partial \text{lnC}/\partial \text{lnY}$ to 1. This is equivalent to $Y = \exp((1-\alpha_1)/2\alpha_2)$. Solving gives an estimated MES of 1.25 million LMU. Operation at this level is considerably beyond the largest size group mean of almost 300,000. Extrapolation of the data to this extent is suspect because of likely coordination problems at this size. However, the average cost curve becomes relatively flat beyond 100,000 LMU so that the largest size group (> 200,000 LMU) suffers a cost penalty of only 4 percent above the estimated minimum cost of $2.01 per LMU (Table 2). Significant subscale economy penalities of 10 percent are encountered at markets in the 100,000 LMU per year size range, and as size decreases the penalty increases up to almost 60 percent for markets in the 5,000 annual LMU size range. Since 93 percent of posted auctions in 1976 handled less than 100,000 LMU a year and 41 percent less than 20,000, there appears to have been a significant number of inefficiently small auction markets in operation in 1976.

Model II also leads to a measured scale economy of less than one signifying increasing economies of scale up to MES while with Model I a scale economy of greater than one meaning diseconomies is estimated. Increasing scale economies are expected *a priori.*

Operational Efficiency

Because a fitted frontier function such as that reported in Table 1 gives an approximation of the "true" envelope curve, deviations from the estimated function may be compared to determine the relative efficiency of operation. Deviations are represented by the estimated residuals for each observation (size group). However, since the residuals must be positive the function is sensitive to the observations contained in a particular sample. The parameter most sensitive is the intercept, and any shift in the intercept causes an opposite change in every residual. To remove the sample specific effect on the residuals, they should be ranked relative to each other or the mean value, not to the frontier.

Using the mean as a basis for ranking and defining an observation as operating relatively inefficiently if the corresponding residual exceeds the mean, the efficiency of livestock auction markets is found to vary considerably from group to group (Table 3). In particular the smallest size group, the 105 firms in 1976 handling less than 5,000 LMU, are especially inefficient

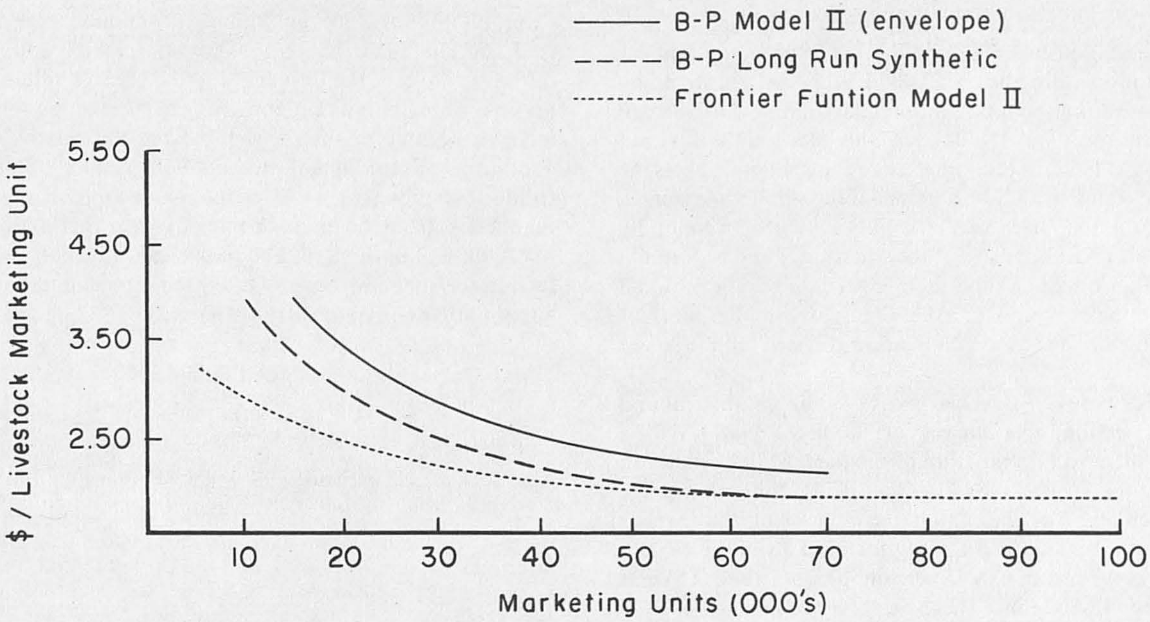
Table 1

Frontier Function Parameter Estimates for 1976

Model Total Costs	α_0	α_1LMU	α_2LMU^2
I	1.96 (72.18)	.8985 (35.21)	
II	3.57 (17.00)	.592 (14.49)	.0145 (7.35)

Note: t-ratios are in parentheses

LMU is Livestock Marketing Units (see text)



Sources: B-P Buccola and Polishuk, p. 7
Frontier Function, Table 1

Figure 1.
Comparison of Statistical, Economic Engineering and Frontier Function Estimates of Livestock Auction Markets, Size Economies and Operational Inefficiencies

operationally. More consequential in terms of numbers are the 343 firms (21 percent of all firms) averaging between 40,000 and 85,000 LMU which are relatively less efficient than larger and smaller markets. Further research is necessary to determine why these groups are generally less efficient.

Total technical inefficiency includes both the amount of operation inefficiency and the cost of operating above the minimum efficient scale. Total inefficiency may be estimated as follows for the 50,000 to 60,000 LMU group. The penalty for operating below MES is almost 17 percent or 34 cents per LMU. Operationally this group has a residual of .126 compared to the sample mean of .103, a 22 percent margin (Table 3). With a minimum unit sales cost of nearly $2.35 for this group, this is an estimated cost inefficiency of $.52 per unit or a total technical inefficiency of $.86, or 36 percent. This may be considered to be substantial.

To give an idea of how our results compare to those developed using more conventional estimation techniques, the frontier function is plotted in Figure 1 with both a regular (two-sided

Table 2
Cost Penalties of Livestock Auction Markets Operating Below the Minimum Economic Scale, 1976, Model II

Group Size in 1000's Livestock Marketing Units	Estimated *Marketing Costs/ Livestock Marketing Unit	Penalty Above Minimum Economic Size
5	$3.15	57%
10	2.85	42
20	2.59	29
50	2.35	17
100	2.21	10
250	2.09	4
500	2.04	2
750	2.02	.5
1,000	2.02	.5
1,288*	2.01	—

*Minimum Estimated Cost (MES)

Table 3
Determining Operational Efficiency From the Residuals, Model II

Group Mean (1,000's)	Residual
3.0	.465*
7.7	.024
12.4	.056
17.3	.122*
22.5	.038
27.3	.069
35.0	.053
44.9	.098
54.4	.126*
64.9	.125*
74.7	.109*
84.9	.149*
94.3	.057
119.2	.057
164.7	.070
298.6	.037
Mean	.103
S.D.	.104

*Relatively operationally inefficient compared to the mean where inefficiency is defined as a value which exceeds the mean.

residuals) cost function and a long run synthetic cost function, both from Buccola and Polishuk (B-P, p. 7). Our results show smaller cost penalties for operating below 50,000 LMU than that found by Buccola and Polishuk (who used a different definition of a livestock marketing unit, footnote 1). Beyond this level all estimation procedures predict few size economies. For the smaller markets the disparity in the results would be obtained if the smaller markets in the national sample had older facilities which were fully depreciated. This is the opposite of the situation found in Virginia (Buccola and Polishuk, p. 8) and there is no data for the national sample. It nevertheless seems unlikely that many smaller markets with their notable size diseconomies would have been built in recent years.

The difference between Buccola and Polishuk's statistical and economic engineering cost curves of 30 cents per LMU is interpreted by them to be a measure of the average inefficiency in Virginia's livestock auction industry (pp. 10-11). No such average figure was calculated for the national sample using the frontier function but the estimated inefficiency for markets in the 40,000-90,000 groups ranged from 6 to 45 percent, or from about 15 cents to one dollar per LMU. Since these markets account for over 20 percent of the markets in operation in 1976 it appears that the Buccola and Polishuk estimate understates the level of inefficiency in livestock auction markets in the national sample.

CONCLUDING COMMENTS

The frontier function estimator used here has several advantages over other techniques for estimating livestock auction market cost functions as well as those for other processes. It provides consistent and more efficient estimations than OLS in many situations and permits estimation of operational efficiency. An application of the frontier function using 1976 grouped, national P&SA cost data suggests a long-run cost curve which is relatively flat beyond 50,000 LMU. However, 78 percent of the markets reporting that year operated below this range. Additionally, there appear to be substantial operational cost inefficiencies in some markets, most notably those on the 40,000 to 85,000 LMU range, for an estimated total technical inefficiency of $.86 per LMU for markets in the 50,000-60,000 LMU range. This amount is notable, and if market technical efficiency (size economies plus operational inefficiencies) alone were the basis of intermarket competition a substantial attrition of the smaller markets would be expected.

However, from the perspective of the consigner, commission fees are minor compared to trucking and, more especially, shrinkage costs. Livestock truckers in New York State, for example, charged from $5 to $15 to haul a cow to the nearest market in 1978 (unpublished data from auction markets). The net shrink differential after fillback for a 10 to 50 mile haul is one percent (St. Clair, p. 15). For a $65/cwt choice 1,000 pound steer this amounts to $6.50, or $4.50 for a 1,000 pound cutter cow. These cost differences exceed the technical cost differences among market size groups. Thus the market for livestock marketing services would seem to be able to sustain well-located but relatively inefficient operations. Eventual adjustments will probably result as much from subsector changes such as the continuing decline of dairy herd numbers as from the direct operation of market forces on high-cost operations. The limited alternative-use value of many market facilities also slows the rate of market rationalization despite apparent losses by some firms (Kuehn).

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