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Operating Cost Efficiency on Pennsylvania Dairy Farms

William Grisley and Juan Mascarenhas

Operating cost efficiency is evaluated on Pennsylvania dairy farms using a modification of the Farrell efficient unit isoquant frontier method. Evaluating farms by herd size groups, the average measure of cost efficiency ranged from 70 to 80 percent. Farms with larger herds were more homogeneous in efficiency than farms with smaller herds. Regression analysis was used to evaluate for differences in cost efficiency by herd size group.

In a recent issue of this *Journal*, Richard King reviewed the theory and application of the efficient unit isoquant developed by Farrell. He concluded, "the use of Farrell's unit isoquant representation of input-output relationships is appropriate for a wide variety of topics that interest agricultural economists," p. 7. However, data requirements necessary to measure technical, pricing, and economic efficiency are often lacking in most farm level data sets. In most cases farm level data are collected for purposes of financial analysis.¹ Information on operating inputs is most commonly recorded in terms of costs and not units consumed and prices paid per unit. As a result, these data are not of direct use in addressing many farm production issues. Efficiency and input substitution in production, technical change, and economies of size and scale cannot be easily analyzed with these data. However, financial data are of direct use in evaluating cost efficiency in production. The purpose of this paper is to measure the cost efficiency of operating input consumption in milk production from a selected cross section sample of Pennsylvania dairy producers using a modified approach of the Farrell efficient unit isoquant frontier. The analysis demonstrates that farm level financial data can be of use in examining efficiency and provide results that

may be of use to dairy management specialists.

The paper is organized into four main sections and a conclusion. Section one reviews methods used previously to measure efficiency, as well as the method used in this study. Section two identifies the area studied and characteristics of the variables used, and section three describes the methodology. The results of the analysis are presented and discussed in section four.

Methods of Measuring Efficiency

Different methods of measurement of production and economic efficiency have been used by economists. Included are the cost synthetic, production function, frontier production function, dual profit and cost function, and the efficient unit isoquant frontier approaches. Each of these methods has important advantages and disadvantages with respect to model assumptions, application, and data requirements. The cost synthetic approach was used by Matulich to evaluate economies of scale in dairy farming. While of use in determining cost advantages in moving to larger herd sizes, it does not model actual behavior by operating farms. The production function approach has been used by Carley, and Paris, Molossini, Pilla, and Romita to estimate elasticities of substitution between feed inputs in milk production. While theoretically appealing, this approach has the disadvantage of specifying the functional form of the production structure in advance. In addition, full information on all inputs are rarely available and omitted variables can result in biases of

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¹ Farm financial record keeping services in the Northeast include the Pennsylvania Farmers' Association, AGRIFAX, ELFAC, and New York farm management business records.

the estimates (Varian, pp. 124-26). The frontier production function and dual approaches are theoretically appealing, but require data on input quantities in the former case and data on input quantities and prices in the latter case (for application of these approaches see Lesser and Greene, Huang and Bagi, Lau and Yotopoulos, and Grisley and GITU).

A conceptual and computational framework for measuring technical, pricing, and economic efficiency was developed by Farrell in 1957. His original work has been extended and applied by Farrell and Fieldhouse, Seitz (1968, 1970), Timmer, Afriat, Richmond, Araj, Hall and Leveen, and Schmidt and Lovell. Using ratios of the quantity of individual production inputs to output produced, Farrell derives an efficient unit isoquant frontier that identifies the most technically efficient firms in a set of firms. Firms not on the frontier are technically inefficient and the degree of efficiency of each can be determined relative to those on the frontier.

Important computational limitations of the Farrell approach are that scale effects cannot be easily dealt with and efficiency is measured with respect to only a few of the firms being studied (Bressler). In addition, the position of the frontier is sensitive to data measurement error and outliers in the data. Scale effects across firms of different size were examined by Seitz (1968) in an analysis of the steam electric generating industry in California and by Araj in a study of beef cow-calf operations in Idaho. In the computation of efficiency measures across firms of different size, they used output as a proxy for scale. More recently, Bravo-Ureta measured technical efficiency on Maine and Vermont dairy farms using the Farrell approach. Using inputs labor, capital, concentrates, and roughages, he found considerable variability in efficiency. An important limitation of this study was that the set of inputs was not considered simultaneously in measuring technical efficiency.

Because financial data identify operating input utilization in terms of costs, the cost rather than the production approach is used in this study. Since a cost function has a well defined underlying production function, the cost approach can be used to analyze efficiency. Starting from the premise of the Farrell efficient unit isoquant frontier, an efficient unit isocost frontier is developed. This frontier can be conceptualized and inter-

preted in a manner analogous to the efficient unit isoquant frontier. Consider the two input, single output case shown in Figure 1. Under the unit isoquant approach, the quantities of the two inputs, X_1 and X_2 , are divided by the level of output Q . Firms with input-output points on the frontier FF' are technically efficient in the sense that they are using the least amount of the inputs X_1 and X_2 to produce a unit of output. Under our modified approach the cost of the two input quantities, Q and C_2 , are divided by the units of output. By computing this ratio for a set of firms the efficient unit isocost frontier can be identified. In the neoclassical theory of the firm, the isocost line is taken to be linear because of the assumption of perfect competition in input markets. Under the unit isocost approach the frontier is curvilinear and convex to the origin due to the shape of the unit isoquant and its multiplication by prices paid. If firms pay different prices for inputs the unit isocost frontier could be more or less curvilinear, depending on whether high input users pay higher or lower prices.

Firms falling on the efficient unit isocost frontier HH' have the least input cost per unit of output and are cost efficient. Firms falling to the right of the frontier have higher input costs per unit of output and are cost inefficient relative to those on the frontier. The cost efficiency of each firm not on the frontier can be computed using the same procedure as used by Farrell in computing technical efficiency. The cost efficiency of Firm P in Figure 1 can be computed as the ratio of the

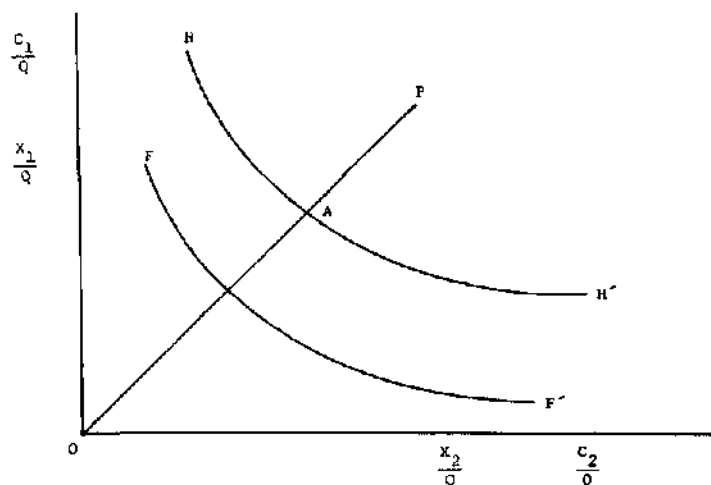


Figure 1. The Efficient Unit Isoquant (FF') and Efficient Unit Isocost (HH') Frontiers

length of the line OA to the length OP. The length of the line AP is a measure of the excess cost of the two inputs relative to what is feasible.

Area of Study and Data Description

Data used in this study are from Pennsylvania Farmers Association annual records for 1981 and 1982. Records of dairy farmers for both years were merged, and the annual average of each operating input used was taken. Two years of data were used to even out the operating expenses over a longer period of time. Before averaging, 1981 values were converted to 1982 dollars using the implicit price deflator. A total of 701 family owner operated dairy farms employing both unpaid family and hired labor were selected and divided into four groups by herd size. In a limited number of cases, a small percentage of cropland under production was rented or sharecropped. The farms studied had herd sizes ranging from 20 to 120 cows. On average, the farms obtained over 94 percent of their total cash receipts from the sale of milk and dairy livestock and produced more than 60 percent of the total value of feed fed. These farms are considered to be better than the average farm in the state in terms of milk production per cow, labor efficiency, and profitability. A complete description of the farms studied can be found in Dum, and Grisley.

Operating inputs were aggregated by type into four categories—feed, livestock, labor, and miscellaneous expenses. The reason for the aggregation is that many farms did not use an identical set of inputs, and the observed variability of the cost of individual inputs used was large across farms in some cases. Since the method used in measuring the unit isocost frontier is sensitive to extreme data points, aggregation of individual inputs into input categories would even out the input costs per hundredweight of milk sold. However, aggregation of inputs eliminates much of the detail of the cost structure if the aggregation cuts across inputs used for different purposes. The aggregate used here summed across inputs used for specific production purposes.

The feed variable is composed of feeds purchased, custom work hired, crop and seed supplies, fertilizer and lime, machinery repairs, gas and oil, machinery and equipment

depreciation, and adjusted for changes in feed inventory. Since these inputs were not used exclusively in the production of inputs (feed and replacement heifers) going into milk production, the aggregated value was multiplied by the percent of total farm receipts coming from the sale of milk and dairy livestock. This may not exactly measure the percentage of input expenses going into milk production, but is a close approximation. This adjustment in costs is used in the annual *Pennsylvania Dairy Farm Business Analysis* to measure milk production costs.

The livestock variable is composed of breeding, testing, and registration, veterinary and medicine, livestock supplies, and livestock purchases. Livestock purchases were included since farmers produce different percentages of their replacement heifers. The cost data used includes costs incurred in producing replacements. Labor expenses include both hired and unpaid labor. Unpaid labor was valued at the same rate as hired labor. Miscellaneous expenses are the sum of building repairs, utilities, insurance, and other miscellaneous expenses. The livestock, labor, and miscellaneous expense variables were also multiplied by the percent of farm receipts coming from the sale of milk and dairy livestock.

The farms studied used different proportions of debt and equity financing. Financing expenses were not included in the analysis since no acceptable method could be found to accurately value equity capital. However, this omission may not bias the results since efficiency in operating input allocation is normally considered to be independent of the source of financing.

Methodology

A linear programming model developed by Boles was used to derive the efficient unit cost frontier and measures of cost efficiency for each farm. The value of each input category (feed, livestock, labor, and miscellaneous expenses) used by the farm is divided by the farm's level of milk production. This yields a vector of costs used per unit output. These vectors become the A matrix for a series of linear programming problems:

$$\begin{aligned} \text{Max } G &= VX \\ AX &\leq BJ \\ X &\geq 0. \end{aligned}$$

The constraints are the input categories, and all $V_i = 1$. Each vector in A becomes, one at a time, the B_j vector. Thus the j th linear programming problem finds the maximum of G_j using the inputs per unit of output for the j th farm. If G_j is greater than one, the j th farm is inefficient because some combination of activities can produce more than one unit of output. The efficiency index is determined by taking the reciprocal of G_j . Alternatively, if G_j is one, then the j th farm is efficient since no combination of farms can produce more than one unit of output with the j th vector of resources.

Farms with an efficiency index of one form the efficient unit isocost frontier. All farms with an optimum solution of the linear programming problem of greater than one fall above and to the right of the frontier. Four series of linear programming problems were used, one for each of the four herd size groups.

Results

Results of the linear programming model solutions for each of the four herd size groups are reported in Table 1. The number of farms on the frontier ranged from 7 to 18 percent across the different groups. These farms were found to be the most cost efficient within their respective group in converting purchased feed and feed production inputs, livestock inputs, labor, and miscellaneous inputs, measured in dollars, into milk. Farms off the cost frontier were not efficient in the sense that they had higher costs per unit of output. The mean val-

lies reported are a measure of the average cost efficiency for each group relative to the most efficient farms in that group.

Across herd size groups, both the mean and standard deviation of the cost efficiency measure showed a distinct pattern. The mean level of efficiency was less for the two smaller herd size groups and the variability in efficiency decreased for increases in herd size. These results suggest that farms were more homogeneous in cost efficiency as herd size increased. While a large number of factors can contribute to this result, one explanation may be that management practices and the level of overall technology employed were more homogeneous on the larger herd size farms.

It is not possible to determine if one group was more or less cost efficient than another because the measures for each group were determined relative to the most efficient farms in that group only. However, a comparison of the means and variance between groups can be made to assess for differences in the relative measures. A smaller mean implies the group is relatively less inefficient, and a smaller variance implies less dispersion in efficiency. Hypothesis tests for equality of means and equality of variances between groups are shown in Table 2. No significant differences in means were found when comparing the two smallest herd size groups and when comparing the two largest herd size groups. All other pairwise tests were found to be significant. For the between group equality of variance tests, only the smallest group was found to have a significantly different variance from the two largest groups. Even though significant differences in means and variances

Table 1. Frequency Distribution of Cost Efficiency by Herd Size Group, Pennsylvania Dairy Farms

Percent level of efficiency	Herd Size—Cows			
	20 to 39	40 to 59	60 to 79	80 to 120
100	9 ^a	7	11	18
90 to 99	7	5	20	13
80 to 89	14	13	19	25
70 to 79	21	23	30	29
60 to 69	30	32	16	12
50 to 59	14	16	2	2
40 to 49	4	5	1	1
39 or less	1	0	1	0
Mean level of efficiency (%)	73	70	81	82
Standard deviation of efficiency (%)	15	14	13	12
Number of farms	160	291	153	97

^a Percent of farms by level of efficiency.

Table 2. Between Herd-Size Group Tests for Equality of Means and Equality of Variances of the Measure of Cost Efficiency

Herd size groups compared	Mean test-t-value	Variance test F-value
20 to 39 and 40 to 59	1.52 -	1.11
20 to 39 and 60 to 79	5.16*	1.33**
20 to 39 and 80 to 120	-5.29*	1.45*
40 to 59 and 60 to 79	-7.52*	1.19
40 to 59 and 80 to 120	-7.27*	1.31
60 to 79 and 80 to 120	-0.83	1.10

Single and double asterisks indicates significance at 0.05 and 0.10 probability levels, respectively.

were found, it cannot be concluded that one herd size group was more or less efficient than another group. The results do show, however, that larger herd size groups were more homogeneous in efficiency than smaller herd size groups. The large variation in efficiency within groups suggests farms have considerable room to increase cost efficiency and perhaps increase farm profitability.

While these results indicate wide differences in cost efficiency occurs within herd size groups, they provide no information on why differences in efficiency occurs across farms—a question of considerable importance to dairy herd management specialists. Differences could be due to the level of technology employed in feed and milk production, crop and dairy management practices, quality of operating inputs, and cropland resource endowments. In this study, regression analysis is used to evaluate for differences in cost efficiency by herd size group. The cost efficiency measures determined from the solutions of the linear programming model are regressed on available farm characteristics and management practices. The explanatory variables used are; 1) debt per cow, 2) building investment per cow, 3) machinery investment per acre, 4) ratio of hired to total labor, 5) milk sold per cow, 6) percent of feed produced, 7) ratio of heifers to cows, 8) percent milk butterfat, and 9) four regional dummy variables. Other variables that may be important in explaining variability of cost efficiency in milk production were not available. In part, these would include genetic merit of the cows, type of barn and machinery and equipment, and managerial expertise of the farm operator.

The regression estimates for each of the four herd size groups are shown in Table 3. The R-squares were low, ranging from 0.12 to 0.23,

suggesting other factors were important in explaining the variability of cost efficiency. However, the F-statistics were significant for all herd size groups at the 0.05 probability level or greater. A positive (negative) sign on the coefficient indicates a *ceteris paribus* change in that variable has a negative (positive) effect on cost efficiency.

The debt per cow variable was included to test the hypothesis that the source of financing has no effect on cost efficiency. The variable was significant for only the 40 to 59 cow herd size group. While the variable was highly significant, a \$100 increase in debt per cow had only a marginal effect on cost efficiency. Normally, debt financing would not be expected to effect cost efficiency since production cost is not related to the source of financing used. In practice, however, high levels of debt could have various effects on cost efficiency. If a capital constraint emerges at high debt levels and forces a shift to more labor intensive techniques, costs could increase. However, if lender participation in management decisions increases because of high debt levels, costs could decrease from an improvement in management.

Building investment per cow and machinery investment per acre were included in the model as proxies for level of technology employed and associated labor productivity in feed and milk production. A larger investment would imply higher levels of mechanization, suggesting a potential for greater labor productivity. These variables were significant with an unexpected positive sign for only the smallest herd size group, implying a larger investment was directly related to greater inefficiency. The finding that these two variables were significant for only the smallest group may suggest that this group has greater heterogeneity in levels of investment than groups with larger herd sizes. Better measures to explain cost efficiency with respect to technology employed would be information on the type of cow housing and feed storage and delivery systems and size and type of machinery and equipment components. This information was, unfortunately, not available.

The ratio of hired to total labor was included as a proxy for the quality of labor employed. Normally, family labor is considered to be of higher quality than hired labor because of the high commitment to the success of the farm and detailed familiarity of the production tasks to be performed. The variable was significant

Table 3. Regression Estimates of Farm Characteristics on Cost Efficiency, Pennsylvania Dairy Farms

Independent Variable	Herd Size—Cows			
	20 to 39	40 to 59	60 to 79	80 to 120
	0.294 (0.47)	1.529 (11.36)	1.317 (7.26)	1.215 (5.55)
	0.0002 (0.11)	-0.003* (2.64)	-0.0005 (0.43)	-0.002 (1.41)
Intercept Debt/cow (\$100)	0.010* (2.24)	0.002 (0.63)	0.003 (0.86)	0.001 (0.15)
Build invest/cow (\$100)	0.030* (2.00)	0.004 (1.13)	-0.006 (0.41)	0.017 (0.96)
Mach. invest/acre (\$100)	0.332* (2.57) -	0.272* (3.02) -	0.198* (1.97)	0.218* (1.99) -
Hired to total labor Milk	0.036* (3.04)	0.022* (2.72)	-0.020* (2.25) -	0.019** (1.87)
sold/cow (cwt.) % feed	-0.003** (1.93)	0.0005 (0.61)	0.001 (0.73)	0.001 (0.60)
purchased Heifers/cow	0.107 (1.12)	0.198* (2.24)	0.270* (2.68)	0.267* (2.85)
Butterfat (%) Region	0.431* (2.68)	-0.0003 (1.35)	0.003 (0.20)	-0.006 (0.60) -
dummy 1 Region dummy	-0.068 (1.11) -	-0.028 (0.61)	-0.074 (1.39)	0.091 (1-53)
2 Region dummy 3	0.134* (2.45)	-0.032 (0.69)	-0.008 (0.14)	-0.055 (0.69) -
Numbers of farms R-square	-0.131** (1.88)	0.018 (0.72)	0.043 (0.72)	0.010 (0.16) 97
	160 0.23	(0.37) 291	1530.13	0.22 2.21
	3.92	0.12 3.32	1.89	

t-statistics in parentheses. Single and double asterisks indicates significance of 0.05 and 0.10 probability levels, respectively.

with a positive sign across all groups. The size of the parameter estimates were large and similar in magnitude. A one unit increase in the ratio decreased the cost efficiency in milk production from 20 to 33 percent at the mean level of efficiency. If quality is the differentiating factor between family and hired labor, operators could increase efficiency by increasing the quality of their hired labor.

Milk production per cow is a function of the genetic technology of the cow and level of feeding and quality of feeds. Higher producing cows are believed to be more efficient converters of feed. The parameter estimates were significant and had the expected negative sign across all herd size groups. While the parameters were of the same order of magnitude, they were small. A hundredweight increase in milk production resulted in an increase in cost efficiency of 1.9 to 3.6 percent. Higher producing herds were therefore only marginally more cost efficient from lower producing herds.

Farm produced feeds are usually considered

to be cheaper than purchased feeds when farms produced feeds are valued at their cost of production. Feeds produced on the farm are also thought to be of higher quality than purchased feeds. Surprisingly, the variable was significant for only the smallest herd size group and the size of the parameter was small. Increasing the proportion of total feed fed that was purchased had no effect on cost efficiency for the three larger herd size groups.

The ratio of heifers to cows was included in the model to test for differences in efficiency due to the production of replacement heifers. The variable was significant with a positive sign for the three largest groups, but not significant for the smallest group. The size of the parameter estimates was large, ranging from 0.20 to 0.27, implying that an increase in the ratio had a large negative effect on cost efficiency. The farms studied produced most of their replacement cows. On average, the group means of the ratio of heifers to cows ranged from 0.75 to 0.78 with standard devia-

tions ranging from 0.20 to 0.25. Dairy farms not only produce heifers for replacements, but also for sale off the farm. Production for the latter category would increase total farm production costs, but would also increase farm profitability. Lack of detailed information prevented an exclusion of farms that produced significant numbers of heifers for the cow replacement market.

The percent milk butterfat variable was significant for only the smallest herd size group. The parameter estimate was positive and small in magnitude, 0.43, implying that herds producing higher levels of butterfat are only marginally less efficient. This result could have been due to the breed of cows milked or other characteristics of cows that are directly related to butterfat production. While higher butterfat content of milk brings higher milk prices, butterfat content cannot appreciably be altered through the feeding program.

Since Pennsylvania is not homogenous with respect to soil fertility and field topography, factors which influence crop yields and crop selection, regional dummy variables were included to test for differences in cost efficiency by region. Region 1 comprises the highly productive southeast area, region 2 the central mountain valleys, region 3 the northern tier counties, and region 4 the western one-fourth of the state. While soil fertility varies within regions, regions 1 and 2 have better soils and more gently sloping land on average. Regional location was significant for only the smallest size group with regions 2 and 3 having greater cost efficiency than the omitted dummy variables for region 4. The result for region 1 and the nonsignificant results found for the remaining groups for region 1 were surprising. Farms in the southeastern region of the state are usually regarded as more being more efficient.

Conclusions

The objective of this study was to measure cost efficiency of allocating operating inputs on Pennsylvania dairy farms using farm level financial records. A modification of the Farrell efficient unit isoquant frontier approach was used. Because financial data records information on operating inputs in terms of costs rather than quantities used, an efficient unit isocost frontier was calculated. The cost efficiency of each farm by herd size group was measured using a linear programming model. Large differences in individual farm measures

of efficiency were found within each of the four herd size groups analyzed. The least efficient farms were two to three times more inefficient than the most efficient farms. The mean measures of efficiency were similar for the two smaller groups and significantly less than the two larger groups. Variance of cost efficiency decreased for increases in herd size group. Farms in the larger herd size groups were therefore more homogenous in the cost efficiency of allocating operating inputs.

Farms with a high percentage of hired labor were less cost efficient than farms employing more family labor. Herds producing higher levels of milk per cow were only marginally more cost efficient than lower producing herds. For the three largest herd size groups, an increase in the number of heifers per cow was inversely related to efficiency. Farm location by region within the state was significant in explaining cost efficiency for the smallest herd size group, but not the three larger groups.

In summary, these results demonstrate farm level financial data can be used to evaluate cost efficiency. A major advantage of the unit isocost frontier approach is that the degree of efficiency of each farm in the set of farms can be measured. Given the wide availability of computer services and the simplicity of Bole's linear programming model, dairy management specialists could evaluate cost efficiency. Using detailed information on characteristics of farms, the reasons for differences in cost inefficiency across farms could be examined.

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