Short-Run and Long-Run Efficiencies of New York Dairy Farms

Loren W. Tauer

Short-run and long-run technical and allocative efficiencies were computed for 395 New York dairy farms using data envelopment or nonparametric procedures on 1990 Dairy Farm Business Summary data. The farms were, on average, more allocatively efficient in the short run than in the long run, but were more technically efficient in the long run than in the short run. Stanchion barns were as efficient as milking parlors, and milking more than two times per day did not increase efficiency.

Central to modern production analysis are the concepts of technical and allocative efficiency (Cornes). Since farmers individually do not know what prices will transpire during a year, the prices they use for planning purposes may be different, leading to allocative inefficiency. They may also fail to equate correct price ratios to the marginal rates of technical substitutions. Likewise, the inability to operate on the frontier of a technology set is inherent in the concept of the distance function defining technical inefficiency. Not surprisingly, extensive efforts have gone into developing alternative techniques to measure efficiencies and empirically apply those various techniques to firm data (Dogramaci and Färe). Bauer discusses recent developments in the econometric estimation of frontiers, and Seiford and Thrall discuss recent developments in the mathematical approach.

This paper reports an application of the nonparametric or data envelopment technique to measure both the allocative and technical efficiencies of dairy farms. A distinction is made between being efficient in the short run, subject to levels of quasi-fixed inputs, and long-run efficiency, where the allocative and technical efficiency of quasi-fixed inputs as well as variable inputs are computed. Previous empirical applications have calculated long-run efficiency only, but given that most firms can adjust variable inputs more quickly than they can adjust quasi-fixed inputs, the calculation of short-run efficiencies may be of more immediate value. An attempt is then made to explain efficiency as a function of farm characteristics. Much previous work has measured efficiencies, with less effort until recently in explaining why some firms are more efficient than others (Bravo-Ureta and Rieger; Weersink, Turvey, and Godah). These efforts are necessary for prescriptive efforts aimed at increasing firm efficiency. Increasing firm efficiency is not only of value to individual firms but also to society in a competitive industry.

Measuring Short- and Long-Run Efficiencies

The inclusion of exogenously fixed inputs in data envelopment analysis was first proposed by Banker and Morey (1986a), who also generalized the methodology to include all exogenous factors affecting efficiency (Banker and Morey (1986b)). The Banker and Morey (1986a) application was to fast food restaurants, where many of the input decisions (i.e., national advertising) are beyond the control of the local manager. Analogously, quasi-fixed inputs may be viewed as beyond the control of any firm in the short run.

Short-run technical efficiency is measured for each firm by the following linear programming problem:

$$\min_{\lambda} T$$

subject to

$$\begin{aligned} y &\le \lambda Y \\ Tx &\ge \lambda X \\ z &\ge \lambda Z \\ \lambda &\in R^k_+. \end{aligned}$$

In this problem, T is a scalar, λ is the intensity vector, y is the m dimensional vector of output

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produced by a particular firm, and Y is the matrix of output for all K firms. In this study there is only one output, so m = 1. The matrices X and Z are the variable and fixed inputs, respectively, used by the K firms to produce their corresponding output in Y. The vectors x and z are the variable and fixed inputs of the k^{th} firm. This problem determines whether it is possible to produce the output of firm k using a linear combination of inputs used by other firms. The scalar T can range from zero to one, where one represents a firm that is technically efficient. This specification assumes radial technical inefficiency and strong disposability of inputs and outputs. Alternative specifications can be found in Färe, Grosskopf, and Lovell. This solution measures short-run technical efficiency conditional upon quasi-fixed inputs. To measure long-run technical efficiency, the quasi-fixed inputs are redefined as variable inputs, producing a larger X matrix and a null Z vector.

Note that the constraint on the quasi-fixed inputs is constructed similar to the constraint on the output but with the inequality reversed. The approach thus determines the minimum combination of variable inputs such that the output produced is at least as great as the output produced by the k^{th} firm, and the quasi-fixed inputs used are no greater than the k^{th} firm.

Banker and Morey (1986a) prove that measured technical efficiency in the short run with quasi-fixed inputs is always less than or equal to the measured technical efficiency in the long run when all inputs are variable (their Proposition 1). The mathematical reason is that any optimal solution to the long-run problem is a feasible solution to the problem with quasi-fixed inputs.

The economics can be illustrated with a replication of Figure 1 from Banker and Morey (1986a). Given the unit isoquant and an inefficient firm in the interior at point A, the technically efficient point for that firm is E given that both X_V and X_F can be reduced, for a savings in X_V of $X_{VA} - X_{VE}$. However, since X_F is fixed at X_{FR}, the amount that X_V must be reduced to reach the unit

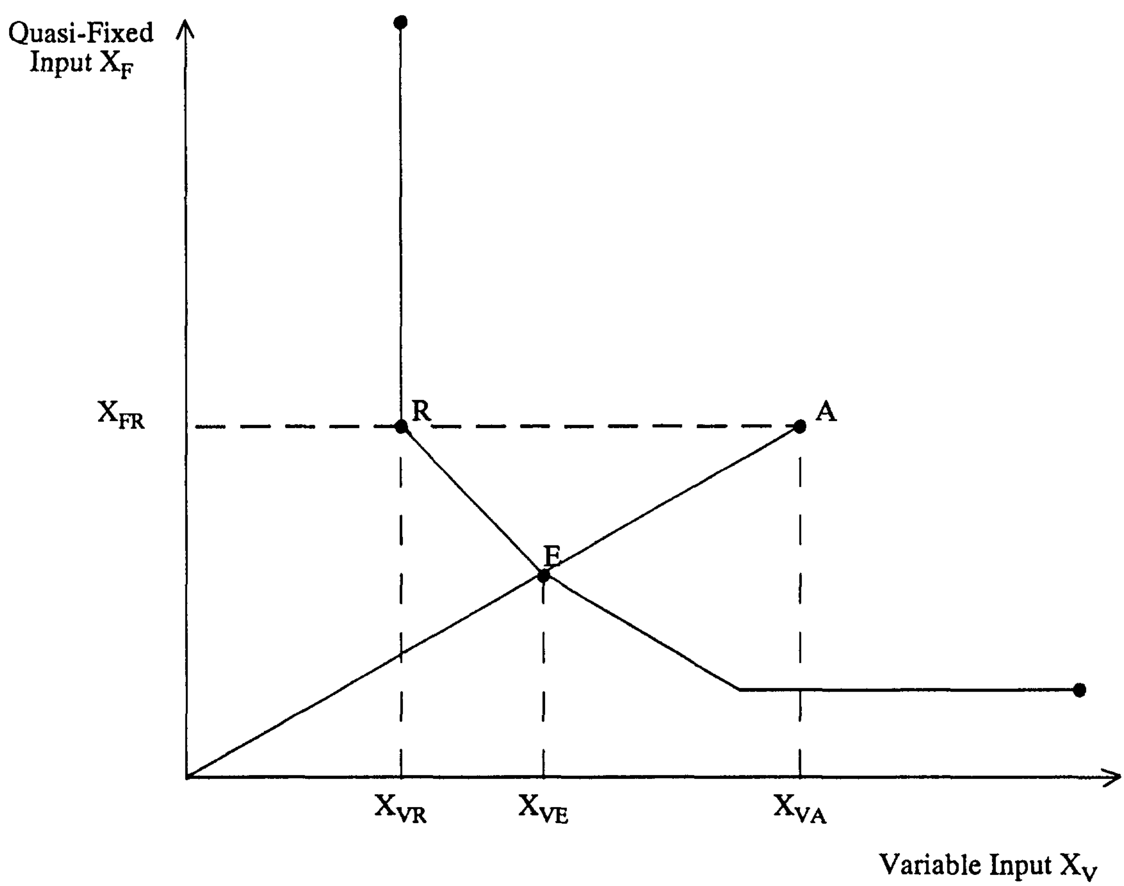

Figure 1. Maximum Reduction in Input X_V Given Fixed Input X_F

isoquant is the larger amount of $X_{VA} - X_{VR}$, leading to a larger inefficiency measure for the short run.

These efficiency measures do ignore the dynamics of the adjustment process. In the long run, the firm would like to move to point E, but in the short run, it must begin moving to R. However, given that X_F is only quasi-fixed, some adjustment in its use might be possible even immediately, producing an adjustment path other than A → R → E. As a result, the computed short-run efficiency may be considered a lower bound estimate.

An overall measure of short-run cost efficiency comprising both technical and allocative efficiency is measured for each firm by the following linear programming problem:

$$\min_{v,\ \mu} r \cdot v$$

subject to

$$\begin{aligned} y &\leq \mu Y \\ v &\geq \mu X \\ z &\geq \mu Z \\ v, \mu &\in R^k_+. \end{aligned}$$

In this problem, y is the m dimensional vector of output produced by a particular firm, and Y is the matrix of output for all K firms. In this study there is only one output, so $m = 1$. The matrices X and Z are the variable and fixed inputs, respectively, used by the K firms to produce their corresponding output in Y. The vector r is the input prices for firm k, and the vector z is the fixed factors used by firm k.

The variable input vector v is chosen in order to minimize the variable cost of producing the output of firm k using a linear combination of variable inputs and fixed inputs identified by the intensity vector μ. Unlike the x vector of the previous programming problem which contained the observed use of the variable inputs by firm k, the v vector now contains the optimal values for these variable inputs. The solution value provides the minimum variable cost of producing the output of firm k. That amount is divided by the actual variable cost expenditure of firm k to derive overall cost efficiency. The linear program is solved K times (for each firm) after replacing vectors r, y, and z for each firm.

The solution to this problem is short-run cost efficiency since cost is minimized subject to the levels of quasi-fixed inputs. To compute long-run cost efficiency, the quasi-fixed inputs are redefined as variable inputs, producing a larger X matrix and a null Z vector. The reason for treating any inputs as quasi-fixed is to acknowledge the possibility that the first-order conditions for cost minimization are not satisfied for those inputs because of insufficient time for adjustment. That, of course, would be a reason for long-run inefficiency.

Given that the long-run cost minimization includes the cost of the variable inputs as well as the cost of the quasi-fixed inputs, the long-run cost will always be larger than the short-run costs alone. It is also true that the actual variable input expenditures of a firm are a component of the firm's total expenditures. It is not necessarily true, however, that the ratio of optimal minimum variable input expenditures to the actual variable input expenditures will also be less than or equal to the ratio of optimal total expenditures to actual total expenditures. Thus, the short-run cost efficiency may be less than, equal to, or greater than long-run cost efficiency.

Since overall cost efficiency (CE) consists of technical efficiency (TE) and allocative efficiency (AE) such that CE = TE · AE, the next step is to compute short-run and long-run allocative efficiency for a firm k by dividing its short-run or long-run cost efficiency by its corresponding short-run or long-run technical efficiency.

In the above specification of technical efficiency, constant returns to scale were assumed by not constraining the λ vector. Variable returns to scale are tested by adding the constraint $\Sigma\ \lambda_s = 1$, where λ_s are the individual components of the λ vector. This restriction ensures that the production frontier is quasi-concave, thereby allowing the production frontier to exhibit increasing, decreasing, or constant returns to scale (Afriat). The objective function of this new linear programming problem can be defined as TV. With an additional constraint added to the linear program, it is true that $S \equiv T/TV \leq 1$. If constant returns to scale exist, then the value S equals 1; all values less than 1 reflect scale inefficiency of the specific firm. To determine whether any scale inefficiency is due to increasing or decreasing returns, another linear programming problem is solved where the λ vector is constrained as $\Sigma\ \lambda_s \leq 1$. Defining the new objective function value as TD, if $S \neq 1$ and $TD = TV$, then decreasing returns to scale exist. Alternatively, if $S \neq 1$ and $TD \neq TV$, then increasing returns to scale are shown. A detailed discussion of these tests can be found in Färe, Grosskopf, and Lovell. An application and further discussion is in Weersink, Turvey, and Godah.

The use of a nonparametric deterministic approach to measure efficiency has advantages and disadvantages. The main advantage is that a functional form need not be specified for the technology of the firm. Although flexible functional forms are available, it is believed that complete flexibility is preferred. The major disadvantage is that any error in measurement is attributed to inefficiency, as is a stochastic-exogenous event beyond the control of the firm. The inability to measure error can produce a downward bias in computed efficiencies. This may be acceptable as long as the computed efficiencies are interpreted as relative rather than absolute measures.

The reasons for firm inefficiency have been debated but are usually attributed to poor management (Hall and Winsten; Leibenstein; Stigler). A firm may be allocatively inefficient because it either used an incorrect price for planning purposes or it does not know the marginal productivity of its inputs. Technical inefficiency may be due to wasting inputs or combining inputs incorrectly, thus failing to maximize output. Since empirical efficiency analysis entails using inputs aggregated at some level, the impact of poor management may either occur in combining the aggregated inputs, or at the disaggregated level, reflected as lower-quality aggregated inputs.

Data

Data were obtained from the 1990 New York Dairy Farm Business Summary program (Smith, Knoblauch, and Putnam). Farms that have cash crop operations or other major nondairy enterprises are not included in the Dairy Farm Summary reports. That data set contains 395 complete farm records recorded on an accrual basis. This is not a random sample from the population of New York dairy farms, but might be viewed as a sample of farms that would participate in the Farm Business Summary Program. Since any dairy farm that requests an analysis is included in the summary, inclusion is by self-selection. Kaufman and Tauer, using Agricultural Census data and Farm Business Summary data, show that there may be differences between the two groups. The Dairy Farm Summary farms are larger and have higher milk production per cow.

Although the parametric approach allows multiple outputs, these farms primarily produced milk, which averaged 86 percent of total accrual receipts (standard deviation of .07). Other outputs, such as cull cows and male calves, are mostly byproducts of milk production. Livestock sales and other miscellaneous receipts were converted into a milk-equivalent basis by dividing by the farm's price received for milk and then added to milk output.

The four variable inputs defined were hired labor, purchased feed, all crop expenses, and miscellaneous inputs. These variables were constructed by combining detailed expense items. The two quasi-fixed inputs were the number of milk cows as a measure of capital size and the months of operator's labor (many farms had more than one operator). The use of milk cows as a proxy for capital size allowed for a quantity (number of cows) and a price (value per cow) measure of capital that would not have been possible using a dollar measure for capital. Using the number of cows as a measure of size on a dairy farm is tantamount to using acres as a measure of size on a crop farm.

As an alternative, capital may have been decomposed into cows plus equipment and land plus machinery. Using land plus machinery would incorporate the concept that farmers grow, versus purchase, various combinations of feed. Unfortunately, land value in the data set is not separate but a component of real estate, which includes buildings, many of which are used to house and milk cows besides sheltering machinery. The percentage of real estate value attributed to barns and milking equipment varies but can be significant on many dairy farms.

The farm records include months and expenditures on hired labor, so the wage per month was computed by farm. Also available were crop expense and dry matter produced, so the price per ton of dry matter was computed by farm. Other characteristics of produced feed, such as protein, were not available. Purchased feed consisted of purchased grain and concentrate, and roughage. Given the state 1990 prices for dairy concentrate and hay, a weighted price for each farm was computed. Miscellaneous inputs included so many items that its price was set at $1 for all farms.

For the quasi-fixed inputs, the value of all capital assets per cow by farm was available and was used as the price proxy. This is the capital investment per cow and includes land, buildings, equipment, machinery, and cows. Although this is a stock value rather than a flow price, the age structure of each herd and capital vintage was not known to permit computing differentiated flows. Operators estimate their own value of labor and management, and these individual estimates were used as the price of operator's labor per month.

The means and standard deviations of the variables are listed in Table 1. Some of the price standard deviations are quite large and probably reflect individual farm input quality differences as well as the effects of local supply and demand conditions.

Table 1. Summary of Data for Efficiency Analysis, 395 New York Dairy Farms, 1990

Input	Units	Quantity Mean	Quantity S.D.	Price Mean	Price S.D.
				($)	($)
Variable					
Hired labor	Months	23.8	29.1	$1,269	$ 522
Purchased feed	Cwt.	7,923	9,233	10.87	4.01
Grown feed	Tons	960	894	60.97	20.46
Miscellaneous	Dollars	63,546	68,892	1	0
Quasi-fixed					
Cows (capital)	Number	108.3	115.0	6,107	1,906
Operators	Months	16.7	7.8	1,873	647
Output					
Milk equivalent	Cwt.	22,492	25,996		

Of course, one reason for technical inefficiency may be the use of a lower quality input. If two farmers use the same months of hired labor but one farmer pays a higher monthly wage because of higher labor quality, the technical efficiency of the farmer with the lower quality labor should be appropriately measured lower than the farmer with the same quantity of higher quality labor. Unfortunately, however, the farmer with the lower quality and thus lower priced labor will be measured as using too little labor given the low price (allocatively inefficient) since the efficiency analysis presumes he uses the higher efficiency labor. This is a severe limitation to empirical efficiency computation. There has been some work on extracting hedonic prices based on quality from a production system, but quality would be undistinguishable from efficiency measures (Ohta).

Results

These 395 farms under constant returns are, on average, .74 technically efficient in the short run, but are, on average, .79 technically efficient in the long run. All are measured as more technically efficient in the long run, as they should be. Their short-run allocative efficiency averages .87, and in the long run averages .70 (Table 2). All but eleven are more allocatively efficient in the short run. That short-run allocative efficiency is greater than long-run allocative efficiency is not surprising since knowledge of prices in the short run should be better than knowledge of long-run prices.

The averages and standard deviations in Table 2 hide the distributions of efficiencies as shown in Figure 2. Although the average short-run technical efficiencies are lower than the average short-run allocative efficiencies, about 49 of the dairy farms are technically efficient or nearly so (>.99), while only 12 of the farms are completely allocatively efficient or nearly so (>.99). This should not be surprising since many of the farmers are very good dairymen in a technical sense, yet they do not know with certainty what the price of feed (or other inputs) will be for the year when they plan purchases.

In a previous dairy farm efficiency study, Grisley and Mascarenhas computed technical efficiencies using data envelopment techniques on 701 Pennsylvania dairy farms using 1981 and 1982 data. They used expenditures on four inputs and separated the data into four size groups. The average efficiencies for the two smaller size groups were .73 and .70, and for the two larger size

Table 2. Efficiencies of 395 New York Dairy Farms, 1990

	Average	S.D.	Min
	-------- Constant returns ($\Sigma\ \lambda_s$ unconstrained) --------		
Technical, short run*	.74	.15	.39
Technical, long run	.79	.13	.41
Allocative, short run	.87	.09	.47
Allocative, long run	.70	.09	.42
	------- Variable returns ($\Sigma\ \lambda_s = 1$) -------		
Technical, short run	.78	.15	.30
Technical, long run	.85	.11	.24
(Constant/variable) short-run	.95	.08	.39
(Constant/variable) long run	.93	.09	.41
	--------- Scale returns ($\Sigma\ \lambda_s \leq 1$) ---------		
Technical, short run (increasing returns)	.75	.15	.39
Technical, long run (increasing returns)	.79	.13	.41

*The short run means there are some inputs set as quasi-fixed. The long run means that all inputs are set variable.

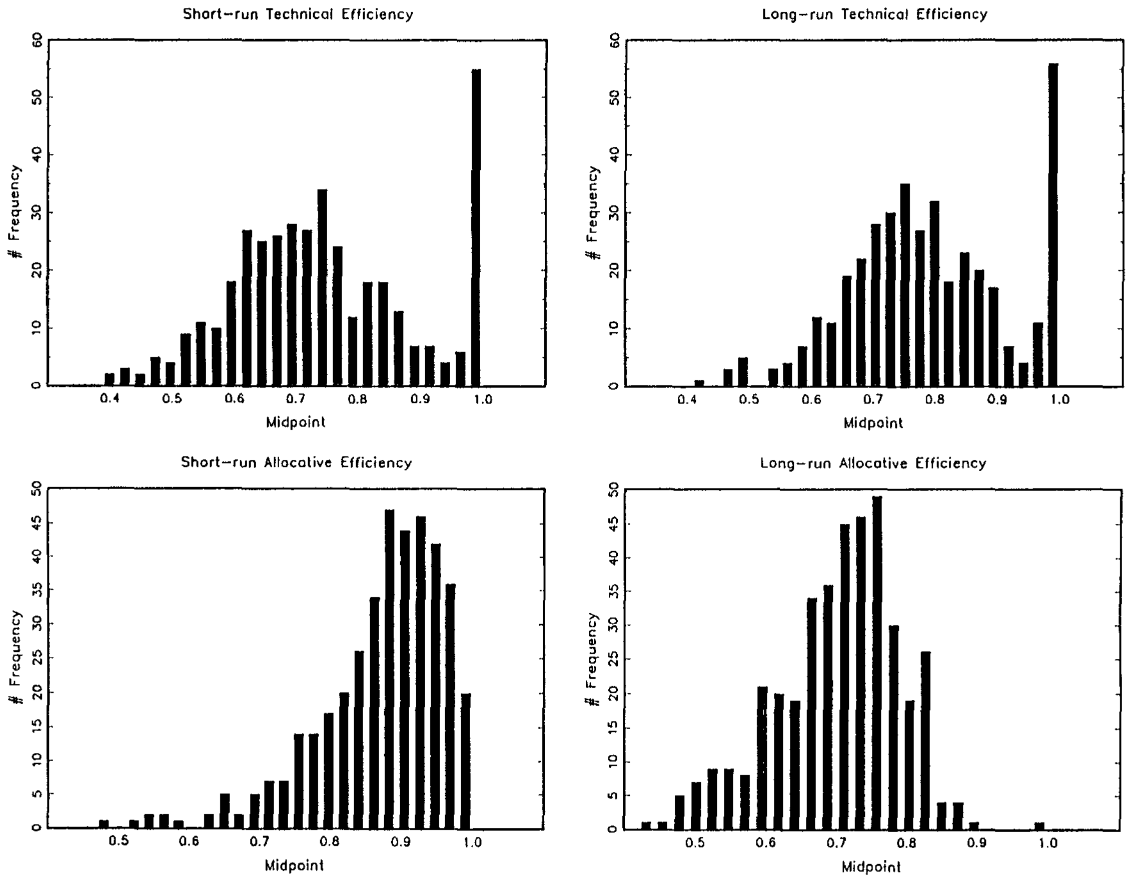

Figure 2. Efficiency of 395 New York Dairy Farms, 1990

groups were .81 and .80. They also found that 45 of the 701 farms were 100 percent technically efficient. These results are similar to the results here. In contrast, using 511 New England Dairy Herd Improvement Records for 1984, Bravo-Ureta and Rieger, using a stochastic econometric model, estimated an average short-run technical efficiency of .83 and allocative efficiency of .85. None of their farmers were above .90 technically efficient, but 94 were at least .95 allocatively efficient. Their different results may be partially due to the fact that their procedure allowed for error in measurement. Finally, Tauer and Belbase, using corrected ordinary least squares for a Cobb-Douglas function and seven inputs (expenditures), found a group of 430 New York dairy farms to average .69 technically efficient in 1984 compared with .79 here.

The cross-correlation coefficients of the four efficiencies are shown in Table 3. All are statistically different from zero. The short-run and long-run technical coefficients are positively correlated at .96, as they should be since embedded in the long-run efficiency measure is short-run efficiency. The same is true for the short-run and long-run allocative coefficients with a correlation of .56. The four correlations across technical and allocative efficiencies are all negative, however. This implies that farms that are technically efficient are allocatively inefficient relative to their peers and vice versa. One would have expected that technically efficient farms might also be allocatively efficient. Although the negative correlations may be valid, they may also be due to data deficiencies. The allocative efficiencies were derived by dividing

Table 3. Correlation Coefficients of Efficiencies for 395 New York Dairy Farms, 1990

	Technical long run	Allocative short run	Allocative long run
Technical, short run	.96	−.27	−.37
Technical, long run	—	−.24	−.30
Allocative, short run	—	—	.56

Ho: $r = 0$, rejected for all r at $\alpha = .01$.

computed economic efficiencies by computed technical efficiencies. The correlation between short-run technical efficiency and computed short-run economic efficiency was .83, and for the long-run versions was .71. Positive correlations are expected since embedded in economic efficiency is technical efficiency. But if the computed economic efficiencies were inaccurate, say, due to incorrect data on firm-unique prices or because prices were not adjusted for quality, then these computed economic efficiencies may be measured with significant error (Farber). Dividing by an accurately measured technical efficiency could produce an allocative efficiency negatively correlated with technical efficiency as observed here.

Short-run and long-run technical efficiencies were also computed assuming variable returns to scale (Table 2). The ratio of technical efficiency under constant returns divided by technical efficiency under variable returns for each farm averaged .95 in the short run and averaged .93 in the long run. These are numerically less than one, which would indicate variable returns to scale for this group of farms. However, since the standard deviation of these statistics are .08 (short run) or .09 (long run), a statistical one-tail test of the null hypothesizes that $S \leq 1$ for the group would fail. Nonetheless, technical efficiencies were computed under the constraint ($\Sigma\ \lambda_s \leq 1$) to determine the existence of decreasing or increasing returns to scale. Since the average computed short-run technical efficiency of .75 is less than the average short-run technical efficiency under variable returns of .78, any variable returns to scale in the short run consists of increasing returns. The long-run average efficiency of .79 is lower than the long-run average efficiency of .85 under variable returns, implying greater increasing returns in the long run. Farms operating with increasing returns for the long run but closer to constant returns in the short run is a classic assumption reinforced here.

Although many early efficiency studies simply reported empirical efficiency computations, recent efforts have focused on causation. This is critical for any efforts focused at trying to increase the efficiencies of individual farmers. The data used in this study are from the annual New York Dairy Farm Business Summary Program. As part of that program, a limited number of business and family characteristics of each farm is collected. This provides an opportunity to determine whether the characteristics of the business or farmer listed in Table 4 explain any variation in computed efficiencies across farms.

Since the computed efficiencies are bounded numerically between zero and one, the logistic function was fitted, $E_i = 1/(1 + e^{-(\alpha + \beta X_i)})$, which is bounded by the open set (0,1), where E_i is the computed efficiency, e is the natural number, X is the vector of explanatory variables, and α and β (vector) are the estimated coefficients. Rearranging and taking the natural logs of both sides results in the linear estimated function

$$\ln (E_i/(1 - E_i)) = \alpha + \beta X_i.$$

Since some of the computed efficiencies were equal to one, which would have produced $\ln(\infty)$ which is undefined, but all were greater than zero, all efficiencies were shifted downward by subtracting the value .001. The largest efficiency was then .999 rather than 1.0. Regressions were then completed on the four types of computed efficiencies as summarized in Table 5.

The regressions explained very little of the variation in computed efficiencies with adjusted R squares of .13 and lower. There may be a number of reasons. It is often stated that good management is easy to spot but difficult to describe. The char-

Table 4. Definition of Variables Used in Regressions of Table 5

Variable	Definition	Value
Business organization	0 if sole proprietor	273
	1 otherwise	122
Age	Years old	44.8 ave.
Education of sole or first proprietor	0 for grade, high school	186
	1 for some college +	209
Accounting system	0 for account book	177
	1 for computer, professional	218
Milking system	0 for stanchion	243
	1 for parlor	152
Milking frequency	0 for 2 times per day	343
	1 for 2+ times per day	52
DHIA	0 for non-DHIA	56
	1 for Dairy Herd Improvement Association member	339
Cows	Number of cows	108 ave.

Table 5. Linear Logistic Function Regression of Computed Efficiencies on Characteristics of 395 New York Dairy Farms, 1990 (t-Values in Parentheses)

	Short-run technical	Long-run technical	Short-run allocative	Long-run allocative
Constant	1.20	1.40	2.10	.74
	(2.30)	(2.77)	(7.34)	(5.43)
Business organization	.13	.18	−.28	−.11
	(.57)	(.85)	(−2.31)	(−1.85)
Age	.00	.00	.00	.00
	(.04)	(.10)	(−.05)	(−1.22)
Education	.14	.17	.13	−.02
	(.65)	(.84)	(1.15)	−.38)
Accounting system	−.08	−.05	.06	.18
	(−.40)	(−.25)	(.55)	(3.28)
Milking system	.08	.11	.02	−.01
	(.34)	(.50)	(.19)	(−.24)
Milkings	.21	.28	.11	.13
	(.65)	(.88)	(.65)	(1.56)
DHIA	−.24	−.24	−.29	.25
	(−.83)	(−.87)	(−1.84)	(3.27)
Number of cows	.01	.005	.003	.00
	(5.13)	(4.93)	(5.63)	(.48)
$\bar{R}^2$	.11	.12	.13	.08

acteristics available from the records may not be the determining factors of management. Alternatively, the computed efficiencies may not be good measures of management results either because of data limitations or because the theory measuring efficiencies is inappropriate. This inability to explain inefficiencies is not unique to this study. Grisley and Mascarenhas, in their four sets of Pennsylvania dairy farms, had R-square values ranging from only .12 to .23. Bravo-Ureta and Rieger found little difference in efficiencies of farms sorted by size, education, experience, or extension contact. Low explanatory power is not unique to dairy farms. In a study of efficiencies in banking, the R-square value ranged from .01 to .13 (Aly, Grabowski, Pasurka, Rangan).

Multi-owner dairy farms have lower short-run and long-run allocative efficiencies where the opportunity cost of additional owner-managers may not be justified. Age and education have no effect on computed efficiencies. A more elaborate accounting system (other than account books) may have a positive impact on long-run allocative efficiency. The type of milking system has no effect. Stanchion barns appear to be efficient for this group of mostly family operations with an average herd size of only 104 cows. Milking the cows more than two times a day has no impact on efficiency. The negative effect of DHIA on short-run allocative efficiency is perplexing, since the purpose of that organization is to assist in the management process by data collection and analysis. However, since all but 56 of the 395 farms are members, and the coefficient is not consistent across equations, the negative result may be spurious. Finally, although cows are a quasi-fixed input in the efficiency computations, they should only have an impact on the measures computed under constant returns if variable returns to size actually exist. The t-statistics reinforce the result that increasing returns to scale in the long run were shown from the computed efficiencies (Table 2).

Summary

Short- and long-run technical and allocative efficiencies were computed for 395 New York dairy farms using their 1990 farm record data. On average, the farms were .74 technically efficient in the short run and .79 technically efficient in the long run. A significant number of farms were 100 percent technically efficient. Short-run allocative efficiency averaged .87 and averaged .70 in the long-run. Surprisingly, farms that were technically efficient tended to be allocatively inefficient and vice versa. A statistical test would support constant returns, although numerically, small increasing returns were shown for the short run, and larger increasing returns were shown for the long run. Age and education of the farm operators had no impact on computed efficiencies. Stanchion barns were as efficient as milking parlors, and milking more than two times a day did not increase efficiency. Yet, very little of the efficiencies from farm to farm were explained by characteristics of the farm.

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