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Abstract: We use DEA (Data Envelopment Analysis) techniques to determine if measured inefficiencies are caused by a missing management input. We replace the quantity of operators' labor with estimates of the value of labor and management, and then with net farm income from the previous year, to determine if those replacements for operator labor changes calculated efficiencies. We calculate not only technical efficiencies, but also cost and revenue efficiencies and decompose them into allocative efficiencies. The empirical results are disappointing, in that our management inputs make little impact on measured inefficiencies. Very few articles have measured technical, cost, and revenue efficiency in the same study, and then not with a 10 year panel data set. Many may be interested in the estimates of DEA efficiencies on these dairy farms over the 10 years using the various specifications.

Keywords: Dairy farms, data envelopment analysis, efficiency, management input

Introduction

The notion of efficiency has been an active area of economic research for more than fifty years. Broadly defined, inefficiency is any deviation from a frontier, whether production, cost, revenue, or profit. In his groundbreaking work, Farrell (1957) proposed numerical measures of efficiency for individual firms. From Farrell's work, in combination with the enumeration of Shephard's (1970) distance function, came the

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development of empirical tools to measure the efficiency of firms, including mathematical programming techniques (Charnes, Cooper and Rhodes 1978; Färe, Grosskopf, and Lovell 1985).

Yet, the measurement of inefficiency does not explain why it exists. Some explanations of inefficiency predate its measurement, and are based on more general criticisms of neoclassical production theory. Knight (1921) argued that it is not possible for firms to calculate optimal decision rules, and that production functions are mere theoretical ideals. A similar explanation of the inability for individuals to process the vast amounts of information necessary to behave optimally is presented in Hayek (1945). The "bounded rationality" theory of Simon (1959) and the evolutionary theory of Nelson and Winters (1982) can similarly be invoked to question the existence of known frontiers and, by extension, the meaning of efficiency.

Other explanations for observed inefficiencies are consistent with neoclassical production theory. Tauer (2001) shows that inappropriately aggregating inputs results in the measurement of technical inefficiency. A formal proof of the bias in efficiency measurement for the case of the use of a linear aggregator in mathematical programming techniques is found in Thomas and Tauer (1994).

Another explanation of computed inefficiencies is the failure to include all relevant inputs in the estimation of the efficient frontier. This is the basis for Leibenstein's (1966) theory of "X-efficiency." According to Leibenstein, differences in output across firms using the same input sets are due to differences in incentives for workers and managers to perform optimally, or simply differences in inherent capabilities. This view was criticized by Stigler (1976), who argued any variation in output can be attributed to specific inputs, namely management ability. The manager (or entrepreneur) must decide prior to any allocative decisions, the production technology to use and how much knowledge to invest. Once that decision is made, according to Stigler, each firm is operating on the efficient frontier, although not necessarily the same frontier as other firms.

Measuring and defining management ability is a problem that has long perplexed economists. At an abstract level, management can be considered a fourth factor of production, apart from the conventional land, labor, and capital. Rougoor, Trip, Huirne, and Renkema (1998) argue that management ability consists of both personal aspects of the farmer and the decision-making process. The personal aspects of the farmer such as motivations, abilities, and experience directly affect the decision-making process, which encompasses planning, implementation, and control. Together these determine technology choice (the production function), which affects farm results in terms of efficiency and profitability.

Nuthall (2001) employs psychological concepts to define managerial ability. Among these are the desire or ability to be fully rational, and the use of memory, and learning. Indeed, as discussed above, rationality is necessary for efficiency to have any meaning. Memory and learning are interrelated in that memory involves the observation and storage of knowledge and learning. According to Anderson (1983), interpreting and compiling that knowledge to improve existing production structures entails management. Thus, management ability can change over time, for better or for worse, depending on a farmer's ability to remember and learn from past successes and mistakes.

Castle, Becker, and Nelson (1987) define farm management as "decisions affecting the profitability of the farm business." Citing Robbins (1928), Stigler (1976) argues that just as different productivities of inputs are reflected in factor prices, different managerial abilities should also be reflected in differences in profits. In an investigation of the effects of management ability on scale economies for dairy farms in England and Wales, Dawson and Hubbard (1987) define the management ability as returns over feed costs, a method also used in a similar study of scale economies in the South African dairy sector by Beyers (2001).

The early efficiency studies attempt to explain differences in computed efficiencies by performing a regression or other statistical exercise of efficiency on a set of explanatory variables, some of which may proxy for management ability. For example, Tauer (1993) regress short-run and long-run technical and allocative efficiencies for a sample of New York dairy farms on a set of variables including operator age and education. In an efficiency study of Mid-Atlantic sea scallop vessels, Kirkley, Squires, and Strand (1998) regress computed technical efficiencies on vessel captain age and experience, finding a significant positive effect of each on efficiency. In a non-frontier efficiency study of Pennsylvania dairy farms, Stefanou and Saxena (1988) find higher levels of education and experience have positive effects on allocative efficiency.

The purpose of this paper is to test whether computed inefficiency is due to the failure to include a measure of the management input. We compute technical, cost, and revenue efficiency for a sample of New York dairy farms using farm-level data. We test our hypotheses using nonparametric data envelopment analysis (DEA) with two outputs (milk and other receipts) and six inputs by defining two input sets, one including operator labor, hired labor, purchased feed, livestock, capital, and crop inputs, and a second which replaces the operator labor input with a proxy for the management input. The resulting technical efficiency estimates for each farm computed from each input set are then compared. We use two separate proxies for the management input - operators' own estimates of the value of their management and labor, and net farm income from the previous year. The previous year's net farm income is used to avoid any simultaneity bias that may arise from using concurrent farm performance measures.

Operators' own valuation of their labor and management is a subjective measure. The previous year's net farm income is a *results* oriented measure consistent with the definition of management ability given in Castle et al. (1987), as well as Stigler's (1976) observation that differences in managerial ability should be captured by differences in profits.

Because the management input serves two functions: technology choice, and choice of input and output combinations to achieve desired production and returns, we expect increases in both computed technical and allocative efficiency from its inclusion in our analysis, but there is no theoretical basis to justify a larger impact of one measure over the other.

For a dairy farm, technology choice involves choices of livestock housing structures, milking systems, feeding systems, and machinery. Once these decisions are made, they are not likely to be revised very often inasmuch as each decision involves a fair amount of fixed capital. Allocative decisions on a dairy farm include allotting quantities of labor, purchased feed, livestock, other capital, and crop production as well as the determination of milk production relative to other possible outputs like livestock and crop sales. The most obvious input tradeoffs involve possible substitution between purchased feed and farm-grown crop production as well as between operator (farm manager) labor and hired labor. Both of these examples fit nicely into the standard make or buy allocative decisions common in the management literature, which entails the minimization of production, management, and transactions costs (Demsetz 1991).

Ideal measures of the management input or farmer management ability would quantify all of the above decisions. Farmers' subjective valuations of their own values of labor and management, we argue, may approximate this true unknown measure because it is a general measure of managerial skill or ability. It is, in a sense, what farmers' would be willing to pay themselves, and thus may reflect mostly the results of allocative decisions if in fact farmers take their technology choices as fixed. Using past farm profitability as the management measure also provides a general overview of how well the farmer has made all of his or her managerial decisions, but cannot distinguish between the technology choice and allocative decisions.

Management ability may also change over time as farmers gain more experience (learning by doing), interact with other farmers, or educate themselves through taking advantage of extension services or communications with vendors. In this case, we would expect to see some increase in efficiency over time if indeed we are measuring the management input or farmer managerial ability in a satisfactory way. In fact, our results do show a tendency for farm efficiency to increase over the sample period

Technical Efficiency with DEA

Data envelopment analysis computes technical efficiency as a weighted average of outputs over inputs. The weights applied to the inputs and outputs are selected by solving the well-known “ratio problem” of Charnes, Cooper, and Rhodes (1978):

$$\begin{aligned}
&\mathbf{Max}\ \frac{\mathbf{p}_i^T \mathbf{y}_\mathbf{i}^\mathbf{T}}{\mathbf{w}_\mathbf{i}^T \mathbf{x}_\mathbf{i}^T}\ ; \qquad\qquad [1]\\
&\text{s.t.}\\
&\left(\mathbf{w}_\mathbf{i}^T \mathbf{X}\right)^{-1}\left(\mathbf{p}_i^T \mathbf{Y}\right) \leq \mathbf{1}\ ;\\
&\mathbf{p}_\mathbf{i}, \mathbf{w}_\mathbf{i} \geq \mathbf{0}
\end{aligned}$$

Where $\mathbf{y_i}$ is a (k x1) vector of outputs, and $\mathbf{x_i}$ is a (j x 1) vector of inputs for the i^{th} firms. $\mathbf{Y}$ is a (k x n) matrix containing the output vectors of the n firms. $\mathbf{X}$ is a (j x n) matrix of input vectors for the n firms. The dimensions of $\mathbf{p_i}$ and $\mathbf{w_i}$ are (k x1) and (j x 1), respectively and $\mathbf{0}$ is an (n x 1) null vector. The problem is to choose $\mathbf{p}$ and $\mathbf{w}$ that maximizes the average product of aggregate output to aggregate input of the i^{th} firm subject to the constraint that no other firm has an average product greater than unity.

If the condition $\mathbf{w_i}^T\mathbf{x_i} = 1$ is imposed and the first constraint is rearranged, the problem can be solved by linear programming methods. The problem then becomes:

$$\begin{aligned}
&\mathbf{Max}\ \ \mathbf{p}_\mathbf{i}^T \mathbf{y}_\mathbf{i}\ ;\\
&\text{s.t.} \qquad\qquad\qquad\qquad [2]\\
&\mathbf{p}_\mathbf{i}^T \mathbf{Y} - \mathbf{w}_\mathbf{i}^T \mathbf{X} \leq \mathbf{0}\ ;\\
&\mathbf{w}_\mathbf{i}^T \mathbf{x}_\mathbf{i} = 1\ ;\\
&\mathbf{p}_\mathbf{i}\ ,\ \mathbf{w}_\mathbf{i} \geq \mathbf{0}\ .
\end{aligned}$$

The implication of adding this normalization constraint is that the objective function has a maximum at unity. The dual of the problem is the envelopment model for technical efficiency:

$$\begin{aligned} &\mathbf{Min}\ \theta\ ; \\ &\text{s.t.} \\ &\mathbf{y}_\mathbf{i} \geq \mathbf{Y\lambda}\ ; \\ &\theta\mathbf{x}_\mathbf{i} \leq \mathbf{X\lambda}\ ; \\ &\boldsymbol{\lambda} \geq \mathbf{0},\quad \theta \text{ free}\ . \end{aligned} \qquad [3]$$

In this problem $\boldsymbol{\lambda}$ is an (n x 1) intensity vector, and the scalar, θ, is the measure of technical efficiency. The intensity vector, $\boldsymbol{\lambda}$, forms a "new" firm by taking a linear combination of input and output sets of other observed firms, which are called peers of the firm being analyzed. This measure of technical efficiency can be interpreted as the maximum radial reduction in inputs possible for the i^{th} firm to produce at the boundary of the efficient production set. Problem [3] is an input oriented measure of technical efficiency in that it seeks the largest possible radial reduction in inputs possible given an output vector **y**. As such, it is a nonparametric estimate of the inverse of Shephard's input distance function.

If we substitute $\phi = \frac{1}{\theta}$, and $\mu = \frac{1}{\theta}\lambda$, we arrive at an output oriented measure of technical efficiency.

$$\begin{aligned} &\mathbf{Max}\ \phi\ ; \\ &\text{s.t.} \\ &\phi\mathbf{y}_\mathbf{i} \geq \mathbf{Y\mu}\ ; \\ &\mathbf{x}_\mathbf{i} \leq \mathbf{X\mu}\ ; \\ &\boldsymbol{\mu} \geq \mathbf{0},\quad \phi \text{ free}\ . \end{aligned} \qquad [4]$$

The optimal solution to problem [4] is the radial expansion in output vector necessary for the i^{th} firm to be producing at the boundary of the efficiency production set given its input vector, and is the nonparametric estimate of the inverse of Shephard's output distance function. The output oriented technical efficiency indicator is usually computed as ϕ^{-1}. This is the envelopment problem, which can also be derived by normalizing the numerator of [1] to unity, and then minimizing the denominator subject to the relevant constraints that no firm can have efficiency greater than unity. Both problems [3] and [4] assume constant returns to scale (CRS) technology, and under this assumption the optimal solution to [3] is equal to the inverse of the optimal solution to [4] for each firms; $\theta_i^* = (\phi_i^*)^{-1}$.

The CRS assumption can be relaxed to allow variable returns to scale (VRS) technology by imposing the added restriction that the components of the intensity vector sum to unity, which implies that the envelopment process generates a “new” firm that is a convex combination of its peer firms. Problem [3] becomes:

$$\begin{aligned} &\textbf{Min}\ \ \theta\ ; \\ &\text{s.t.} \\ &\mathbf{y_i} \geq \mathbf{Y\lambda}\ ; \\ &\theta\mathbf{x_i} \leq \mathbf{X\lambda}\ ; \\ &\mathbf{1}^T\boldsymbol{\lambda} = 1\ ; \\ &\boldsymbol{\lambda} \geq \mathbf{0},\ \ \theta \text{ free} \end{aligned} \qquad [5]$$

Similarly, problem [4] becomes:

$$\begin{aligned} &\textbf{Max}\ \ \phi\ ; \\ &\text{s.t.} \\ &\phi\mathbf{y_i} \geq \mathbf{Y\mu}\ ; \\ &\mathbf{x_i} \leq \mathbf{X\mu}\ ; \\ &\mathbf{1}^T\boldsymbol{\mu} = 1\ ; \\ &\boldsymbol{\mu} \geq \mathbf{0},\ \ \phi \text{ free}\ . \end{aligned} \qquad [6]$$

It should be noted, however, that once we allow variable returns to scale, the optimal solutions to each problem are not necessarily inverses of each other for each firm.

Variable returns can also be imposed through the primal with the following modifications:

$$\begin{aligned} &\textbf{Max}\ \ \mathbf{p}_i^T\mathbf{y_i} - u_0 \\ &\mathbf{s.t.} \\ &\mathbf{p}_i^T\mathbf{Y} - \mathbf{w}^T\mathbf{X} - 1u_0 \leq 0; \\ &\mathbf{w}^T\mathbf{x}_i = 1; \\ &\mathbf{p}_i^T\ ,\ \mathbf{w_i} \geq 0. \end{aligned} \qquad [7]$$

This is equivalent to imposing an extra input (or some unknown fixed input) that has a level of unity for each firm in the analysis.

Cost Efficiency with DEA

For DEA cost efficiency, given a set of input prices, the problem is to calculate the input vector that minimizes total cost subject to the constraints that the optimal input vector is feasible, and that it will produce at least as much output as the observed output of the firm under consideration. Cost efficiency is then the ratio of observed total cost, C of the firm, to optimal total cost, C^*. The DEA cost minimization problem, assuming that all firms face identical price vectors is:

$$\begin{aligned}
&\textbf{Min}\ \ \mathbf{c}_{\mathbf{x}}^{T}\mathbf{x} = C_i^{*} \\
&\textbf{s.t.} \\
&\mathbf{y}_{\mathbf{i}} \geq \mathbf{Y}\boldsymbol{\lambda}\ ; \\
&\mathbf{x}\ \ \leq \mathbf{X}\boldsymbol{\lambda}\,; \\
&\mathbf{x}, \boldsymbol{\lambda} \geq \mathbf{0}\,.
\end{aligned} \qquad [8]$$

Allowing variable returns to scale, the problem becomes:

$$\begin{aligned}
&\textbf{Min}\ \ \mathbf{c}_{\mathbf{x}}^{T}\mathbf{x} = C_i^{*} \\
&\textbf{s.t.} \\
&\mathbf{y}_{\mathbf{i}} \geq \mathbf{Y}\boldsymbol{\lambda}\ ; \\
&\mathbf{x}\ \ \leq \mathbf{X}\boldsymbol{\lambda}\,; \\
&\mathbf{1}^{T}\boldsymbol{\lambda}\ = \mathbf{1}\ ; \\
&\mathbf{x}, \boldsymbol{\lambda} \geq \mathbf{0}\,.
\end{aligned} \qquad [9]$$

The dimensions of **x, $\mathbf{y}_\mathbf{i}$, λ, X,** and **Y** are the same as in problems [1] – [4], and $\mathbf{c}_\mathbf{x}$ is a (jx1) vector of known input prices. The computed cost efficiency of the i^{th} firm is C_i^*/C_i, where C_i is the observed cost of firm i.

Farrell’s decomposition of cost efficiency into its allocative and technical components is:

$$\frac{C_i^*}{C_i}\frac{1}{\theta_i} = Allocative\ Efficiency. \qquad [10]$$

Revenue Efficiency with DEA

Given a known set of output prices, revenue efficiency can be calculated by selecting the output vector that maximizes revenue, subject to the constraint that the output vector is feasible and the input vector is not greater than a linear combination of observed input vectors. Revenue efficiency is then the ratio of actual revenue, *R*, to optimal revenue, R^*. The DEA problem for revenue maximization is:

$$\begin{aligned} &\textbf{Max}\ \ \mathbf{c}_{\mathbf{y}}^{T}\mathbf{y} = R_i^* \\ &\text{s.t.} \\ &\mathbf{y} \geq \mathbf{Y}\boldsymbol{\lambda}\,; \\ &\mathbf{x}_{\mathrm{i}} \leq \mathbf{X}\boldsymbol{\lambda}\,; \\ &\mathbf{y}, \boldsymbol{\mu} \ \geq \mathbf{0}\,. \end{aligned} \qquad [11]$$

Allowing variable returns to scale, the problem becomes:

$$\begin{aligned} &\textbf{Max}\ \ \mathbf{c}_{\mathbf{y}}^{T}\mathbf{y} = R_i^* \\ &\text{s.t.} \\ &\mathbf{y} \geq \mathbf{Y}\boldsymbol{\lambda}\,; \\ &\mathbf{x}_{\mathrm{i}} \leq \mathbf{X}\boldsymbol{\lambda}\,; \\ &\mathbf{1}^{T}\boldsymbol{\lambda} = 1\ ; \\ &\mathbf{y}, \boldsymbol{\mu} \ \geq \mathbf{0}\,. \end{aligned} \qquad [12]$$

The dimensions of $\mathbf{x_i}$**,** $\mathbf{y}$**,** $\boldsymbol{\mu}$**,** $\mathbf{X}$**,** and $\mathbf{Y}$ are the same as in problems [1] – [4], and $\mathbf{c_y}$ is a (*k*x1) vector of known output prices. The computed revenue efficiency of the i^{th} firm is R_i/R_i^*, where R_i is the observed revenue for firm *i*.

Derivation of output oriented allocative efficiency is the ratio of revenue efficiency to output oriented technical efficiency:

$$\frac{R_i}{R_i^*}\frac{1}{\phi^{-1}} = AllocativeEfficiency. \qquad [13]$$

Data Sources

Data for the analysis were taken from the annual New York State Dairy Farm Business Summary (DFBS), which collects data from New York dairy farmers on a voluntary basis. The number of farms participating varies each year and ranged from a high of 354 farms in 1993 to a low of 199 farms in 2004.

Inputs and outputs were taken from the DFBS for each year from 1993 to 2004. Six inputs and two outputs are defined for the analysis by aggregating collected inputs and outputs. Table 1 shows the DFBS items aggregated to form the inputs and outputs and the price indexes used for aggregation. The aggregate inputs are operator labor input, hired labor input, purchased feed input, livestock input, capital input, and crop inputs. The two outputs are milk and other output. These are all accrual measures. Summary statistics for the aggregated inputs and outputs are found in Table 2. Price indexes taken from *Agricultural Prices* used to deflate the accrual and inventory accounts to 1990 -1992 U.S. dollars and are reported in Table 3.

For the dairy farms in this sample, milk production is by far the most important of the two outputs we have defined, accounting for 88 percent of the total output at the mean of our sample. The outputs aggregated to form "other output" consist largely of what may be considered by-products of milk production, such as livestock sales (cull cows and calves), government payments, and herd appreciation. On average, the capital and purchased feed inputs are the largest in the input set, followed by livestock, hired labor, and crop, inputs.

Revenue and cost efficiency DEA problems require knowledge of output and input prices. Prices indexes were calculated for the aggregate inputs by means of a weighted average of the price indexes used for the individual DFBS items used in the aggregation process. The weights assigned are the average over all farms in each year of the proportion of the total input accounted for by each DFBS item. This ensures that although the quantities of the DFBS items may be different for each farm, all farms face the identical prices for the aggregate input or output. The aggregate input price indexes are displayed in Table 3.

Incorporating Management Inputs

We define two separate management inputs. The first is the operators' own estimate of the values of their management and labor, which they provide as part of the DFBS survey. For farms with more than one operator, we simply sum up the values for each operator. This is a subjective estimate in that it is each farm operator's best guess at his or her own value in the production process. As such, it could suffer from systematic bias if farmers consistently underestimate or overestimate the value of their own labor and management. The second is net farm income, with appreciation, as calculated by the DFBS. To avoid any contemporaneous bias in efficiency measurement that may result from using concurrent net farm income as the management input, the panel nature of our data set allows us to use net farm income from the previous year. However, not all farms participated in the survey each year, so some observations are lost in the process.

To test the hypothesis that computed inefficiencies are the result of failing to include a management input, we first compute technical efficiencies (both output and input oriented), allowing variable returns to scale using the two outputs and six inputs described above. Next, we compute the technical efficiencies, replacing the operator labor input with operators' own values of labor and management. The resulting two sets of computed efficiencies are then compared using a paired two-sample t-test. We test the null hypothesis: $\text{mean}(TE^1_{val} - TE^1_{lab}) = 0$, where TE^1_{val} is technical efficiency computed using operators' value of labor and management and TE^1_{lab} is technical efficiency computed using operator labor. The superscripts refer to the sample number, where 1 signifies that the efficiencies were computed using the full sample of observations. The above steps and tests are repeated for both cost and revenue efficiency (and their allocative components).

This method keeps the same number of inputs and outputs, as well as farm observations for each computation of technical, cost, and revenue efficiencies, thus avoiding dimensionality bias that affects computed efficiencies calculated by DEA when the number of inputs and outputs or observations increases (see Tauer and Hanchar 1995).

We also test for differences in computed efficiencies when the operator labor input is replaced by net farm income from the previous year. We test the hypothesis, mean ($TE^2_{nfi} - TE^2_{lab}$) = 0, where TE^2_{nfi} is technical efficiency computed using net farm income from the previous year, and superscript 2 refers to the smaller sample resulting from using the lagged values of net farm income, because not all farms participated in the survey every year. Again, this sequence is repeated for both cost and revenue efficiency and their imputed allocative components.

If computed technical inefficiency is the result of not including a management input, then we expect that all the above hypotheses would be rejected in favor of a positive average change in computed efficiencies.

Technical Efficiency Results

The average computed technical efficiency scores for each year and input set, as well as orientation are presented in Table 4. For sample one, average input oriented computed technical efficiency using operator labor is 0.9355, with the lowest annual average computed technical efficiency of 0.9203 in 1999, and the highest annual average of 0.9492 occurring in 2004. Output oriented computed technical efficiency using operator labor averages 0.9129. The lowest annual average 0.8925 occurs in 1998 while the highest annual average 0.9354 occurs in 2004.

When operators' values of labor and management are used in place of operator labor, computed input oriented technical efficiency averages 0.9228. The lowest, annual average of 0.9077 occurs in 1998 and the highest annual average, 0.9475 occurs in 2004. Output oriented computed technical efficiency averages 0.9168, with the lowest annual average, 0.9019 occurring in 1998 and the highest annual average, 0.9416 in 2004.

Sample two, which contains only those farms that participated in the survey for at least two consecutive years, the computed technical efficiency averages 0.9395 using an input orientation and operator labor in the input set. The lowest average computed technical efficiency is 0.9203 and occurs in 1999. The highest average computed technical efficiency is 0.9492 in 2004. Using an output orientation, the computed technical efficiency using operator labor averages 0.9259. The lowest is 0.9097 in 1995 and the highest is 0.9406 in 2004

When net farm income from the previous year is used in place of operator labor, computed input oriented technical efficiency averages 0.9457 over the 11 years in the small sample. The smallest average computed technical efficiency of 0.9285 occurs in 1995, while the largest is 0.9606 and occurs in 2004. Output oriented technical efficiency using net farm income from the previous year averages 0.9442, with the smallest average computed technical efficiency of 0.9251 in 1995 and the largest of 0.9586 in 2004.

The paired-sample t-test results are presented in Tables 7 and 8. The average change in technical efficiency depends on whether an input or output orientation is used. Using an input orientation, the average change in computed technical efficiency is negative in eight of twelve years, statistically significant less than zero in three, and statistically significant greater than zero in two. The absolute magnitudes of these changes are quite small. The smallest is -0.006 and the largest is 0.006. Using an output orientation, the average change in computed technical efficiency is positive in ten of twelve years, and statistically significant in six. The smallest change is -0.0036 in 2001. The largest is 0.0114 in 1999.

A similar dependency on orientation is also evident in the average changes in technical efficiency from including net farm income from the previous year in place of operator labor, although not as pronounced. The average change in technical efficiency from including net farm income from the previous year is positive in all eleven years and statistically significant in eight years using an input oriented measure. They range from 0.0018 to 0.0230. Using an output oriented measure, the average change in computed technical efficiency is also positive in all eleven years. They are statistically significant in ten years, ranging from 0.0056 to 0.0317.

Cost Efficiency Results

Computed average cost efficiencies and imputed allocative efficiencies are presented in Table 5. Using operator labor in the input set, average cost efficiency over the twelve years in the sample is 0.7922, ranging from 0.7572 in 1999 to 0.8377 in 2004. When operators' values of labor and management are included in the input set in place of operator labor, average cost efficiency is 0.7968, ranging from 0.7582 in 2001 to 0.8326 in 2004. The imputed average allocative efficiency using operator labor is 0.8583, ranging from 0.8266 in 1999 to 0.8905 in 2004. Using operators' values of labor and management, the average imputed allocative efficiency is 0.8643, ranging from 0.8337 in 2001 to 0.8833 in 1997.

For sample two, average computed cost efficiency allowing variable returns to scale, is 0.8088 over the 11 years of the sample, ranging from 0.7684 in 1999 to 0.8438 in 2001. Using net farm income from the previous year, average computed cost efficiency is 0.8226, ranging from 0.7963 in 2001 to 0.8375 in 1994. The average imputed allocative efficiency is 0.8583, ranging from 0.8266 in 1999 to 0.8905 in 2004.

Results from the t-tests are presented in Tables 7 and 8. There is considerable variability across years as to the effects of including both management input variables. The average change in computed cost efficiency from the inclusion of operators' values of labor and management is 0.0045. The average changes are negative in six years and positive in six years, and statistically significant in eleven years, ranging from -0.0092 in 1994 to 0.0275 in 1999. The average change in imputed allocative efficiency is 0.0060, ranging from -0.0111 in 2004 to 0.0254 in 1999.

Using net farm income from the previous year in place of operator labor, the average change in computed cost efficiency is 0.0118. Under this formulation, the average changes in computed cost efficiencies are positive for the first seven years in the sample and negative for the last four, and statistically significant in ten of the eleven years. Changes range from -0.0447 in 2002, to 0.0584 in 1999. The average change in imputed allocative efficiencies is 0.0033.

Revenue Efficiency Results

Computed average revenue efficiencies and allocative efficiencies are presented in Table 6. Average revenue efficiency over the twelve years in the sample using operator labor in the input set was 0.8862, ranging from 0.8659 in 1998 to 0.9145 in 2004. When operators' values labor and management are used in place of operator labor, computed revenue efficiency averages 0.8910, ranging from 0.8751 in 2001 to 0.9228 in 2004. Average imputed allocative efficiency averages 0.9696 using operator labor in the input set, ranging from 0.9600 in 2000 to 0.9782 in 2003. Replacing operator labor with operators' values of labor and management, average imputed allocative efficiency is 0.9709, ranging from 0.9594 in 2000 to 0.9796 in 2003.

Computed average revenue efficiency using operator labor for sample two is 0.9005, ranging from 0.8810 in 1995 to 0.9201 in 2004. Average imputed allocative efficiency using sample two with operator labor in the input set is 0.9715, ranging from 0.9647 in 2000 to 0.9781 in 2003. When net farm income from the previous year is used in place of operator labor in the input set, average computed revenue efficiency is 0.9202, ranging from 0.8984 in 1995 to 0.9440 in 2004. Average imputed allocative efficiency is 0.9736, ranging from 0.9601 in 1997 to 0.9840 in 2004.

The results from the t-tests for revenue efficiency are again shown in Tables 7 and 8. The average change in computed revenue efficiency from using operators' values of labor and management in place of operator labor alone is 0.0052, ranging from -0.0065 to 0.0133. The results are statistically significant different from zero in eight of twelve years. The average change in allocative (revenue) efficiency is 0.0014, ranging from -0.0033 to 0.0047. The changes in allocative efficiency are statistically significant in six of the twelve years.

The average change in computed revenue efficiency from using net farm income from the previous year in place of operator labor alone is 0.0197, ranging from 0.0031 to 0.0374. These results are statistically significant in ten of eleven years. The corresponding average change in imputed allocative efficiency is 0.0021, ranging from -0.0080 to 0.0070. These results are statistically significant in eight of eleven years.

Conclusions

The change in economic efficiency (cost efficiency and revenue efficiency) from the inclusion of net farm income from the previous year in place of operator labor is, on average, due mostly to changes in computed technical efficiency. This implies that when the previous year's net farm income is used as a measure of the management input, it reflects farmers' abilities in technology choice more than it does the allocative process.

The effects of using operators' values of labor and management are less clear. While its inclusion implies that the change in revenue efficiency is mostly due to changes in average computed technical efficiency, the relationship does not hold when the orientation is changed. The average change in imputed allocative efficiency from the inclusion of operator labor and management in the input set is larger than the average change in cost efficiency, because the average change in technical efficiency, using an input orientation, is negative. Nevertheless, the absolute magnitudes of the changes in average computed efficiencies using operators' values of labor and management are quite small, indicating that little is gained by measuring the management input this way.

The inclusion of operators' values of labor and management do not provide conclusive evidence for our hypothesis that computed technical inefficiency is due to the exclusion of a management input. At best, these individual estimates of the management input serve as a limited proxy for the true value of management, little or no better than using operator labor alone. It is possible that farmers underestimate or overestimate their own management value. If these errors in estimation are severe, then the computed technical efficiencies may suffer from measurement error bias. Thus, given the limitations of a deterministic analysis such as this one, a more exact measure of the management input may be necessary.

The results from using net farm income from the previous year are stronger. This measure of the management input is more objective, in that it only assumes that better managers are more profitable than are lower quality managers and does not rely on individual estimates of management value.

Table 1. DFBS Items Aggregated to form Inputs and Outputs

Input	Price Index	DFBS Items Aggregated
Operator labor and Management	CPI	Operator Value of Labor and Management
Operator Labor	Wages	Operator Months X DFBS Imputed Monthly Wage Rate
Hired Labor	Wages	Hired Labor Months X DFBS Imputed Monthly Wage Rate Family paid labor X DFBS Imputed Monthly Wage Rate Family unpaid labor X DFBS Imputed Monthly Wage Rate
Purchased Feed	Complete Feeds	Grain Nondairy Feed
	All Hay	Purchased Roughage
Livestock	Replacement Cows	Cattle Lease Replacement Cattle Expansion Cattle Other Livestock Interest on Cattle Inventory (5% of the Average Value)
	Supplies	Bedding Milking Supplies Miscellaneous Expenses BST Expenses
	Other Services	Breeding Services Veterinarian Services Milk Marketing Expenses Custom Boarding Expenses
	Fuel	Utilities Expenses
Capital	Farm Machinery	Machinery Rental Machinery Repair Machinery Depreciation Interest on Machinery Inventory (5 % of the average value)
	Building Materials	Building Expenses

Table 1. DFBS Items Aggregated to form Inputs and Outputs (cont.)

Input	Price Index	DFBS Items Aggregated
	Rent	Rent Real Estate Depreciation Interest on Real Estate (5 % of the average value)
	Taxes	Tax Expenses
	CPI	Insurance
	Interest	Interest
Crop	Fertilizer	Fertilizer Expenses
	Seeds	Seed Expenses
	Chemicals	Spray Expenses
	Fuel	Fuel Expenses
Output	**Price Index**	**DFBS Items Aggregated**
Milk	Milk	Milk Receipts
Other Output	Livestock	Cattle Accrual Receipts Calf Accrual Receipts Other Livestock Accrual Receipts
	All Hay	Crop Accrual Receipts
	Custom Rates	Custom Machine Accrual Receipts
	CPI	Government Receipts Other Receipts

Table 2. Summary Statistics for Aggregate Inputs and Outputs

Variable	Mean	Std. Dev.	Min	Max
Milk Output	6538	8830	375	83724
Other Output	931	1277	-326	10180
Operator Labor Input	274	136	34	857
Hired Labor Input	631	850	0	8324
Purchased Feed Input	1800	2463	60	22460
Livestock Input	1538	2176	94	21539
Capital Input	1849	2161	174	17785
Crop Input	415	490	5	3919
Operator Value of Labor and Management	347	244	45	2080
Net Farm Income	928	1448	-1536	12227

Number of observations = 3375

Table 3. Aggregate Input and Output Price Indexes

Year	Milk Output	Other Output	Operator Value of Labor and Management / NFI	Operator Labor Input	Hired Labor Input
1993	96	102	107	108	108
1994	98	101	109	111	111
1995	96	99	112	114	114
1996	110	106	115	117	117
1997	99	107	118	123	123
1998	114	107	120	129	129
1999	108	107	122	135	135
2000	97	112	126	140	140
2001	116	114	130	146	146
2002	94	114	133	153	153
2003	97	119	136	157	157
2004	124	127	141	161	161

Year	Purchased Feed Input	Livestock Input	Capital Input	Crop Input
1993	102	104	102	98
1994	105	105	108	102
1995	101	107	115	108
1996	127	107	121	114
1997	125	109	125	116
1998	112	107	122	108
1999	104	113	123	108
2000	104	120	125	124
2001	111	124	129	123
2002	114	125	131	118
2003	113	124	133	136
2004	122	133	140	150

Table 4. DEA Results; Average Technical Efficiency

-------- Input Oriented --------

	Sample 1		Sample 2	
	Operator Labor in the Input Set	Operator Value of Labor and Management in the Input Set	Operator Labor in the Input Set	Operator Value of Labor and Management in the Input Set
Year				
1993	0.9374	0.9326	NA	NA
1994	0.9316	0.9276	0.9420	0.9467
1995	0.9181	0.9150	0.9243	0.9285
1996	0.9161	0.9144	0.9329	0.9485
1997	0.9157	0.9195	0.9236	0.9385
1998	0.9060	0.9077	0.9242	0.9344
1999	0.9172	0.9224	0.9203	0.9433
2000	0.9308	0.9272	0.9379	0.9495
2001	0.9172	0.9105	0.9459	0.9478
2002	0.9202	0.9178	0.9450	0.9479
2003	0.9323	0.9315	0.9448	0.9574
2004	0.9412	0.9475	0.9492	0.9606

-------- Output Oriented --------

	Sample 1		Sample 2	
	Operator Labor in the Input Set	Operator Value of Labor and Management in the Input Set	Operator Labor in the Input Set	Operator Value of Labor and Management in the Input Set
Year				
1993	0.9249	0.9260	NA	NA
1994	0.9198	0.9223	0.9311	0.9462
1995	0.9031	0.9081	0.9097	0.9250
1996	0.9056	0.9076	0.9205	0.9473
1997	0.9042	0.9125	0.9116	0.9356
1998	0.8925	0.9019	0.9121	0.9331
1999	0.9069	0.9183	0.9108	0.9424
2000	0.9226	0.9227	0.9319	0.9494
2001	0.9064	0.9028	0.9397	0.9452
2002	0.9120	0.9120	0.9391	0.9465
2003	0.9213	0.9257	0.9376	0.9567
2004	0.9354	0.9416	0.9406	0.9585

Table 5. DEA Results; Average Cost and Allocative Efficiency

-------- Cost --------

	Sample 1		Sample 2	
Year	**Operator Labor in the Input Set**	**Operator Value of Labor and Management in the Input Set**	**Operator Labor in the Input Set**	**Operator Value of Labor and Management in the Input Set**
1993	0.8039	0.8122	NA	NA
1994	0.8163	0.8071	0.8248	0.8375
1995	0.7856	0.8057	0.7948	0.8264
1996	0.7912	0.8064	0.8071	0.8302
1997	0.7956	0.8024	0.8012	0.8168
1998	0.7761	0.7908	0.7858	0.8338
1999	0.7572	0.7847	0.7684	0.8267
2000	0.7741	0.7737	0.7835	0.8302
2001	0.7664	0.7582	0.8438	0.8294
2002	0.7896	0.7825	0.8410	0.7963
2003	0.8132	0.8050	0.8378	0.7984
2004	0.8377	0.8326	0.8429	0.8353

-------- Allocative (Cost) --------

	Sample 1		Sample 2	
Year	**Operator Labor in the Input Set**	**Operator Value of Labor and Management in the Input Set**	**Operator Labor in the Input Set**	**Operator Value of Labor and Management in the Input Set**
1993	0.8580	0.8718	NA	NA
1994	0.8771	0.8712	0.8761	0.8375
1995	0.8567	0.8819	0.8607	0.8264
1996	0.8647	0.8833	0.8653	0.8302
1997	0.8697	0.8712	0.8679	0.8168
1998	0.8577	0.8729	0.8513	0.8338
1999	0.8266	0.8520	0.8360	0.8267
2000	0.8325	0.8359	0.8363	0.8302
2001	0.8354	0.8337	0.8917	0.8294
2002	0.8586	0.8530	0.8897	0.7963
2003	0.8727	0.8652	0.8869	0.7984
2004	0.8905	0.8793	0.8881	0.8353

Table 6. DEA Results; Average Revenue and Allocative Efficiency

-------- Revenue --------

	Sample 1		Sample 2	
	Operator Labor in the Input Set	**Operator Value of Labor and Management in the Input Set**	**Operator Labor in the Input Set**	**Operator Value of Labor and Management in the Input Set**
Year				
1993	0.8981	0.8988	NA	NA
1994	0.8929	0.8998	0.9035	0.9227
1995	0.8709	0.8786	0.8810	0.8984
1996	0.8769	0.8808	0.8948	0.9219
1997	0.8753	0.8843	0.8837	0.8994
1998	0.8659	0.8774	0.8848	0.9060
1999	0.8809	0.8943	0.8875	0.9250
2000	0.8874	0.8868	0.9004	0.9213
2001	0.8817	0.8751	0.9185	0.9262
2002	0.8871	0.8860	0.9130	0.9160
2003	0.9027	0.9077	0.9182	0.9411
2004	0.9145	0.9228	0.9201	0.9440

-------- Allocative (Revenue) --------

	Sample 1		Sample 2	
	Operator Labor in the Input Set	**Operator Value of Labor and Management in the Input Set**	**Operator Labor in the Input Set**	**Operator Value of Labor and Management in the Input Set**
Year				
1993	0.9701	0.9696	NA	NA
1994	0.9701	0.9749	0.9696	0.9741
1995	0.9634	0.9666	0.9671	0.9702
1996	0.9673	0.9696	0.9706	0.9723
1997	0.9668	0.9679	0.9680	0.9601
1998	0.9690	0.9720	0.9690	0.9701
1999	0.9709	0.9734	0.9741	0.9812
2000	0.9600	0.9594	0.9647	0.9692
2001	0.9709	0.9676	0.9769	0.9792
2002	0.9717	0.9708	0.9716	0.9667
2003	0.9782	0.9796	0.9781	0.9829
2004	0.9769	0.9794	0.9773	0.9840

Table 7. Results from Sample 1

Average Change in Efficiency from the Inclusion of Operator Value of Labor and Management

Year	Output Oriented Technical Efficiency		Input Oriented Technical Efficiency		Cost Efficiency		Allocative (Cost) Efficiency		Revenue Efficiency		Allocative (Revenue) Efficiency	
1993	0.0011		-0.0048	**	0.0083	**	0.0138	**	0.0007		-0.0005	
	(0.5506)		-(2.7677)		(5.0051)		(7.1259)		(0.3049)		-(0.4068)	
1994	0.0025		-0.0040		-0.0092	**	-0.0058	**	0.0068	**	0.0048	**
	(0.9219)		-(1.7376)	*	-(5.6206)		-(2.8016)		(2.3512)		(3.9333)	
1995	0.0050		-0.0031		0.0201	**	0.0251	**	0.0077	**	0.0033	**
	(1.8111)	*	-(1.1972)		(10.6969)		(9.7235)		(2.3454)		(2.3699)	
1996	0.0020		-0.0017		0.0152	**	0.0186	**	0.0039		0.0023	*
	(0.8782)		-(0.7887)		(9.2191)		(9.0549)		(1.5544)		(1.93)	
1997	0.0083	**	0.0037		0.0068	**	0.0015		0.0090	**	0.0012	
	(3.7094)		(1.6919)	*	(3.6852)		(0.4348)		(3.4794)		(0.6785)	
1998	0.0094	**	0.0017		0.0147	**	0.0152	**	0.0115	**	0.0030	**
	(4.2582)		(0.7746)		(7.9529)		(6.2042)		(4.4822)		(3.1106)	
1999	0.0114	**	0.0052	**	0.0275	**	0.0254	**	0.0133	**	0.0025	**
	(5.5203)		(2.278)		(12.2995)		(9.2996)		(6.2768)		(2.2582)	
2000	0.0001		-0.0036		-0.0004		0.0034		-0.0006		-0.0006	
	(0.0472)		-(1.5949)		-(0.2117)		(1.5705)		-(0.1999)		-(0.4148)	
2001	-0.0036		-0.0068	**	-0.0082	**	-0.0016		-0.0065	**	-0.0033	**
	-(1.1697)		-(2.3205)		-(4.3354)		-(0.6176)		-(1.9724)		-(2.4861)	
2002	-0.0001		-0.0023		-0.0071	**	-0.0056	**	-0.0011		-0.0010	
	-(0.0352)		-(0.951)		-(3.6409)		-(2.2167)		-(0.4519)		-(0.836)	
2003	0.0044	*	-0.0008		-0.0082	**	-0.0074	**	0.0050	*	0.0013	
	(1.7323)		-(0.3031)		-(3.6345)		-(2.3806)		(1.7911)		(0.9678)	
2004	0.0062	**	0.0062	**	-0.0051	**	-0.0111	**	0.0084	**	0.0024	**
	(3.0322)		(2.8501)		-(3.1538)		-(5.0063)		(3.3366)		(2.0293)	

(t-statistics in parentheses); *, ** signify 90 and 95 percent significance.

Table 8. Results from Sample 2

Average Change in Efficiency from the Inclusion of Net Farm Income from the Previous Year

Year	Output Oriented Technical Efficiency	Input Oriented Technical Efficiency	Cost Efficiency	Allocative (Cost) Efficiency	Revenue Efficiency	Allocative (Revenue) Efficiency
1994	0.0152 **	0.0047	0.0127 **	0.0090 **	0.0192 **	0.0045 **
	(3.8003)	(1.3089)	(3.0065)	(2.4005)	(4.2198)	(2.7775)
1995	0.0154 **	0.0042	0.0316 **	0.0305 **	0.0174 **	0.0031 *
	(3.4562)	(1.0139)	(7.5832)	(7.2293)	(3.6917)	(1.7647)
1996	0.0268 **	0.0156 **	0.0231 **	0.0101 **	0.0271 **	0.0017
	(6.4361)	(4.0155)	(5.4493)	(2.5480)	(5.7729)	(0.9295)
1997	0.0240 **	0.0149 **	0.0156 **	0.0021	0.0157 **	-0.0080 **
	(5.7686)	(3.9005)	(3.3710)	(0.5096)	(3.5146)	-(3.3908)
1998	0.0211 **	0.0102 **	0.0481 **	0.0416 **	0.0212 **	0.0011
	(5.4848)	(2.7786)	(12.4609)	(10.5849)	(5.1956)	(0.5237)
1999	0.0317 **	0.0230 **	0.0584 **	0.0417 **	0.0374 **	0.0070 **
	(7.8727)	(5.6371)	(12.1122)	(9.0369)	(9.0337)	(3.9087)
2000	0.0176 **	0.0116 **	0.0468 **	0.0391 **	0.0209 **	0.0045 **
	(5.0423)	(3.1647)	(10.4285)	(9.8745)	(4.8463)	(2.3963)
2001	0.0056	0.0018	-0.0144 **	-0.0162 **	0.0077 *	0.0022
	(1.5087)	(0.5356)	-(2.8248)	-(3.3820)	(1.8896)	(1.2644)
2002	0.0075	0.0028	-0.0447 **	-0.0500 **	0.0031	-0.0049 **
	(1.8847)	(0.7409)	-(7.3964)	-(8.7750)	(0.6923)	-(2.3253)
2003	0.0191 **	0.0126 **	-0.0394 **	-0.0523 **	0.0229 **	0.0048
	(3.8659)	(2.7288)	-(7.0889)	-(9.6291)	(3.6019)	(1.7261)
2004	0.0179 **	0.0114 **	-0.0076	-0.0191 **	0.0239 **	0.0066 **
	(4.0859)	(2.7101)	-(1.4432)	-(4.1633)	(4.8550)	(3.1576)

(t-statistics in parentheses); *, ** signify 90 and 95 percent significance.

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