Identifying Efficient Dairy Producers Using Data Envelopment Analysis

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ABSTRACT

The objective of this research was to calculate the efficiency of a group of Pennsylvania dairy farms to determine factors that contributed to efficiency in production and business management. Data envelopment analysis (DEA) was used to estimate the efficiency. Two models were developed to measure the efficient use of physical (land, cows, and labor) inputs to produce physical (milk and butterfat) outputs, and the use of physical and economic (debt capital) inputs to produce physical and economic (income) outputs. The results showed that about 29% of the producers in our sample were DEA-efficient and demonstrated that there was no combination of inputs used by efficient producers that was best. In addition, the method of analysis illustrated the benefits of DEA in that it is possible to identify the set of efficient producers that inefficient producers can benchmark to in an effort to achieve similar levels of efficiency. Finally, the analysis demonstrated that producers should not benchmark to the highest level of production, but rather should combine resources in land, labor, cows, and debt capital to achieve an efficient level of production, which indeed may be less than the maximum production level of the group.

Key words: efficiency, dairy, production, data envelopment analysis

INTRODUCTION

Dairy producers combine multiple inputs such as land, labor, cows, feed, capital equipment, and managerial ability to produce multiple outputs such as the milk and milk components fat and protein. Yet, as the costs of inputs increase and prices for milk and milk products remain steady or decline, producers are required to become more efficient in combining these inputs to produce milk to remain profitable. The challenge for producers is to identify the most efficient combination of inputs to produce outputs. One method of determining

best practice is to use benchmarks, such as milk per cow, milk sold per worker, or costs per unit of milk produced. But these measures are only partial measures of efficiency. The problem with these partial measures is that when producers attempt to address one benchmark, they affect others, directly or indirectly (Fraser and Cordina, 1999). Also, benchmarks concentrate on differences in average production between farms in the benchmark group, rather than on optimizing the farm-specific production in the benchmark group (Fraser and Hone, 2001).

An alternative to partial efficiency measures is to use a measure of the efficiency of the farming system as a whole. Techniques such as data envelopment analysis (DEA) or stochastic frontier analysis are capable of measuring whole-farm system efficiency (Jaforullah and Premachandra, 2004). Data envelopment analysis is a nonparametric method of calculating the efficiency of individual decision-making units (DMU) such as dairy farms for performance measurement, analysis, and benchmarking (Weersink et al., 1990; Tauer, 1993). This method of analysis has many attributes to assist producers and advisors in determining the best allocation of farm business resources and the scale of operation for that business to ensure the system is producing at an efficient level (Fraser and Cordina, 1999). Stochastic frontier analysis (SFA) is a parametric method of estimating efficiency and further differs from DEA in that an error term is included in the model (Bravo-Ureta and Rieger, 1991). Because of the parametric method used in SFA and the ability of DEA to identify benchmarks, DEA is preferred in this research.

Data envelopment analysis compares the levels of inputs and outputs for a given DMU against all other DMU in the data set to determine which DMU are producing at efficient levels relative to the entire group. The method assigns an efficiency score ranging from 0 to 1 to each DMU in the analysis group and can be used to determine how inputs and outputs should be adjusted to obtain DEA efficiency. Data envelopment analysis provides specific information about which efficient DMU the inefficient DMU should benchmark to (Jaforullah and Whiteman, 1999). Unlike regression, DEA allows for multiple outputs (dependent variables)

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Figure 1. Example data envelopment analysis efficient frontier for 2 inputs and 1 output with 6 decision-making units, A to F. Points A through F represent combinations of inputs 1 and 2 that result in 1 unit of output being produced. Because inputs are costly, combinations A, B, and C form the efficient frontier, whereas combinations E, F, and D are inefficient. Delta represents an efficient input combination, with $0 \rightarrow \Delta$ being a measure of how inefficient input combination D is.

in a single equation and is a distribution-free (i.e., non-parametric) technique.

Tauer (1993) and Weersink et al. (1990) utilized DEA to estimate the technical and allocative efficiency of dairy farms in New York State and Ontario, respectively, but did not examine the efficiency of each input or DMU individually. Tauer (2001), using a frontier analysis model of the efficiency of New York State dairy farms, concluded that further study was needed to identify cost-efficient production methods for efficient producers and how other producers could implement these production methods. The primary objective of this research was to calculate the DEA efficiency of a group of Pennsylvania dairy farms to help determine factors that contribute to efficiency in production and business management. Two DEA models were developed to measure the efficient use of physical inputs to produce physical outputs and the use of physical and economic inputs to produce physical and economic outputs.

MATERIALS AND METHODS

DEA Efficiency

The basic concept behind DEA efficiency can best be described with a simple example. As noted above, the entities under investigation with DEA are referred to as decision-making units or DMU. Depicted in Figure 1 is a simple example of 6 DMU each using 2 inputs to

produce a single output. The input values were assumed “normalized” so that each DMU’s use of the 2 inputs results in 1 unit of the output being produced.

As shown, DMU A, B, and C are DEA-efficient in the sense that they use the least amount of costly inputs to produce 1 unit of output, albeit with different combinations of the inputs. The line segments connecting points A, B, and C are collectively referred to as the “efficient frontier” in the DEA literature. Because inputs are costly, the efficient frontier represents all least-cost combinations of inputs capable of producing the common output level.

The remaining 3 DMU in Figure 1 are DEA-inefficient because they are using more of each input (or a convex combination of inputs) than DMU A, B, and C to produce 1 unit of output. For example, DMU D could reduce its use of either or both inputs to move back to the efficient frontier. Reducing the use of input 1 (or input 2) moves DMU D to the left (or down) toward DMU A (or DMU B) and closer to the frontier. Reducing the use of both inputs will move DMU D back to the frontier somewhere along the line segment AB (Cooper et al., 2000).

An estimate of relative efficiency can be obtained for each DMU by projecting a ray from the origin to each DMU point like D. An estimate of efficiency is then $\theta = 0\Delta/0D$ (θ is the ratio of the distances from the origin, 0, to point Δ and the origin, 0, to point D), which is always less than 1 for an inefficient DMU and equal to 1 for frontier (efficient) DMU. The efficiency estimate indicates the percentage by which both inputs should be reduced to efficiently produce the 1 unit of output (Cooper et al., 2000). For example, $\theta = 0.75$ would imply that the use of each input should be reduced by 25% (or to 75% of current input levels) to achieve DEA-efficient production.

It is important to point out that the DEA technique is nonstochastic. This means that either the data are observed without error or the relationship between inputs and outputs is deterministic. Although this assumption is relatively stringent, it is counterbalanced somewhat because no assumptions on the nature of the uncertainty (i.e., the errors) have to be made to use the technique. Stochastic frontier analysis was designed to address this specific shortcoming of DEA, although, in doing so, SFA relies on very specific distributional assumptions for the error and functional form for the relationship between inputs and outputs. If the distributional assumptions or the functional form are misspecified, it is likely that the results would be no more credible than those associated with a (deterministic) DEA specification.

The Charnes, Cooper, Rhodes DEA Model

The DEA model implemented to examine Pennsylvania dairy farm efficiency is the Charnes, Cooper, Rhodes (CCR; Charnes et al., 1978) model with an input orientation. [Although Charnes et al. (1978) are credited with the first empirical application of DEA, research going back to at least Seitz (1971) is related.] This model embodies the basic ideas discussed in the previous section. The input orientation feature simply means that DEA inefficiency is estimated with respect to the inputs as opposed to the outputs. With an output orientation, inefficiencies are stated in terms of outputs rather than inputs, so taking an output orientation will not change the results.

The CCR model is implemented as a linear program expressed for each DMU j as

$$\begin{aligned} \min \theta_j \\ \theta_j x_{jm} &\geq \sum_{k=1}^K x_{km} \lambda_{jk} \quad \text{for all } m \\ \sum_{k=1}^K y_{ki} \lambda_{jk} &\geq y_{ji} \quad \text{for all } i \\ \lambda_{jk}, \theta_j &\geq 0, \end{aligned} \quad [1]$$

where m indexes inputs so that x_{jm} is the amount of input m used by DMU j and x_{km} is the amount of input m used by each of the other K DMU. Also, in Eq. 1, i indexes outputs so that y_{ji} represents the amount of output i produced by DMU j and y_{ki} is the amount of output i produced by each of the other K DMU. Notice that the linear program above is solved once for each DMU, so that efficiency is gauged for each DMU j relative to each of the other K DMU in the sample.

The objective of the linear program is to find an optimal set of weights denoted by λ_{jk} that satisfy the $m \times i$ constraints and give an efficiency score denoted by $0 \leq \theta_j \leq 1$. The magnitude of the weights gives information about relevant benchmarks for each inefficient DMU. That is, the weights taking on positive values form the set of potential benchmarks for the inefficient DMU in question. Furthermore, the largest weight is the most appropriate efficient DMU for the inefficient DMU to benchmark. This is an important point in that it is the DEA model solution that determines the appropriate benchmarks for the inefficient DMU rather than an exogenous source such as an average.

DEA Inputs, Outputs, and Data

Decision makers have 2 sets of inputs, controllable and noncontrollable (Jaforullah and Whiteman, 1999). Controllable inputs are those that the manager can

control, such as hectares to farm, barn type, breed type, labor use, number of cows, and milking system. Noncontrollable inputs are those over which the manager has no control such as the weather and the prices for inputs and outputs. Also, when comparing efficiencies across systems it is necessary to ensure that production technology is homogeneous across DMU. If different technologies are compared, differences in efficiencies may be due to technology and not to the mix of inputs used. Differences in efficiencies between DMU are the result of variables not included in the DEA model such as production and business management ability. Hence, when constructing these models it is important to capture variables that have the most impact on the efficiency of the system (Jaforullah and Whiteman, 1999). Other factors that may affect the efficiency of the system include producers' goals and other nonmeasurable factors. The region of production can affect efficiency scores across systems; however, in this case all producers were located in Pennsylvania to maintain the homogeneity of the data set.

Although a dairy farm is designed to produce a single output, namely milk, this output represents a joint or multiproduct output because both milk and fat contribute to the revenue-generating activities of the farm business. Therefore, perhaps the most obvious outputs for a dairy farm are milk and butterfat production. All else being equal, higher milk production is more desirable as is higher butterfat production. Protein and milk solids contribute to the income of dairy producers and would have similar effects on income as butterfat and milk yield; however, in the data set used this information was not available.

The number of cows, acres farmed, and labor used form a set of important inputs for determining how much milk and butterfat a dairy farm produces. More cows produce more milk, so the number of dairy cows is a critical, if not obvious, input affecting milk production. Similarly, the more hectares a dairy farm uses, the more milk production that is anticipated. Lastly, more labor would generally be associated with more milk production and labor full-time equivalents (FTE) are used as the relevant input variable. Therefore, a representation of the input/output relationship is simply:

$$y \text{ (milk, butterfat)} = x \text{ (land, labor, cows)}, \quad [2]$$

where y is a general output function with milk and butterfat production arguments and x is a general input function with land, labor, and cow arguments. In reality, many more inputs affect output. On the other hand, data limitations preclude the inclusion of more inputs such as feed or genetic quality.

Table 1. Inputs and outputs used in the data envelopment analysis models¹

DMU	Labor (FTE)	Cows	Land (ha)	Milk production (kg/cow)	Butterfat production (kg/cow)	Debt (\$)	Net income (\$)
1	2.66	70	98	10,490	372	0	15,186
2	3.06	67	97	8,736	337	0	40,838
3	3.59	72	38	8,267	319	70,769	26,630
4	1.00	60	48	10,010	392	140,627	49,149
5	2.80	180	166	8,918	330	0	78,718
6	2.00	112	66	9,953	359	18,005	85,055
7	1.60	40	109	7,446	302	0	19,226
8	2.28	55	105	9,362	337	0	44,055
9	4.71	118	121	9,016	347	171,277	28,996
10	1.80	55	19	9,067	317	120,473	19,756
11	2.00	58	57	8,605	339	205,506	31,365
12	2.00	87	63	9,148	336	179,000	68,797
13	1.80	40	36	6,802	262	6,939	13,352
14	2.00	53	136	8,433	298	24,809	16,982
15	4.18	249	257	7,339	294	556,447	121,596
16	1.60	43	40	8,530	303	104,729	42,544
17	1.38	55	101	6,795	256	30,971	49,162
18	1.60	36	85	4,870	183	31,931	138
19	1.90	44	60	7,426	297	17,646	44,342
20	1.51	54	81	8,350	315	118,951	76,682
21	1.00	98	121	9,406	365	87,517	6,057
22	1.65	36	89	7,166	267	16,639	9,443
23	1.67	54	147	4,391	155	0	18,397
24	3.20	110	127	9,981	349	0	118,858
25	1.00	64	51	11,438	405	178,839	89,216
26	3.72	110	42	8,995	352	384,223	81,825
27	1.93	81	80	11,201	410	111,901	92,366
28	2.17	56	74	7,015	267	49,777	33,510
29	2.00	71	61	6,689	254	16,232	66,026
30	1.00	30	45	6,105	245	13,065	4,206
31	2.00	82	52	5,379	202	25,487	0
32	2.00	73	113	7,844	278	28,563	41,272
33	3.00	143	126	9,045	353	112,180	97,610
34	1.15	62	86	8,621	322	0	27,844
Mean	2.15	77	88	8,260	309	83,015	45,859
SD	0.92	45	47	1,657	59	118,534	34,298
Minimum	1.00	30	19	4,391	155	0	0
Maximum	4.71	249	257	11,438	410	556,447	121,596

¹DMU = decision-making unit (i.e., dairy farm); FTE = full-time equivalent.

Farm Bureau tax records from 349 Pennsylvania dairy farms for 2001 were used for analysis. Farms in the sample had ≥ 20 cows and generated at least half of their gross farm receipts from milk sales (Roth and Hyde, 2001). The data were stratified to control for breed, milking barn setup, and milking system. This resulted in a data set of 34 DMU consisting solely of Holstein herds using stanchion barns and operating pipeline milking systems. It should be noted that DEA is often applied to far fewer DMU (Ragsdale, 2007). Because DEA is nonparametric, statistical hypothesis testing is not possible. Most likely, a large number of data points (i.e., DMU) will increase the computational burden because a linear program must be solved for each DMU in the sample.

Due to the structure of the data set it was not possible to determine whether all resources such as land or labor were utilized by the dairy operation. Excess resources

will be identified in the analysis as surpluses. Because DEA is a nonparametric method, the relatively few farms in the data set are not a concern in a statistical sense. That is, the DEA approach is not a statistical approach from which tests of significance are conducted and therefore, degrees of freedom issues associated with 34 observations are not an issue. Input and output data and summary statistics are shown in Table 1, as well as 1 additional economic input (dollars of debt capital used) and 1 additional economic output (dollars of net income) to be discussed later in the paper.

RESULTS AND DISCUSSION

The DEA results are presented in Table 2. As shown, 6 out of the 34 DMU were identified as DEA-efficient. That is, 6 dairy farms have no input or output inefficiencies, thereby having DEA efficiency scores equal to

Table 2. Results of the technical data envelopment analysis (DEA) model, decision-making units (DMU; i.e., dairy farm) ranked by efficiency scores with slacks¹ for labor and land and target and actual milk and butterfat production

DMU	Efficiency	Slack labor (full-time equivalent)	Slack land (ha)	Actual milk production (kg/cow)	Target milk production (kg/cow)	Actual butterfat production (kg)	Target butterfat production (kg)
6	1.0000	— ²	—	9,953	—	359	—
10	1.0000	—	—	9,067	—	317	—
21	1.0000	—	—	9,406	—	365	—
25	1.0000	—	—	11,438	—	405	—
26	1.0000	—	—	8,995	—	352	—
27	1.0000	—	—	11,201	—	410	—
4	0.9688	0.0470	—	10,010	11,431	392	405
1	0.9187	1.3970	38.0763	10,490	11,418	372	405
24	0.8726	1.2925	35.3607	9,981	11,438	349	405
33	0.8660	0.1756	—	9,045	11,325	353	407
3	0.8585	1.4121	—	8,267	9,915	319	372
9	0.8467	1.5998	4.4579	9,016	11,201	347	410
12	0.8455	0.3450	—	9,148	11,078	336	397
11	0.8274	0.5245	—	8,605	11,210	339	410
8	0.8271	0.9863	46.6068	9,362	11,318	337	407
2	0.8225	1.2036	25.6409	8,736	11,201	337	410
5	0.8160	—	18.4496	8,918	11,412	330	404
34	0.7929	—	26.1823	8,621	11,356	322	407
20	0.7678	0.1691	21.6433	8,350	11,201	315	410
16	0.7471	0.6709	3.7076	8,530	11,418	303	405
14	0.7373	0.8640	69.0549	8,433	11,438	298	405
7	0.7356	0.4747	51.1073	7,446	11,201	302	410
19	0.7246	0.6158	12.3096	7,426	11,201	297	410
15	0.7238	—	38.8779	7,339	11,404	294	406
32	0.6858	0.5894	38.1310	7,844	11,438	278	405
22	0.6502	0.5131	34.5807	7,166	11,201	267	410
28	0.6502	0.5397	12.5756	7,015	11,201	267	410
13	0.6418	0.6230	—	6,802	11,291	262	408
29	0.6252	0.4349	—	6,689	11,359	254	407
17	0.6248	0.0441	29.1322	6,795	11,201	256	410
30	0.5986	0.1700	8.9709	6,105	11,201	245	410
31	0.5253	0.0852	—	5,379	10,525	202	385
18	0.4455	0.3300	22.0682	4,870	11,201	183	410
23	0.3839	0.3159	40.1557	4,391	11,438	155	405

¹Slack indicates the amount by which a DEA model constraint is not satisfied with equality and therefore, represents the amount by which an input is overused relative to how efficient producers use the input.

²Indicates no surplus labor or land (in the slack labor and land columns), and indicates that the target milk or butterfat production is equal to actual milk or butterfat production (in the milk and butterfat columns).

1. These 6 dairy farms define the efficient frontier and represent the best practice farms for combining land, labor, and cows to produce milk and butterfat. These efficient dairies average 1.91 labor FTE, 87 cows, and use 156 ha to produce 10,010 kg/cow of milk and 368 kg/cow of butterfat.

The DEA efficiency scores, slack labor, land, and target milk and butterfat production for the inefficient dairy farms are presented in Table 2. A slack value indicates the amount by which a DEA model constraint is not satisfied with equality and therefore, represents the amount by which an input is overused relative to how the most efficient producers use the input. Inefficient dairies average 2.16 labor FTE, 77 cows, and use 102 ha to produce 7,300 kg/cow of milk and 275 kg/cow of butterfat. The average target level of inputs for this

group is 1.21 FTE, 61 cows, and 57 ha to produce 9,900 kg/cow of milk and 359 kg/cow of butterfat. In all instances cows were used at an efficient level, meaning there was no slack in the cow inputs; thus, the cow input is not reported in Table 2.

For the inefficient dairy farms, in most cases labor and land were far in excess of the requirements of the system to achieve an efficient level of production. On average, labor was in excess by 0.62 FTE per farm (range 0 to 1.5998 FTE) and land was in excess by 28.85 ha (range 0 to 69.05 ha).

Data envelopment analysis also allows a DMU to identify how to change the input mix to achieve an efficient level of production for the farming system under review. As an example of how to interpret the results to achieve this level we used DMU 4 (the least

inefficient DMU) as an example. This DMU had a DEA efficiency score of 0.9688 indicating that this farm should decrease its use of land, labor, and cows by 3.12% (i.e., $1 - 0.9688$) as a first step toward becoming DEA efficient. Alternatively, DMU 4 should be able to achieve its current level of production using 96.9% of its current input levels. However, as indicated in Table 2, 2 subsequent steps for complete DEA efficiency are required. First, labor use should be further adjusted downward by 0.047 FTE as indicated by the slack labor column. Second, milk and butterfat production should both be increased. Milk production should increase from 10,010 kg/cow (Table 1) to 11,431 kg/cow, and butterfat production, which should increase from 392 to 405 kg, in percentage terms would actually decrease from 3.92 to 3.54%. The percentage declines because of the increase in milk production reported. In more general terms, the DEA results suggest that for DMU 4, milk and butterfat production should be raised relative to current levels and the target levels of production should be obtainable with the use of less land, labor, and cows as indicated.

As another example, DMU 23 is the least efficient dairy farm in the sample with a DEA score of 0.3839. Therefore, adjusting all input levels to about 38%, or reducing inputs by 62%, of the levels currently used on the farm is a first step toward efficient milk and butterfat production. After these reductions, the farm should be capable of producing 11,438 kg/cow of milk after further reducing labor use by 0.32 FTE and land use by about 40 ha. For this farm, butterfat production is already at a level consistent with efficiency and hence no further adjustments are necessary. In these 2 cases and in all other cases where inefficiencies were identified the challenge for producers is to change the level of inputs or outputs to achieve the efficient levels of production, which may not be easy, especially in the case of inputs such as land.

Benchmarking is another important way for inefficient DMU to improve their situation. Yet, the question of what level of inputs or outputs to benchmark to is an open question. For example, the average level of milk production for the 34 DMU in the sample is 8,260 kg/cow. Benchmarking to this average is not unlike benchmarking to the state average or some other average. The DEA technique suggests a different way of benchmarking by actually identifying the efficient DMU that each inefficient DMU should use as a benchmark. When a set of benchmarks is identified for an inefficient producer, it may be possible for the producer to study these benchmarks to determine if changes can be made to the production systems to achieve the efficiency targets estimated.

Table 3. Benchmark decision-making unit (DMU; i.e., dairy farm) and returns to scale for the inefficient DMU from the technical model ranked by efficiency score

Rank	DMU	Benchmark #1 DMU	Benchmark #2 DMU
7	4	25	27
8	1	25	27
9	24	25	
10	33	25	27
11	3	25	26
12	9	27	
13	12	25	26
14	11	25	27
15	8	25	27
16	2	27	
17	5	21	25
18	34	25	27
19	20	27	
20	16	25	27
21	14	25	
22	7	27	
23	19	27	
24	15	25	27
25	32	25	
26	22	27	
27	28	27	
28	13	25	27
29	29	25	27
30	17	27	
31	30	27	
32	31	25	26
33	18	27	
34	23	25	

Presented in Table 3 are the top 2 benchmarks for each inefficient DMU listed in Table 2. Using DMU 4 as an example again shows that DMU 25 is the dairy farm that DMU 4 should emulate. Decision-making unit 4 is a 60-cow dairy that is using 1 FTE of labor and 48 ha of land to produce 10,010 kg/cow of milk and 392 kg/cow of butterfat, whereas DMU 25 is a 64-cow dairy using 1 FTE of labor and 51 ha of land to more efficiently produce 11,438 kg/cow of milk and 405 kg/cow of butterfat. Clearly, benchmarking to the group average of 8,260 kg/cow of milk is too low a target for DMU 4 and will not resolve their production inefficiency. Other benchmarks in Table 3 are interpreted similarly.

An extension to the basic production-oriented model presented in the previous section was developed by including 1 additional economic input and 1 additional economic output. Dollars of debt capital is an important input for most dairy farms because modern dairy production is very capital intensive. The use of this input has important business management implications in that debt capital is an inexpensive way to finance business growth because it is generally less expensive than equity capital. The use of debt capital can accelerate the rate of growth in equity capital, but this accelerated growth comes at the expense of the farm's risk position

Table 4. Results of the economic data envelopment analysis model, decision-making units (DMU; i.e., dairy farms) ranked by efficiency scores with slacks¹ for labor, land, and debt, and target and actual milk and butterfat production

DMU	Efficiency	Labor (full-time equivalent)	Land (ha)	Debt (\$)	Actual milk production (kg)	Target milk production (kg)	Actual butterfat production (kg)	Target butterfat production (kg)	Target net income (\$)
1	1.0000	—	—	—	10,490	—	372	—	—
5	1.0000	—	—	—	8,918	—	330	—	—
6	1.0000	—	—	—	9,953	—	359	—	—
10	1.0000	—	—	—	9,067	—	317	—	—
20	1.0000	—	—	—	8,350	—	315	—	—
21	1.0000	—	—	—	9,406	—	365	—	—
24	1.0000	—	—	—	9,981	—	349	—	—
25	1.0000	—	—	—	11,438	—	405	—	—
26	1.0000	—	—	—	8,995	—	352	—	—
27	1.0000	—	—	—	11,201	—	410	—	—
29	0.9913	0.3775	—	—	6,689	10,044	254	357	—
4	0.9806	—	—	—	10,010	11,231	392	400	26,338
34	0.9624	—	24.4687	—	8,621	9,131	322	335	—
8	0.9477	0.5180	35.8924	—	9,362	10,119	337	356	—
2	0.9347	0.7624	10.7437	—	8,736	10,233	337	361	—
33	0.9157	—	12.0059	—	9,045	10,592	353	385	27,157
3	0.8932	1.7996	—	—	8,267	9,715	319	357	21,856
19	0.8822	0.5550	5.7546	—	7,426	9,684	297	343	—
12	0.8571	0.4929	—	—	9,148	11,003	336	392	21,494
9	0.8467	1.5998	4.4579	6,995	9,016	11,201	347	410	84,939
7	0.8314	0.1895	47.3092	—	7,446	10,277	302	363	—
11	0.8274	0.5245	—	101,146	8,605	11,210	339	410	23,822
17	0.8097	—	36.1634	—	6,795	10,261	256	361	—
14	0.7859	0.1871	54.1111	—	8,433	10,731	298	385	5,085
32	0.7519	—	28.6032	—	7,844	10,432	278	374	—
16	0.7497	0.6283	2.6648	—	8,530	11,378	303	406	317
15	0.7322	—	26.0035	—	7,339	11,126	294	401	91,295
13	0.7133	0.5508	—	—	6,802	10,226	262	367	3,223
22	0.6925	0.3112	29.9473	—	7,166	10,728	267	385	3,666
28	0.6756	0.3988	8.2571	—	7,015	10,903	267	395	—
30	0.6391	—	4.3256	—	6,105	10,706	245	384	5,645
31	0.5533	0.2604	—	—	5,379	10,108	202	366	36,518
18	0.4606	0.2570	20.3554	—	4,870	10,946	183	397	13,289
23	0.4379	—	35.7709	—	4,391	10,062	155	355	—

¹Slack indicates the amount by which a DEA model constraint is not satisfied with equality and therefore, represents the amount by which an input is overused relative to how efficient producers use the input.

because greater debt capital use generally increases the risk of equity loss. Therefore, it seems reasonable that an efficient if not optimal level of debt capital is preferable.

The additional output variable included in the model is dollars of net income. In contrast to milk and butterfat production, net income efficiency is influenced by effective business management of costs, and perhaps price risk, as well as production efficiency. Here, milk pricing and the effective use of capital including machinery is accounted for when measuring DEA efficiency. The resulting DEA model is the CCR model outlined in Eq. 1, where inputs and outputs are now generally specified as

$$\begin{aligned} y' \text{ (milk, butterfat, net income)} &= \\ x' \text{ (land, labor, cows, debt capital).} & \end{aligned} \quad [3]$$

The results from the DEA model with production and economic inputs and outputs are presented in Table 4. The first thing to notice is that all the efficient DMU from the previous model are included in the efficient set for this model. This is to be expected, because the only change to the model is the addition of 2 extra dimensions. Hence, producers that were efficient in the first model are still on the frontier with respect to the original input and output variables and therefore still efficient. Nevertheless, with the additional input and output variables, the dimensions of the frontier increase 2-fold, and more DMU are identified as being efficient.

The addition of the new variables changes the relative rankings, slack resources, target levels of production, and benchmarks of the inefficient DMU. For example, DMU 29 had an efficiency score of 0.6252 in the production-oriented model and slack labor of 0.4349

FTE. In the economic model, the efficiency of this DMU is now 0.9913 with slightly less slack labor. This large difference highlights the effect of economic information on estimates of DEA efficiency. By changing the nature of the efficient frontier by including economic information, a dairy farm that is very inefficient with respect to production may be much less inefficient from an economic perspective. Superior business management skills are the likely cause of DMU 29 being much closer to the new efficient frontier because this farm makes efficient use of debt capital and generates an efficient level of net income relative to the other DMU.

For DMU 29, the target level of milk production is now 10,044 kg/cow, down from 11,359 kg/cow in the production model. Similar levels of reduction were observed for butterfat production down from 407 to 357 kg/cow. The benchmark group for this producer changed from the previous model. The production-oriented benchmark producers were DMU 25 and 27, whereas in the economic model, the benchmark group now consists of DMU 6, 24, and 25.

As another example, DMU 11 has the same efficiency score in both models, indicating that this dairy farm is no further from or closer to the new frontier. But, as shown in Table 4, DMU 11 has a high amount of slack debt capital and net income. In addition to using about 17% less of all inputs, DMU 11 would have to use about \$100,000 less debt capital and generate about \$24,000 more net income to be DEA-efficient. This result is not surprising given that the reason net income is too low is simply that the farm has too much debt capital and is seeing much of its profitability leave the farm as interest expense. In fact, the slack net income of \$23,822 expressed relative to the farm's debt capital of \$205,506 is 11.6%, which likely approximates DMU 11's cost of debt capital. Decision-making unit 11 is actually a profitable dairy, but much of its profitability is being enjoyed by its creditor.

CONCLUSIONS

Data envelopment analysis is used to examine the production and economic efficiency of a sample of Pennsylvania dairy farms. The technique is nonparametric and capable of handling multiple outputs as well as multiple inputs. The results generally indicate that

overall input inefficiency and in some cases, more specific input and output inefficiencies can be readily identified for dairy farms. Too much labor use and an overinvestment in land in conjunction with too little milk and butterfat production characterize inefficient dairy producers. When considering economic inputs and outputs, the overuse of debt capital is identified as one possible way for dairy farms to be inefficient. The technique provides information regarding the specific way a given inefficient dairy farm can become efficient. Lastly, the approach has merit for assisting in the identification of appropriate benchmarks for inefficient producers to emulate. This information provides a more meaningful goal for a producer to aim for compared with, for example, a state average.

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