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Cost Efficiency and Scope Economies of Crop and Livestock Farms in Missouri

Shunxiang Wu and Tony Prato

This study investigates productive efficiency for a sample of Missouri crop-only (specialized) and integrated crop-livestock (diversified) farms using a cost frontier approach. Results suggest that significant cost inefficiency exists among sample farms. Lower cost efficiency in both types of farms was attributed to improper scale of operations and misallocation of inputs. On average, diversified farms were as technically and scale efficient as specialized farms. Lower allocative efficiency diluted gains in technical efficiency and resulted in greater cost inefficiency for diversified farms than for specialized farms. Technical efficiency was independent of farm size, whereas allocative, scale, and scope efficiencies were not.

Key Words: cost efficiency, crop, livestock, Missouri farms, scope economies

JEL Classifications: Q12, R32

Structural transformation of agriculture has been going on for many years in Missouri. The number of farms has declined continuously and average farm size has increased over time. Many small farms have gone out of business or been consolidated. From 1980 to 2001, the number of farms decreased by 10% to 108,000, and average farm size increased by 6.1% to 277 acres (MASS 2003). The decreasing number of farms and increasing average farm size indicate that large, specialized farms are replacing traditional small, diversified farms because of efficiency advantages.

Many have attributed recent structural changes such as competitive pressure, price decline, and policy changes. Intense competition from other countries, such as Canada and the EU, has resulted in the decline in exports of Missouri agricultural products (MASS 2003). Recent declining trends in the global prices of agricultural commodities, especially food grains, have caused prices to fall well below cost of production in Missouri. Meanwhile, input costs for feed, labor, machinery, and supplies have continued to rise. Average production expenditures in Missouri reached $87,407 per farm in 2001 (MASS 2003). High production costs and lower commodity prices have reduced or eliminated farm profit margins. Net farm income in Missouri declined at an annual rate of 7.2% since 1997, a trend that has forced many farmers to explore alternative management strategies for remaining competitive. Changes in government farm policies also stimulate structural change. The latest two farm bills reduce payments to growers, but allow greater cropping flexibility and encourage farmers to respond to market price incentives.

Movement toward a more dynamic and competitive agricultural environment underscores the need for farmers to improve their productive efficiency to remain competitive

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and profitable. Given the tight farm economic conditions in recent years, it is important to understand the nature of production efficiencies, and identify the causes of inefficiencies. The latter would help farmers to make more informed production decisions. An analysis of efficiency would also provide useful information on how farm characteristics, such as size, land ownership, degree of specialization, and financial variables, influence farm efficiency. Improving efficiency could strengthen the competitive position of Missouri's agricultural industry.

This study evaluates the relative economic competitiveness and cost efficiency of crop-only (specialized) and integrated crop-livestock (diversified) farms in Missouri. A nonparametric technique is applied to cost frontier analysis to determine technical, allocative, and scale efficiencies as well as economies of scope. The relationships among cost efficiency measures, profit, and farm characteristics are examined using regression analysis. The second section of the paper reviews literature relevant to measuring farm efficiency. The third section describes the theoretical framework used to measure cost efficiency and its components, followed by a description of the data used in the regression analysis. The fourth section discusses the empirical results. The last section summarizes the analysis and draws conclusions.

Previous Studies of Farm Cost Efficiency

Beginning with the pioneering work of Farrell, farm efficiency has been measured using production, cost, or profit frontiers. A production frontier shows the maximum output that can be produced with any given input vector or the minimum inputs needed to produce a given level of output. A cost frontier shows the minimum expenditure required to produce any scalar output for given input prices. A profit frontier represents the maximum excess of total revenue over total cost attainable from given scalar output–input prices. Several techniques have been used to estimate these frontiers, which differ in terms of specification (parametric vs. nonparametric), computation (programming vs. econometric), and interpretation of deviations from the frontier (inefficiency vs. mix of inefficiency and statistical noise) (Forsund, Lovell, and Schmidt; Seiford and Thrall; Kumbhakar and Lovell). Advantages of the nonparametric programming technique are that it: (1) does not restrict the functional form of the underlying production technology; (2) explicitly tests for efficiency rather than treating it as a maintained hypothesis; and (3) is computationally simple, requiring only a standard linear algorithm. Several studies have used nonparametric techniques to estimate frontiers (Byrnes, Färe, Grosskopf, and Kraft; Weersink, Turvey, and Godah; Wu, Devadoss, and Lu). These studies measured efficiency in terms of the distance an individual farm is from the optimal or "best practice" farm on a production frontier. Kumbhakar and Lovell criticized the production frontier approach for the difficulty of obtaining the requisite data and its limiting definition of efficiency.

Few studies have evaluated and decomposed efficiency using cost frontier analysis at the farm level. Construction of a cost frontier allows one to test for cost-minimizing behavior (e.g., Featherstone, Moghnieh, and Goodwin). Featherstone, Langemeier, and Ismet used cost frontier analysis to evaluate the cost efficiency of beef production in Kansas. They found a high correlation between profitability and technical efficiency, and that farm inefficiency is related to farm size and degree of specialization. Similarly, Rowland et al. evaluated the competitiveness of swine farms in Kansas in terms of cost efficiency and determined that economic efficiency is positively related to litter size and scale efficiency is negatively related to farm size.

Kalaitzandonakes, Wu, and Ma used a production frontier approach to evaluate the size-efficiency relationship for a sample of 54 Missouri farms over the period of 1987–1992. They found that technical efficiency is positively related to farm size irrespective of the estimation method (i.e., nonparametric, deterministic parametric, and stochastic). Wu, Prato, and Kaylen assessed cost efficiency for Missouri grain farms using a cost frontier approach, and Qiu, Kalaitzandonakes, and Wellman examined changes in productivity for 53 crop farms and 46 dairy farms over the period 1970–1990 separately using a Mamlquist productivity index. The latter study found substantial productivity growth during the evaluation period.

Other efficiency studies for Missouri farms utilized crop or livestock sales as output measures. This procedure can give misleading results because many Missouri farms produce both crops and livestock. Even if a crop or livestock farm exhibits scale economies, an integrated crop-livestock farm may not.

Hallam discussed theoretical frameworks for measuring economies of scope. Nehring, Fernandez-Cornejo, and Banker compared the relative performance of U.S. corn-soybean producers with and without off-farm income in terms of scale and scope economies. Their study showed that economies of scale decrease the competitiveness of small farms when off-farm income is not taken into account. Corn-soybean producers have partially adapted to such pressures by increasing off-farm income, thus achieving economies of scope. Ray found that the marginal cost of producing crops is negatively related to livestock production in the United States, implying jointness in crop and livestock production. Leathers found economies of scope between milk and crop production for large farms, and that small farms are more likely to exhibit diseconomies of scope. In contrast, Chavas and Aliber determined that small Wisconsin farms benefit from integrating crops and livestock. Fernandez-Cornejo et al. identified the presence of dynamic economies of scope between cattle production and crop, hog, and milk production in Germany.

The impact of hypothesized variables on efficiency measures is typically determined using a two-step procedure (e.g., Deller and Nelson) that involves measurement of efficiency scores and ordinary least-squares (OLS) regression analysis of the relationship between efficiency score and explanatory variables. This procedure has been criticized on the grounds that it results in biased estimates of efficiency and regression coefficients (Kumbhaker). However, Kalirajan defended the procedure on the basis that socioeconomic variables have a roundabout effect on production. Using OLS regression in the second step is inappropriate because the dependent variable (efficiency score) is limited to the zero–one interval. This limitation can be overcome by using a logit model (Bravo-Ureta and Lee), multiple regression analysis (Kalirajan and Shand), or a Tobit model (Featherstone, Langemeier, and Ismet; Latruffe, Balcombe, Davidova, and Zawalinska; Wu, Devadoss, and Lu).

Our analysis differs from other studies of Missouri farm efficiency because: (1) it uses accrual incomes from crop and/or livestock sales as an aggregate measure of farm output; and (2) it measures relative farm performance in terms of cost efficiency and its components (i.e., economic and scale efficiencies), as well as economies of scope.

Theoretical Framework, Estimation and Data Requirement

This study uses a nonparametric approach to cost frontier analysis due to data availability and our interest in investigating allocative efficiency and economies of scope for Missouri farms.

Measurement of Cost Efficiency

To understand the theoretical basis for cost frontier approach, consider the cost minimization problem under the assumption of perfect competition:

$$(1)\qquad c^*(y, r)|_{\mathrm{CRS}} = \min_{(x)} \{r'x : x \in L(y),\ x \in R_+^N\},$$

where $|_{\mathrm{CRS}}$ stands for constant returns to scale technology, $c^*(y, r)$ denotes the cost frontier, $r'x = \Sigma_j r_j x_{ij}$ is the expenditure on production inputs for the ith farm, and $L(y)$ is the production possibility frontier, which reflects the underlying technologies for producing the outputs designated by y. $L(y)$ is assumed to satisfy axiomatic properties (Kumbhakar and Lovell). The cost frontier indicates the minimum expenditure required to produce any output for given input prices.

Overall cost efficiency (OE), which is a measure of production efficiency, is the ratio of minimum feasible cost to actual input expenditures as follows:

$$(2)\qquad OE(y, x, r) = \frac{c^*(y, r)|_{\text{CRS}}}{r'x}$$

Since $r'x \geq c^*(y, r)|_{\text{CRS}}$, it follows that $OE \leq 1$. Unity values of OE occur only if $x_{ij} = x^*_{ij}(y, r)$, so that $r'x = \Sigma_j r_j x^*_{ij}(y, r)$ attains its minimum value of $c^*(y, r)$. Here x^* is the cost-minimizing input demand function. Overall cost efficiency is the product of technical efficiency (TE), allocative efficiency (AE), and scale efficiency (SE) (Färe, Grosskopf, and Lovell), as follows:

$$(3)\qquad OE(y, x, r) = TE(y, x) \times AE(y, x, r) \times SE(y, r).$$

$OE = 1$ if, and only if, $TE = AE = SE = 1$, and implies that the farm is technically, allocatively, and scale efficient. $OE < 1$ indicates the presence of technical, allocative, and/or scale inefficiency.

Technical efficiency (TE) refers to the ability of a farm to minimize input use in producing given outputs, or maximize output for given levels of input use (Kumbhakar and Lovell). An input-oriented measure of technical efficiency is

$$(4)\qquad TE(y, x) = \min_{(\lambda)}\{\lambda : \lambda x \in L(y)\},$$

where $0 < \lambda \leq 1$ is a scalar variable measuring TE, which can be estimated using the nonparametric technique discussed below. $TE = 1$ implies the farm is producing on the production possibility frontier for y, and $TE < 1$ implies technical inefficiency $(1 - \text{TE}) \times 100$ is the largest reduction in input use that can be achieved.

Allocative efficiency (AE) measures whether a technically efficient farm uses the optimal mix of inputs, given input prices. AE is determined by dividing the minimum production cost with variable returns to scale by the actual cost adjusted for TE.

$$(5)\qquad AE(y, x, r) = \frac{c^*(y, r)|_{\text{VRS}}}{r'(\lambda x)}$$

where $0 < AE \leq 1$ and $|_{\text{VRS}}$ stands for variable returns to scale. $AE = 1$ implies that the farm is using a combination of inputs indicated by the tangency between the isoquant and the negative of the ratio of the input prices. $AE < 1$ implies allocative inefficiency. $(1 - AE) \times 100$ is the maximum proportion reduction in cost that can be achieved by the technically efficient farm.

Measures for technical and allocative efficiencies are conditional on output y. Whether a particular value of y is optimal for a farm is analyzed using scale efficiency and economies of scope. Multiproduct returns to scale can be specified by the production technology and the cost function (Chavas and Aliber). This study uses the latter characterization. Scale efficiency (SE) reflects whether or not a farm is operating at the most efficient size. It is derived using output losses due to deviation from constant returns to scale technology, as follows:

$$(6)\qquad SE(y, r) = \frac{c^*(y, r)|_{\text{CRS}}}{c^*(y, r)|_{\text{VRS}}}.$$

$SE = 1$ implies constant returns to scale and $SE < 1$ nonconstant returns to scale. Inefficiency of scale occurs when a farm operates in the region of nonconstant returns to scale. A farm exhibits increasing returns to scale if $c^*(y, r)|_{\text{CRS}} = c^*(y, r)|_{\text{NDRS}}$, and decreasing returns to scale if $c^*(y, r)|_{\text{CRS}} \neq c^*(y, r)|_{\text{NDRS}}$, where $c^*(y, r)|_{\text{NDRS}}$ is the minimum cost derived under the nondecreasing returns to scale assumption, denoted by $|_{\text{NDRS}}$.

When a farm produces more than one product, the concept of efficiency for a single output is inadequate. For multiple outputs farms, production efficiency can result from not only increased farm size, but also the cost efficiencies of joint production. The effect of producing multiple outputs on production costs is investigated using the concept of scope economies (SC), which measures the cost saving of producing multiple products jointly rather than separately, namely:

$$(7) \qquad SC(y, x, r) = \frac{\sum_{m=1}^{M} c^*(y_m, r)|_{\text{VRS}}}{c^*(y, r)|_{\text{VRS}}},$$

where $c^*(y_m, r)$ is the minimum cost of producing the mth output. If $SC > 1$, the cost of producing each output separately exceeds the cost of joint production, which implies economies of scope; specialization decreases costs. If $SC < 1$, the cost of producing each output separately is less than the cost of joint production, which implies diseconomies of scope; diversification decreases costs.

Nonparametric Technique and Efficiency Estimation.

Determining cost efficiency requires estimation of cost frontiers under alternative returns to scale assumptions. This study uses nonparametric techniques to estimate the cost frontiers. Farrell proposes a nonparametric technique that builds a convex disposal hull based on input and output data. An efficiency index for one farm is determined by comparing its input–output combinations to those of other farms in the sample.

Consider a sample of K farms where each produces M outputs using N inputs and faces a vector of market input prices r. Suppose the ith farm is of interest, t is the period of time, and y and x matrices of observed outputs and inputs, respectively. Then

$$y^t = [y_1^t \cdots y_i^t \cdots y_k^t] = \begin{bmatrix} y_{11}^t & \cdots & y_{i1}^t & \cdots & y_{k1}^t \\ \vdots & & \vdots & & \vdots \\ y_{1m}^t & \cdots & y_{im}^t & \cdots & y_{km}^t \end{bmatrix},$$

$$x^t = [x_1^t \cdots x_i^t \cdots x_k^t] = \begin{bmatrix} x_{11}^t & \cdots & x_{i1}^t & \cdots & x_{k1}^t \\ \vdots & & \vdots & & \vdots \\ x_{1n}^t & \cdots & x_{in}^t & \cdots & x_{kn}^t \end{bmatrix},$$

and

$$r^t = [r_1^t \cdots r_n^t].$$

A typical nonparametric approach reduces multiple inputs and outputs to a single virtual input and virtual output. It is then possible to maximize the ratio of total weighted outputs to total weighted inputs for a farm subject to the constraint that the ratios for other farms in the sample are less than or equal to one, namely:

$$(8) \qquad \max_{(\nu,\tau)} \frac{\nu y_k}{\tau x_k},$$

$$\text{s.t.} \qquad \frac{\nu y_i}{\tau x_i} - 1 \leq 0, \qquad i = 1, \ldots, K,$$

where ν and τ are vectors of weights (for simplicity, time subscripts are suppressed in subsequent equations). Equation (8) can be solved with nonlinear programming techniques. A transformation of equation (8) developed by Charnes and Cooper allows a linear programming (LP) formulation of the optimization problem, which greatly simplifies computation.

The value of technical efficiency is derived using the following equation, which allows variable returns to scale and assumes strong input and output disposability:

$$(9) \qquad \min_{(z,\lambda)} \lambda_i$$

$$\text{s.t.} \qquad \sum_{k=1}^{K} x_{kj} z_k \leq \lambda_i x_{ij}, \quad \forall j$$

$$\sum_{k=1}^{K} y_k z_k \geq y_i \qquad \sum_{k=1}^{K} z_k = 1 \qquad z_k \geq 0$$

where z is a K-dimensional vector of intensity variables (or weights) to be estimated. Strong input disposability does not permit overutilization of inputs, and strong output disposability does not allow production of undesirable outputs, such as pollution. This LP model minimizes λ, a scale variable, subject to a set of input and output constraints. The first constraint states that the optimal use of the jth input for the ith farm must be at least as great as a weighted sum of the amounts of the jth input used by all of the farms. The second constraint states that applying these same weights to the outputs produced by all farms must yield an output at least as great as the level of output produced by the ith farm. Restricting the sum of the elements in the intensity vector, z, to one enforces variable returns to scale technology (Afrait). Disallowing the elements z to take a negative value eliminates the possibility of "running a production process in reverse."

The minimum feasible cost under the *VRS* assumption, $c^*(y, r)|_{\mathrm{VRT}}$, is obtained by using the following equation, which embodies strong input and output disposability restrictions:

$$(10)\qquad c_i^*(y, r)|_{\mathrm{VRS}} = \min_{(z,x^*)} r'x_i^*$$

$$\text{s.t.} \quad \sum_{k=1}^{K} x_{kj}z_k \le x_{ij}^*, \quad \forall j$$

$$\sum_{k=1}^{K} y_k z_k \ge y_i \qquad \sum_{k=1}^{K} z_k = 1 \qquad z_k \ge 0.$$

This LP model minimizes the expenditure incurred by the ith farm subject to a set of input and output constraints (Coelli, Prasada Rao, and Battese), as interpreted above. The minimum cost under constant returns to scale, $c^*(y, r)|_{\mathrm{CRT}}$, is derived by solving equation (10) without the sum-to-one constraint on the zs. The minimum cost under nondecreasing returns to scale, $c^*(y, r)|_{\mathrm{NDRS}}$, is determined by solving equation (10) with the constraint that the sum of the z values is less than or equal to one

Data Requirements

This study uses data for farms that were enrolled in the Missouri Farm Business Analysis (MFBA) program during the period 1998–2001. All input and output variables in the MFBA dataset are in dollar terms. This is problematic because estimation of the cost frontier estimation requires data on quantities. Following Rowland et al., implicit quantities are calculated using nominal price indices (USDA) and the price deflator for personal consumption expenditures. Another issue that arises in applying nonparametric techniques to frontier analysis is how to aggregate variables. Preckel, Akridge, and Boland suggest that aggregation of inputs or outputs should be avoided if possible. However, Tauter, and Hanchar show that for a large number of inputs in the model, all or most observations will be regarded as efficient. Therefore, a certain degree of aggregation is necessary. Since no theory of aggregation exists, we use the input categories in the MFBA program. According to Fernandez-Cornejo, a dimensionality ratio $K/(N + M)$ larger than five is sufficient to differentiate efficiency differences in a sample of farms, where K, N, and M are the number of observations, inputs, and outputs, respectively. The dimensionality ratio in this study is about seven in a single year.

Total cost consists of livestock, material, land, capital, labor, and a composite category of all "other" costs. Livestock cost is the sum of expenses for livestock, crops, and commercial feeds purchased plus nonfeed expenses. Material cost is computed from the annual expenses, which include fertilizers, chemicals, and seeds. Land cost is the current market value of land, which is assigned by the farmers and adjusted by a rental rate of 5.5%. Capital cost contains expenses on machinery, building, and utilities. Machinery expense is measured in terms of annual variable and fixed costs, and includes hired machinery services, depreciation, operating costs, and insurance. Building expense consists of maintenance costs plus depreciation. Utility expense includes electricity, water, heating fuel, telephone, and lubrication. Labor cost is expenditures for hired and contracted laborers plus the opportunity cost for unpaid operators and family labor. Cost of hired labor includes wages paid plus perquisites, social security and employment insurance paid by the employer. Other cost includes marketing and insurance costs, tax, interest, and miscellaneous charges adjusted by the inventory of supplies. Interest cost excludes opportunity charge on owned assets. Miscellaneous charge is expenses, such as dues and office supplies.

Farm outputs are measured on a value-added basis and represented by gross income, including accrual crop and/or livestock income. Accrual crop income is the sales value of crops (i.e., corn, soybeans, wheat, green sorghum, and forage) adjusted for changes in crop inventory. Accrual livestock income is the sales value of livestock (i.e., beef, hog, sheep, and dairy) adjusted for changes in market livestock inventory and breeding livestock. The presence of yield and output price risks makes the model coefficients stochastic. By not pooling data across years and assuming that weather is reasonably homogenous across regions and that soil and other resources are sufficiently uniform in their interaction with weather, nonparametric techniques are applicable.

Table 1 reports descriptive statistics for input and output variables and farm characteristics. For the sample farms as a whole, total land averages about 1,000 acres, of which 85% is used for agricultural purposes. Total cost averages about $256,000. Gross, accrual crop, and accrual livestock income averages about $242,000, $185,000 (76%), and $57,000 (24%), respectively. One third of the laborers are hired. Current assets average about $922,000 per farm. Sample farms make new annual inflation-adjusted investments in machinery, building, and land of about $35,000. Among 55 sample farms, 19 specialize on grain crop production and 36 jointly produce grain crops and livestock. Production scale is larger for specialized than diversified farms in terms of gross income, land, and total crop production. In addition, specialized farms manage resources more efficiently, as revealed by greater returns to assets. Coefficients of variation (CV) show that specialized farms are more clustered around the means than diversified farms.

Factors Influencing Efficiency

This study uses a Tobit model to evaluate the level of inefficiency of farms in the sample, as follows:

$$(11) \qquad \Gamma_k = \begin{cases} \beta' x_k + e_k & \text{if } \beta' x_k + e_k \geq 0, \\ 0 & \text{otherwise} \end{cases}$$

where Γ represents the inefficiency measures for each farm, which are obtained by subtracting various efficiency measures from one; β is a vector of estimated regression coefficients; x is a vector of explanatory variables; and e is a normally distributed error term. The R^2 between observed and predicted values is used as a goodness-of-fit measure for the model.

Three groups of explanatory variables are generally included in investigations of farm efficiency: (1) farm characteristics and technology; (2) human capital; and (3) farm environmental conditions. Explanatory variables included in the Tobit model are farm size, specialization, hired labor, tenancy position, returns to assets, and new investments in machinery, equipment, and land. Other variables, such as farmers' age and the degree of education, have been traditionally used in the literature to explain variations in efficiency. Unfortunately, data on these variables are not available in the MFBA dataset.

Gross income is used to measure farm size. A negative coefficient on this variable suggests that increasing farm size reduces inefficiency. Accrual income from crop sales as a percentage of gross income is used to measure the degree of specialization on a farm. A ratio of one indicates that a farm produces crops only. A negative coefficient for this variable suggests that specialization reduces inefficiency. Hired labor as a percentage of total labor is used to measure the effects of hired labor. Tenancy position, measured by the percentage of land owned, is used to represent the effect of land ownership on efficiency. A negative coefficient for this variable suggests that planting crops on owned land reduces inefficiency. Returns to assets are used as an indicator of the financial managerial ability of the farmer. A negative coefficient for this variable suggests that high profit farms manage their resources more efficiently than low profit farms. A negative coefficient for new investment indicates a decrease in efficiency as new investment increases.

Results and Discussions

Separate linear programming problems are formulated using GAMS and run for each of the LP models. Various efficiency measures are determined using optimal solutions for each of 220 observations (55 farms × 4 years). We begin by discussing results for the

Table 1. Summary Statistics for a Sample of 55 Missouri Farms, 1998–2001

	Full Sample		Diversified[a]		Specialized[b]	
Number of observations	Unit 220	Mean 144	Mean —	CV[c] 76	Mean —	CV —
Revenue, cost, and profit						
Total expense	$1,000	256.3	226.0	78	313.6	66
Livestock	$1,000	31.0	31.0	47[d]	—	—
Materials	$1,000	53.3	40.8	120	77.0	71
Land	$1,000	40.4	31.0	91	58.4	70
Capital	$1,000	58.6	52.2	87	70.7	69
Labor	$1,000	33.7	23.7	111	52.5	96
General	$1,000	39.3	31.0	115	55.0	82
Gross accrual income	$1,000	241.5	213.7	81	293.8	74
Accrual crop income	$1,000	184.7	127.2	123	293.8	74
Accrual livestock income	$1,000	56.8	56.8	88[d]	—	—
Farm characteristics						
Crop yields	1,000 bushels	50.4	34.5	124	80.6	86
Forage	Tons	—	263.7	448[d]	—	—
Livestock production	1,000 lbs.	—	107.2	159[d]	—	—
Crop acreage	Acres	883.9	834.5	83	986.1	75
% of land owned as total	%	56.3	57.4	57	54.4	55
% of forage acre as crop acre	%	29.5	44.3	78	1.6	400
% of hired labor as total	%	31.4	25.3	94	42.8	74
Current asset	$1,000	922.1	756.0	86	1,236.6	65
Returns to Assets	$1,000	61.8	46.2	182	91.4	124
New investment	$1,000	35.0	33.1	246	38.5	121

[a] Crop-livestock farms.
[b] Crop-only farms.
[c] Coefficient of variation.
[d] SD.

overall cost efficiency analysis and its various components. This is followed by examining the regression results for the relationship among the various efficiency measures, profit, and farm characteristics.

The summary statistics and frequency distributions for the various efficiency measures are given in Table 2. The overall cost efficiency averages 0.59 (or 59%) for the 55 farms as a whole for the period 1998–2001, which lies between the results reported by Wu, Prato, and Kaylen for Missouri's grain farms (58%), Featherstone, Langemeier, and Ismet for Kansas dairy farms (60 percent), and Chavas and Aliber (1993) for Wisconsin's crop and livestock farms (32% to 100% of farms efficient in the short run and 44% to 100% in the long run). This result indicates that sample farms exhibit significant cost inefficiencies. If all farms produced on the cost frontier under constant returns to scale, production cost could be reduced by 41% in each time period while maintaining the same output levels.

Overall cost inefficiency is decomposed into its constituent elements of technical, allocative, and scale efficiency. The mean level of technical efficiency is 0.92, with 65% of the observations exhibiting full efficiency (TE = 1.00). Only 8% of the total observations produce less than the maximum feasible level of outputs. The sample farms operate at between 90% and 100% efficiency in three out of four years. These results indicate that farmers in Missouri are generally producing at a high level of technical efficiency. Accordingly, technical inefficiency is not the major contributor to overall cost inefficiency.

The main source of cost inefficiency for

Table 2. Summary Statistics and Frequency Distribution of Efficiency Measures

				Economic Efficiency			Scale Efficiency			
		Observations	Overall Efficiency[a]	Technical Efficiency	Allocative Efficiency	Overall Scale Efficiency	Increasing Returns to Scale	Constant Returns to Scale	Decreasing Returns to Scale	Scope Efficiency
Summary statistics										
Maximum		—	1.00	1.00	1.00	1.00	5.33	1.00	0.99	1.80
Mean		220	0.59	0.92	0.70	0.85	1.87	1.00	0.84	—
Diversified[b]		144	0.57	0.93	0.67	0.85	1.87	1.00	0.84	1.14
Specialized[b]		76	0.63	0.91	0.75	0.85	1.40	1.00	0.83	—
Minimum		—	0.13	0.29	0.19	0.25	1.01	—	0.02	1.00
SD		—	0.19	0.14	0.19	0.15	2.05	—	0.17	0.16
				Frequency Distribution						
Efficiency Interval										
<0.50	80	3	38	9	—	—	—	—		
0.50–0.59	48	8	35	11	—	—	—	—		
0.60–0.69	31	11	49	8	—	—	—	—		
0.70–0.79	30	14	27	36	—	—	—	—		
0.80–0.89	16	21	25	55	—	—	—	—		
0.90–0.99	9	21	20	95	—	—	—	—		
<1	214	78	194	214	—	—	125	—		
=1	6	142	26	6	—	6	—	14		
>1	—	—	—	—	88	—	—	130		
Total	220	220	220	220	88	6	125	144		

Note: Values followed by the same letter are not significantly different ($p = 0.05$) according to the least significant difference (LSD) test.

[a] Product of technical and allocative efficiency.

[b] Diversified designates integrated crop-livestock farms and specialized designates crop-only farms.

sample farms is the misallocation of inputs and improper scale of operation. Allocative efficiency reflects the ability of farms to use inputs in optimal proportions, given input prices. Only 12% of the total observations exhibit full allocative efficiency; the remaining farms have less than full allocative efficiency. Allocative efficiency varies among sample farms, with a mean level of allocative efficiency of 0.70. On average, production cost could be reduced by 30% without affecting the levels of output. Therefore, significant cost saving can be achieved by increasing allocative efficiency.

Overall scale efficiency estimates range from 0.25 to 1.00, with a mean of 0.85. On average, production cost could be reduced by 15% without affecting the levels of output. Of the 220 observations, 88 (40%) exhibit increasing returns to scale, 125 (57%) operate in the region of decreasing returns to scale, and the remaining six observations display constant returns to scale. Accordingly, a majority of sample farms exhibit some degree of scale inefficiency. Average gross accrual income for farms that exhibit increasing, constant, and decreasing returns to scale is about $110,000, $186,000 and $336,000 per farm (full sample), respectively; about $111,000, $157,000, and $391,000 per specialized farm, respectively, and about $109,000, $244,000, and $299,000 per diversified farm, respectively. Small farms clearly tend to operate in the region of increasing returns to sale, while large farms are more likely to operate in the region of decreasing returns to scale.

Results for economies of scope (last column of Table 2) range between 1.00 and 1.80 with a mean of 1.14. Since a score for economies of scope greater than one implies that the cost of joint production is less than the cost of separate production, sample farms exhibit scope economies. In other words, significant cost savings are possible through joint production of crops and livestock. Specifically, the cost of joint crop and livestock production is on average 14% less than the cost of specialized crop or livestock production on farms of similar size.

The mean test results in Table 2 indicate that, on average, diversified farm production is as technically and scale efficient as specialized farm production. This occurs because most livestock production in Missouri is a secondary enterprise that utilizes forage produced on the same farms. For instance, over 44% of cropland on diversified farms is used for forage production, compared to only 2% for specialized farms (Table 1). However, diversified farms show significantly lower allocative efficiency and, in turn, lower overall cost efficiency than specialized farms. A possible explanation of the greater allocative inefficiency for diversified farms is that such farms are not large enough to produce secondary products and may encounter greater difficulties in marketing (e.g., storing, processing, and transporting) their products. Lower allocative efficiency explains in part why the number of small, diversified farms in Missouri has declined in recent years. Allocative inefficiency dilutes gains from technical and scale efficiency for diversified farms causing them to have relatively lower cost efficiency than specialized farms.

A comparison of farms in terms of farm income is given in Table 3. Larger farms tend to be more allocatively efficient and thus, more cost efficient than smaller farms. This result reflects that larger farms manage their resources more efficiently and have more resources for new investment than the smaller farms. On the other hand, smaller farms appear to be as technically and scale efficient as larger farms. In fact, farms with gross income between $100,000 and $250,000 have the lowest technical efficiency. This might explain in part why the number of farms in this size class has declined rapidly in recent years. Economies of scope appear to exist over the entire range of farm sizes. There seems to be a slight negative relationship between scope economies and farm size, especially for farms earning over $500,000. This indicates that the financial incentive for diversification declines as the farm size increases. Average gross income is about $294,000 for specialized farms, and $214,000 for diversified farms (Table 1). Larger farms are more likely to become specialized enterprises than smaller farms because the

Table 3. Farm Income by Farm Size Class for the Full Sample

	Gross Income Per Farm ($1,000)				
Variable	<100	100–250	250–500	>500	Total
Overall efficiency	0.51	0.61	0.60	0.72	0.59
Economic efficiency	0.63	0.65	0.70	0.89	0.66
Technical efficiency	0.93	0.89	0.93	0.99	0.92
Allocative efficiency	0.64	0.65	0.73	0.90	0.70
Scale efficiency	0.78	0.94	0.82	0.80	0.85
Scope efficiency	1.16	1.15	1.14	1.04	1.14
Current assets ($1,000)	262.30	723.08	1,398.07	2,241.87	921.98
Gross income ($1,000)	49.79	168.93	371.60	739.86	241.55
Return to assets ($1,000)	9.75	29.87	89.50	297.70	61.81
New investment ($1,000)	3.31	29.40	50.69	109.30	34.98
Number of farms	14	19	18	4	55

benefit from diversification diminishes and allocative inefficiency increases with farm size.

Table 4 reports the standard deviations of the efficiency measures for each year and across years. The across-year standard deviation is obtained by averaging each farm's efficiency measure over time and then taking the standard deviation of the average efficiencies. For each efficiency measure, the standard deviation is generally smaller across years than for individual years. Hence, there is less variability in farm efficiency over time than among farms in a given year. Allocative efficiency is for the most part more variable than other efficiency measures. Technical, scale, and scope efficiencies are unlikely to exhibit rapid change in the short run after production technology is adopted, farm size is determined, and products are selected. As indicated by the results in last two columns of Table 4, specialized farms have slightly higher variability in allocative efficiency than diversified farms. However, specialized farms have slightly lower variability in scale efficiency than diversified farms. Overall cost efficiency tends to be less variable for specialized farms than diversified farms.

Results of the OLS regression analysis of the relationship between net farm income and alternative efficiency measures are given in Table 5. A positive and statistically significant relationship exists between net farm income and overall cost efficiency. An increase of 1% in overall cost efficiency increases net income by $2,339 (233.9 × $1,000 × 0.01) per farm. Diversified farms have an even greater increase in net farm income than specialized farms as indicated by the farm-type dummy variable in all three models. Net farm income has a moderately high correlation (0.57) with overall cost efficiency. Model 2 indicates positive and statistically significant relationships

Table 4. Standard Deviations of Efficiency Measures

		Year				Farm[a]		
Efficiency Measure	Observations	1998	1999	2000	2001	Full Sample	Livestock-Crop	Crop Only
Overall	220	0.18	0.14	0.16	0.17	0.11	0.12	0.09
Economic	220	0.22	0.24	0.22	0.22	0.15	0.13	0.17
Technical	220	0.12	0.18	0.12	0.12	0.09	0.09	0.10
Allocative	220	0.19	0.20	0.19	0.18	0.13	0.10	0.14
Scale	220	0.16	0.17	0.12	0.07	0.10	0.11	0.09
Scope	144	0.16	0.13	0.16	0.16	0.11	0.11	—

[a] Mean of per farm standard deviations.

Table 5. Results for Regression of Net Farm Income ($1,000/Farm) on Efficiency Measures

Explanatory Variable	Model 1	Model 2	Model 3
Intercept	−167.37* (16.06)	−216.47* (28.52)	−283.92* (37.01)
Overall efficiency	233.91* (22.85)	—	—
Economic efficiency	—	209.64* (17.71)	—
Technical efficiency	—	—	34.92 (35.31)
Allocative efficiency	—	—	243.27* (26.01)
Scope efficiency	—	56.63** (8.43)	57.79** (25.74)
Farm-type dummy (diversified = 1)	23.11* (8.89)	23.42* (8.43)	27.61* (8.63)
n	220	220	220
R^2	0.33	0.40	0.41
r	0.57	—	—

Note: Numbers in parentheses are SEs.
* Significant at the 1% level.
** Significant at the 5% level.

between net income and economic efficiency and net income and economies of scope. However, results from Model 3 indicate that the relationship between net farm income and technical efficiency is not statistically significant. The relative values of the coefficients suggest that allocative efficiency is an especially strong determinant of net farm income. A 1% increase in allocative efficiency raises net income by $2,433 per farm. Accordingly, farm operators should attempt to achieve an efficient use of inputs in order to enhance net income.

Table 6 contains the maximum likelihood estimate of the Tobit model obtained using SHAZAM. Farm size has a statistically significant effect on allocative, scale, and scope inefficiencies. Coefficient signs indicate that an increase in farm size reduces allocative inefficiency but increases scale inefficiency. The effect of farm size on technical inefficiency is statistically insignificant, which is consistent with the results of the nonparametric programming analysis. Hired labor has a significant and positive effect on overall cost, technical and allocative inefficiencies, and a significant negative effect on scale and scope inefficiencies. Land ownership has an insignificant effect on overall, scale, and scope inefficiencies, but significant negative effects on technical and allocative inefficiencies. These results suggest that planting crops on owned land increases economic efficiency, but not necessarily overall cost efficiency. The predominately negative and significant coefficients of returns to assets indicate that better farm financial management reduces economic inefficiency and cost inefficiency. The effects of specialization on the inefficiency measures are insignificant except for the statistically significant positive effect of specialization on scope inefficiency. New investment does not have statistically significant effects on any of the components of inefficiency. Coefficients of the farm-type dummy variable indicate that diversification increases economic inefficiency and allocative inefficiency, but does not have a significant effect on technical and scale inefficiencies.

Conclusions

This study examines the cost efficiency of crops only (specialized) and crop-livestock (diversified) farms in Missouri using a cost frontier approach. Cost efficiency is decomposed into technical, allocative, and scale components, which provides information on the sources of farm inefficiency. Economies of scope for farms are also investigated. Effects of farm income and farm characteristics on various efficiency measures are investigated

Table 6. Results for Tobit Analysis of Effects of Farm Characteristics on Inefficiency Measures

Explanatory Variable	Inefficiency Measure				
		Economic			
	Overall	Technical	Allocative	Scale	Scope
Intercept	2.21***	−0.45	1.75***	0.52*	−1.62***
	(0.38)	(0.45)	(0.37)	(0.36)	(0.36)
Farm size	−0.0004	−0.0006	−0.0019***	0.0015**	0.0019**
	(0.0007)	(0.0009)	(0.0007)	(0.0007)	(0.0010)
Hired labor	0.76**	0.73**	0.96***	−0.21*	−1.01**
	(0.34)	(0.41)	(0.34)	(0.34)	(0.48)
Land ownership	−0.14	−0.69*	−0.70**	0.57	−0.22
	(0.34)	(0.44)	(0.35)	(0.34)	(0.36)
Return to assets	−0.0031***	−0.0040***	−0.0027**	−0.0010	−0.0004***
	(0.0012)	(0.0016)	(0.0012)	(0.0012)	(0.0016)
Specialization	−0.03	0.43	−0.09	0.07	1.20***
	(0.33)	(0.41)	(0.34)	(0.33)	(0.37)
New investment	−0.0006	0.00007	−0.0014	0.0002	−0.0013
	(0.0010)	(0.0014)	(0.0012)	(0.0010)	(0.0015)
Farm-type dummy					
(Diversified = 1,	0.36**	0.22	0.60***	−0.09	—
specialized = 0[a])	(0.17)	(0.20)	(0.17)	(0.17)	—
n	220	220	220	220	144
R^2	0.13	0.15	0.24	0.05	0.29

Note: Single (*), double (**), and triple asterisks (***) denote significance at the 10%, 5%, and 1% level, respectively. Numbers in parentheses are standard errors.

[a] Diversified designates integrated crop-livestock farms and specialized designates crop-only farms.

using regression analysis. A Tobit analysis is used to explain farm inefficiencies.

Results indicate significant cost inefficiencies exist for a sample of Missouri farms. These farms are generally producing at a high level of technical efficiency, only 8% short of potential output. Lower cost efficiency is attributed primarily to misallocation of inputs and improper scale of operations. Technical efficiency is independent of farm size; allocative, scale, and scope efficiencies are not. Small farms are more likely to operate under increasing returns to scale, and large farms under decreasing returns to scale. The Tobit analysis reveals that an increase in farm size and family labor, planting crops on owned land, and better financial management enhance allocative efficiency. Improvement in allocative efficiency in particular enhances farm income. A simple OLS regression analysis shows that an increase of 1% in allocative efficiency results in a $2,433 increase in annual net farm income.

Diversified farms could be as technically and scale efficient as specialized farms. Allocative inefficiency reduces gains in technical efficiency, and results in greater cost inefficiency for diversified farms than specialized farms. Net farm income has a moderately high correlation with improvement of overall cost efficiency, especially for diversified farms. Farm characteristics, such as being a relatively small farm and having better financial management, enhance scope economies for integrated crop and livestock farms. Policies that improve the financial management of small farms and/or increase nonagricultural employment are likely to increase allocative efficiency and economies of scope.

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References

Afrait, S. "Efficiency Estimation of Production Functions." *International Economic Review.* 13(1972):568–98.

Bravo-Ureta, B.E., and T. Lee. "Socioeconomic and Technical Characteristics of New England Dairy Cooperative Members and Nonmembers." *Journal of Agricultural Cooperation* 3(1988):12–17.

Byrnes, P., R. Färe, S. Grosskopf, and S. Kraft. "Technical Efficiency and Size: The Case of Illinois Grain Farms." *European Review of Agricultural Economics* 14(1987):367–81.

Charnes, A., and W. Cooper. "Programming with Linear Fractional Functionals." *Naval Resource and Logistics Quarterly* 9(1962):181–85.

Chavas, J.V., and M. Aliber. "An Analysis of Economic Efficiency in Agriculture: A Nonparametric Approach." *Journal of Agricultural and Resource Economics* 18(1993):1–16.

Coelli, T., D.S. Prasada Rao, and G.E. Battese. *An Introduction to Efficiency and Productivity Analysis.* Boston: Kluwer Academic, 1998.

Deller, S.C., and C.H. Nelson. "Measuring the Economic Efficiency of Producing Rural Road Services." *American Journal of Agricultural Economics* 73(1991):194–201.

Färe, R., S. Grosskopf, and C.A.K. Lovell. *The Measurement of Productivity Efficiency.* Boston: Kluwer Nijhoff, 1985.

Farrell, M.J. "The Measurement of Productive Efficiency." *Journal of Royal Statistic Society* 120(1957):253–81.

Featherstone, A.M., M.R. Langemeier, and M. Ismet. "A Nonparametric Analysis of Efficiency for a Sample of Kansas Beef Cow Farms." *Journal of Agricultural and Applied Economics* 29(1997):175–84.

Featherstone, A.M., G.A. Moghnieh, and B.K. Goodwin. "Farm-Level Nonparametric Analysis of Cost-Minimization and Profit-Maximization Behavior." *Agricultural Economics* 13(1995):109–17.

Fernandez-Cornejo, J., C.M. Gempesaw, J.G. Elterich, and S.E. Stefanou. "Dynamic Measures of Scope and Scale Economies: An Application to German Agriculture." *American Journal of Agricultural Economics* 74(1992):329–42.

Fernandez-Cornejo, J. "Nonradial Technical Efficiency and Chemical Input Use in Agriculture." *Agricultural and Resource Economic Review.* 23(1994):11–21.

Forsund, F.R., C.A.K. Lovell, and P. Schmidt. "A Survey of Frontier Production Functions and their Relationship to Efficiency Measurement." *Journal of Econometrics* 12(1980):5–25.

Hallam, A. "Economies of Size, Theory, Measurement and Related Issues." In *Size, Structure, and the Changing Face of American Agriculture,* A. Hallam, ed. Boulder, CO: Westview Press, 1993.

Kalaitzandonakes, N.G., S. Wu, and J. Ma. "The Relationship Between Technical Efficiency and Firm Size Revisited." *Canadian Journal of Agricultural Economics* 40(1992):427–42.

Kalirajan, K. "The Importance of Efficient Use in the Adoption of Technology: A Micro Panel Data Analysis." *Journal of Productivity Analysis* 2(1991):113–26.

Kalirajan, K.P., and R.T. Shand. "Types of Education and Agricultural Productivity: A Quantitative Analysis of Tamil Nadu Rice Farming." *Journal of Development Study* 10(1985):232–43.

Kumbhakar, S., and C.A.K. Lovell. 2003. *Stochastic Frontier Analysis.* NY: Cambridge University Press.

Kumbhakar, S., S. Ghosh, and J. McGuckin. "A Generalized Production Frontier Approach for Estimating Determinants of Inefficiency in U.S. Dairy Industry." *Journal of Business and Economic Statistics* 9(1991):279–86.

Missouri Agricultural Statistical Service (MASS). 2003. *Farm Facts.* Internet Site: http://agebb.missouri.edu/mass/ (Accessed April 17, 2006).

Latruffe, L., K. Balcombe, S. Davidova, and K. Zawalinska. 2002. "Determinants of Technical Efficiency of Crop and Livestock Farms in Poland." Internet site: http://www.rennes.inra.fr/economie/index.htm (Accessed April 17, 2006).

Leathers, H.D. "Allocatible Fixed Inputs as A Cause of Joint Production: An Empirical Investigation." *Journal of Agricultural Economics* 35(1992):109–24.

Nehring, R., J. Fernandez-Cornejo, and D. Banker. "Off-Farm Labor and the Structure of US Agriculture: The Case of Corn/Soybean Farms." Paper presented at the annual meeting of the American Agricultural Economics Association, Long Beach, CA. July 28–31, 2002.

Preckel, P.V., J.T. Akridge, and M.A. Boland, "Efficiency Measures for Retail Fertilizer Dealers." *Agribusiness* 13(1997):497–509.

Ray, S.C. "A Translog Cost Functions Analysis of the U.S Agriculture, 1939–1999." *American Journal of Agricultural Economics* 64(1985): 660–65.

Rowland, W., M.R. Langemeier, B.W. Schurle, and

A.M. Featherstone. "A Nonparametric Analysis of Efficiency for a Sample of Kansas Swine Operations." *Journal of Agricultural and Applied Economics* 30(1998):189–99.

Qiu, Z., N.G. Kalaitzandonakes, and D. Wellman. "Firm-Level Productivity Growth Decomposition: A Non-Parametric Malmquist Approach." Paper presented at the annual meeting of American Agricultural Economic Association, San Antonio, TX, August 8–10, 1996.

Seiford, L., and R. Thrall. "Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis." *Journal of Econometrics* 46(1990):7–38.

Tauer, L.W. and J.J. Hanchar. "Nonparametric Technical Efficiency with K Firms, N Inputs, and M Outputs: A Simulation." *Agricultural and Resource Economic Review.* 16(1995):185–89.

U.S. Department of Agriculture. July 2002. *Agricultural Prices: 2001 Summary.* Internet site: http://usda.mannlib.cornell.edu/reports/nassr/price/zap-bb/agpran02.pdf (Accessed April 17, 2006).

Weersink, A., C.G. Turvey, and A. Godah. "Decomposition Measures of Technical Efficiency for Ontario Dairy Farms." *Canadian Journal of Agricultural Economics* 38(1990):439–56.

Wu, S., S. Devadoss, and Y. Lu. "Estimation of Technical Efficiency and its Decomposition for Sugarbeet Farms." *Applied Economics* 35(2003): 471–84.

Wu, S., T. Prato, and M. Kaylen. "Cost Efficiency and its Decomposition for Missouri Grain Farms." *The Journal of Economics* 31 (2005): 19–44.