Grass-Fed Beef Enterprise Efficiency Analysis in the U.S.

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Abstract

We determine technical and scale efficiencies, scope economies, marginal productive contributions for inputs and outputs, and efficiency drivers for U.S. grass-fed beef enterprises. Average technical efficiency was 0.82. Increasing returns to scale and scope economies were found. Results suggest grass-fed beef enterprises can be scale efficient at >100 grass-fed beef animals.

Introduction

The grass-fed beef (GFB) industry has expanded rapidly in the U.S. in recent years. This significant U.S. GFB production growth has been positively impacted by greater consumer demand on the basis of human health, environmental, animal welfare, and sustainability perspectives (Mills, 2003; McCluskey et al., 2005). Cost of production and economies of scale are fundamentally important to the overall profitability of the GFB sector. To become more efficient and profitable, existing and potential GFB farmers need to know how their operations can be structured. The present study evaluates the economics of GFB production and the variables that influence the production efficiency of U.S. GFB operations.

As a newly expanded segment of the U.S. beef industry, there is sparse available information about U.S. GFB production, specifically the factors that can impact GFB farm efficiency. Few GFB studies have addressed productivity issues, most of the productivity and efficiency research dealing with the beef industry has focused on conventional or grain-fed beef production. Featherstone et al. (1997) and Rakipova et al. (2003) estimated the technical, allocative and/or scale efficiencies of cow-calf farms using a nonparametric approach known as data envelopment analysis, and used Tobit models to evaluate the impacts of factors influencing technical efficiency (TE). TE was significantly impacted by farm size, with herd sizes of farms up to 48 beef cows exhibiting substantial economies of scale (Featherstone et al., 1997). Recent studies have estimated stochastic production frontiers (SPF) using the Cobb-Douglas functional form to measure the relative efficiencies of cow-calf farms in Europe and Canada (Iraizoz et al., 2005; Samarajeewa et al., 2012).

The objectives of this study are to determine the factors influencing GFB production technical efficiency (TE), the marginal productive contributions of inputs and outputs on U.S. GFB enterprises, and scale and scope economies for GFB production in the U.S. An input distance function (IDF) using SPF techniques is estimated for U.S. GFB production. Production costs for different sizes of operations for U.S. GFB production are estimated and results are complimentary with those of the IDF analysis. To show the consistency of small-sample properties for the IDF analysis, we use empirical Monte Carlo (MC) simulation techniques.

Conceptual Model and Methods

To estimate efficiency, an IDF analysis similar to that used by Paul et al. (2004) is used to reveal the nature of the production technology underlying U.S. GFB production. With the IDF, the set of inputs $L(Q)$ can produce a given output vector (Q) with minimum input set X: $D^I(X,Q) = \max\left\{\lambda\colon \frac{X}{\lambda} \in L(Q)\right\}$, where $X \in \mathcal{R}_+^M$ and $Q \in \mathcal{R}_+^K$ (Coelli *et al*., 2005).

Dividing all inputs and the distance term ($D_i^I(X,Q)$) by an input, *land*, defined as $X_1 = X_{LAND}$ is the same as imposing the homogeneity restrictions and symmetry restrictions of the parameters (by Young's theorem). The IDF is specified on a per-acre basis as:

(1) $$-\ ln\, X_{1,i} = TL(X^*,Q) + \nu_i - lnD_i^I(X,Q) = TL(X^*,Q) + \nu_i - u_i.$$

The expectation of the term $-u_i$ conditional on the composed error term $\varepsilon_i = \nu_i - u_i$ is the TE of the farm, and is measured as $TE = exp^{-u_i}$. The random error ν_i is independent of u_i and independently and identically distributed as $N(0, \sigma_v^2)$. $u_i \geq 0$ is a one-sided error term independently distributed with truncation at zero of the $N(\mu_i, \sigma_u^2)$ distribution, where $\mu_i = \sum_g F_g \zeta$, F_g is a vector of farm efficiency determinants, and ζ are parameters to be estimated.

The output variables are defined (Table 1) as: *GFBanimal* is value of GFB animal production including hay sold from pasture devoted to GFB production and *GFBmeat* is value of GFB meat production. Inputs are: *Land* is quality-adjusted land price[1], *Lab* is hired labor expenses[2], *Var* is total variable expenses[3], and *Fix* is total fixed expenses[4]. This study specifically analyzes the GFB enterprise rather than the whole-farm. We did not request enterprise-specific expenses for the following inputs in the survey questionnaire: *Repairs on Equipment; Insurance; Taxes; Vehicle/Licensing Fees; Depreciation; Custom Work; Cash Value of Feed, Farm Commodities, Fuel, Housing, Meals, Other Food, Utilities, Vehicle for Personal Use; and Farm Management Services*. In order to obtain enterprise-specific expenses for these input variables, first, the percentage or portion of the GFB enterprise total return was calculated as the total GFB enterprise return (GFBER) divided by the total whole farm return (WFR) to

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[1] This study used state-level quality-adjusted land values for the U.S. estimated in Ball et al. (2008) adjusted to 2012 values to account for land heterogeneity.

[2] Hired labor expenses include cash wages paid to hired farm and ranch labor plus payroll taxes and benefits. It also includes cash wages, incentives and bonuses, and payment to other operators and paid family members if they received a wage.

[3] Total variable expenses include feed expenses, marketing charges, seed and plant expenses, fertilizer and chemical expenses, purchased livestock expenses, bedding and litter expenses, medical supplies including veterinary and custom services, fuel and oil expenses, electricity expenses, all other utility expenses, farm supplies and marketing containers including hand tools, maintenance and repair including parts and accessories expenses, machine hire and custom work expenses, other livestock related expenses, and other variable expenses.

[4] Total fixed expenses include depreciation, insurance, interest and fees paid on debts, property taxes, and rental and lease payment expenses.

result in GFBER/WFR. For the GFB enterprise-specific expenses for these inputs, the whole-farm expense values were multiplied by GFBER/WFR.

The U.S. GFB enterprise efficiency variables (Table 1) include *Edu*, an education dummy variable for the farm operator indicating the respondent held a bachelor's degree or higher. *Male* is a dummy variable for GFB operator being a male; a female operator is the base category. Eighty percent of the producers are male in our sample. *Exp* is the farm operator farming experience variable, indicating the number of years the producer had raised GFB.

Table 1. Summary Statistics and Variable Definitions for U.S. GFB Enterprise Producers

Variable	Definition	Mean	SD
GFBah	GFB animal production including hay sold from pasture devoted to GFB production, $	12,840.28	23,356.26
GFBm	GFB meat production, $	44,596.99	103,514.90
Land	Quality-adjusted total enterprise land value, service flow, $	58,100.46	155,565.10
Lab	Total enterprise labor, $	11,446.90	15,115.96
Var	Total other variable expenses, $	35,681.92	46,239.56
Fix	Total fixed expenses, $	17,021.86	28,936.31
Edu	Dummy variable for producer holding 4-year college and higher degree	0.69	0.46
Gen	1 male; 0 female	0.80	0.40
Exp	Years producing GFB	11.30	7.95
Sfarm	Dummy variable for total number of GFB animals ≤ 30	0.35	0.48
Mfarm	Dummy variable for total number of GFB animals >30, ≤ 90	0.35	0.48
Lfarm	Dummy variable for total number of GFB animals >90	0.29	0.46
%Gfbinc	% of annual net farm income from the GFB enterprise: 1: ≤19%; 2: 20–39%; 3: 40–59%; 4: 60–79%; 5: 80–100%	2.90	1.75
Offfarm	% of annual net household income from off-farm sources: 1: ≤19%; 2: 20–39%; 3: 40–59%; 4: 60–79%; 5: 80–100%	3.39	1.65
Seast	1 if in states AR, FL,GA, KY, LA, MD, MS, MO, SC, VA, WV; 0 otherwise	0.22	0.42
Neast	1 if in states CT, MA, NH, NY, PA; 0 otherwise	0.22	0.42
Mwest	1 if in states MI, MN, IL, IN, OH, WI; 0 otherwise	0.23	0.43
West	1 if in states AZ, CA, CO, ID, MT, NE, OR, SD, TX, UT, WA, WY; 0 otherwise	0.33	0.47
Cowcalf	Dummy variable for cow-calf production system: 0 - 1	0.78	0.42
Stockdty	Proportion of the total number of beef animals in rotational and continuous grazing systems to the total acres devoted to the GFB cattle operation	0.55	0.52

Mfarm and *Lfarm* are dummy variables for operation sizes with 30 to 90 and >90 GFB animals, respectively (a small operation with <30 GFB animals is the base). *%Gfbinc* is the percentage of annual net farm income from the GFB enterprise, categorized into five levels in 20% intervals, a measure of farm specialization. *Offfarm* is the percentage of annual net household income coming from off-farm sources, included using five levels in 20% intervals.

Neast, *Mwest*, and *West* are regional dummy variables for the Northeastern, Midwestern and Western U.S. GFB production regions, respectively. (*Seast* is the southeastern GFB production region, considered as the base level.) The U.S. regions differ in forage mixes, land, and weather conditions, so region may impact GFB production efficiency. *Cowcalf* is included as a dummy variable to represent whether or not the farms included the cow-calf segment. *Stockdty* is the total number of grazing beef animals divided by the total acres devoted to the GFB enterprise, providing a measure of GFB animal stocking density.

Having zero values in survey data is common. Zero value observations may lead to biased estimation of the function parameters and are problematic for the regression analysis (Battese, 1997). The *Gfbah* output and the *Labor* input variables may have zero values in our sample. Therefore, we used Battese (1997)'s approach to deal with zero-value observations for the explanatory variables in the IDF analyses. The reader is referred to this paper for greater detail on this procedure.

A single-step ML method estimation procedure is recommended to estimate stochastic frontier models and TE measures (Schmidt, 2011). Therefore, the single-step ML method was used to estimate jointly the parameters of the IDF and the TI model using SPF techniques.

Data

A nationwide mail survey of U.S. GFB producers was conducted during October, 2013 to collect farm cost and returns data for 2012. The cost and returns survey was a follow-up to an earlier mail survey administered in August – September, 2013, which addressed U.S. GFB production technology, marketing practices, farm operation, management practices, selection of animals for grass finishing, pasture and grazing management for the GFB operation, reasons for selecting the GFB enterprise, farmer goal structure, marketing, perceptions of challenges facing the GFB industry, preferences for breeding stock, general financial information, and producer demographics. Dillman et al.’s (2009) Tailored Design Method was followed in preparing the survey.

The last question of the first survey asked GFB producers whether they would be willing to complete a follow-up survey on costs and returns associated with GFB production for 2012. A total of 257 GFB producers agreed to fill out the follow-up survey questionnaire. The survey questionnaire was designed in a similar manner to USDA’s Agriculture Resource Management Survey questions on costs and returns. Detailed information on income and expenses was collected using this survey. Since the respondents had already received up to four mailings on the first survey, we sent only two mailings of the follow-up questionnaire two weeks apart, both with personally-addressed, signed letters and business reply envelopes. For the follow-up survey questionnaire, we received a total of 85 completed responses from producers in 34 states (see table 1, which lists the states by region). After adjusting for undeliverable surveys, producers who did not produce GFB, and incomplete surveys, the effective return rate was 33%.

Missing information is a common issue for survey data and may result in biased estimates and reduce regression estimate efficiency (Rubin, 1987). Therefore, the multiple imputation method (Rubin, 1987; Schafer, 1997), specifically the truncated regression imputation method, was used to estimate missing values of continuous variables in this study.

Monte Carlo Simulation in SPF Models

Given that the sample size in this study is not large, we use a MC simulation model to investigate small-sample properties of the data. We conduct hypothetical and empirical MC simulations to examine consistency. These MC simulations allow us to investigate whether as the sample size increases, the sampling distributions of the estimators become increasingly concentrated at their true parameter values. The main idea behind the MC simulation experiment is to model the data generation process (DGP). Valid statistical inferences of finite-sample distributions are achievable using the MC simulation method with the repeated sample. The hypothetical and empirical MC simulation results are not presented in this paper, but all MC simulation results are available upon request from the corresponding author. The simulation results show that the means of the parameter estimates approach very closely the true values of the DGP and the standard deviations of the parameter estimates become close to the means of the standard errors with increasing numbers of simulations.

Results

This study includes data from both a first survey questionnaire including farm and farmer characteristics and a follow-up survey questionnaire for costs and returns. Therefore, our costs and returns data are from a subsample of respondents to the first survey. For that reason, there was concern as to whether there were differences between the first survey and the follow-up survey sample means. T-tests were conducted to determine whether the means of several key variables (various measures of farm size and farmer experience) in the first survey and the follow-up survey were significantly different in means. Results of the *t*-tests suggest failure to reject the null hypothesis, concluding that there is not sufficient evidence to suggest the first survey and the follow-up survey sample means differ at $p \leq 0.10$ levels. Significant differences were not found between these variables, meaning that they came from similar GFB farms.

The likelihood ratio test was used to test the restrictions on the parameters of the translog model. We tested whether the explanatory variables in the inefficiency model significantly explained the technical inefficiency (TI) effects. Test results show that the TI effects are statistically explained by the variables in the inefficiency models (Table 2). We also tested whether the translog functional form described better the underlying production technology of US GFB farms relative to the alternative Cobb-Douglas production functional form. Results show that the translog model is the more appropriate functional form for the model (Table 2).

Table 2. The Likelihood Ratio Test Results for the U.S. GFB Enterprise Model

H_0 Restrictions	Ln[L(H_0)]	Ln[L(H_A)]	LR	Critical χ^2	Number of Restrictions
No inefficiency ($\tau_0 = \tau_1 = \tau_2 = \cdots = \tau_{12}$)	-47.42	-31.45	28.79	22.362	13
Cobb-Douglas production function ($\alpha_5 = \alpha_6 = \cdots = \alpha_{10} = \beta_3 = \cdots = \beta_5 = \theta_1 = \theta_2 = \cdots = \theta_6$)	-56.65	-31.45	50.40	24.996	15

Notes: The test results at 5% level of significance.

Comparing Grass-fed Beef Cost of Production by Operation Size

We compared costs for three different size categories of U.S. GFB farms. The sample of 82 U.S. farms was divided into three size categories based on GFB production land and number of GFB animals. A comparison of U.S. GFB enterprise expenses per acre of GFB production land by operation size (small, medium, and large) is shown in Table 3. The GFB enterprise labor expenses per acre for medium-sized and large farms were lower than for small farms. The GFB enterprise labor expenses per acre for medium-sized farms were lower than for small farms. The GFB enterprise labor, variable, fixed, and total variable expenses per acre for large farms were lower than for medium-sized and small farms. The fixed expense per acre for medium-sized farms was lower than for small farms.

The comparison of U.S. GFB enterprise expenses per GFB animal produced was also based on three different sizes of operations with results shown in Table 3. The GFB enterprise labor expenses per GFB animal for medium and large farms were lower than for small farms. The GFB enterprise labor expenses per GFB animal for medium-sized farms were lower than for small farms. The GFB enterprise labor, variable, fixed, and total variable expenses per GFB animal for large farms were lower than for medium and small farms. The fixed expense per GFB animal for medium-sized farms was lower than for small farms. Both of the GFB enterprise cost analyses provide evidence that scale of operation is important: with increasing GFB enterprise scale, input expenses (labor, variable, fixed, and total expenses) decrease significantly.

Table 3. U.S. GFB Enterprise Expenses per GFB Production Acre and Animal Produced

	Expense per Acre of Land Used for GFB Production		
Average Expenses	Small Farm^{A} if Land ≤ 100 acres	Medium Farm^{B} if Land >100 & ≤250 acres	Large Farm^{C} if Land >250 acres
Labor	171.45$^{B, C}$	93.97$^{A, C}$	24.27$^{A, B}$
Variable	486.39^{C}	318.82^{C}	91.41$^{A, B}$
Fixed	140.65^{C}	102.62^{C}	49.97$^{A, B}$
Total Expenses	798.48^{C}	515.41^{C}	165.64$^{A, B}$
Number of Farms	**≤ 30**	**>30 and ≤ 90**	**>90**
	Expense per Total Number of GFB Animals		
	Small Farm^{A} if GFB Animals < 10	Medium Farm^{B} if GFB Animals ≥10 & ≤25	Large Farm^{C} if GFB Animals >25
Labor	2017.22$^{B, C}$	925.11$^{A, C}$	371.20$^{A, B}$
Variable	3622.19^{C}	2762.81^{C}	976.80$^{A, B}$
Fixed	1692.31^{C}	1403.74^{C}	383.05$^{A, B}$
Total Expenses	7331.71^{C}	5091.65^{C}	1731.05$^{A, B}$
Number of Farms	**≤ 30**	**>30 and ≤ 90**	**>90**

Notes: Letters (A, B, C) indicate significant differences ($P < 0.10$) in means across columns with A = small farms with ≤ 30 GFB animals, B = medium farms with >30 and ≤ 90 GFB animals, and C = large farms with >90 GFB animals.

Input Distance Function Analysis Results

The ML parameter estimates for the IDF analysis are presented in Table 4. All output and input parameter estimates are statistically significant. Of the inputs, the contribution of labor is larger in magnitude than fixed and total other variable expenses. The cross-input variable parameters are statistically significant except for the interaction of total other variable and fixed expenses. Positive signs indicate the inputs are complimentary; negative signs indicate they are substitutes.

The output variable parameters are statistically significant and have expected signs. The statistically significant GFB animal production (which includes hay sold from pasture devoted to GFB production hereafter referred to simply as GFB animal production) and GFB meat production outputs suggest that increases in these two outputs increase the productive contribution of land. The interaction term for the two outputs is positive and significant, suggesting these two outputs are complimentary.

Table 4. The IDF Estimates for U.S. GFB Enterprise

Variables	Coeff.	*t*-test	Variables	Coeff.	*t*-test
Constant	-5.83***	-7.87	$lnQ_{GFBah}lnX^*_{Fix}$	0.15***	3.96
Q^d_{GFBah}	0.38	0.81	$lnQ_{GFBm}lnX^*_{Lab}$	-0.07**	-2.22
X^d_{Lab}	4.00***	4.76	$lnQ_{GFBm}lnX^*_{Var}$	-0.11*	-1.85
lnX^*_{Lab}	0.71***	6.37	$lnQ_{GFBm}lnX^*_{Fix}$	-0.09**	-2.48
lnX^*_{Var}	0.67***	2.66			
lnX^*_{Fix}	0.36**	2.02	*Inefficiency*	*Model*	
lnX^*_{Labsq}	-0.07***	-4.45	*Constant*	-30.65	-0.01
lnX^*_{Varsq}	-0.01	-0.07	*Edu*	-0.92*	-1.80
lnX^*_{Fixsq}	-0.04	-0.82	*Male*	-1.46*	-1.69
$lnX^*_{Lab}lnX^*_{Var}$	0.16***	4.40	*Exp*	-0.15**	-1.99
$lnX^*_{Lab}lnX^*_{Fix}$	-0.04*	-1.68	*Mfarm*	-2.61*	-1.80
$lnX^*_{Var}lnX^*_{Fix}$	-0.03	-1.20	*Lfarm*	-2.67**	-2.07
lnQ_{GFBah}	-0.37*	-1.93	*%Gfbinc*	0.12	1.62
lnQ_{GFBm}	-0.46**	-2.22	*Offfarmss*	-0.72***	-2.70
$lnQ_{GFBahsq}$	-0.05	-0.66	*Neast*	-0.25	-0.20
lnQ_{GFBmsq}	-0.07***	-4.43	*Mwest*	-1.17**	-2.09
$lnQ_{GFBah}lnQ_{GFBm}$	0.09***	5.61	*West*	-0.29	-0.45
$lnQ_{GFBah}lnX^*_{Lab}$	-0.10**	-2.28	*Cowcalf*	29.73	0.99
$lnQ_{GFBah}lnX^*_{Var}$	-0.05***	-3.11	*Stockdty*	0.29	0.51

Notes: * 10% level of significance, ** 5% level of significance, *** 1% level of significance.

Interaction between outputs and inputs, or $\varepsilon_{XY_kX_m} = \partial\varepsilon_{X,Y_k}/\partial lnX_m$, indicate the increase in Y_k from an increase in X_m (Paul et al., 2004). If $\varepsilon_{XY_kX_m} < 0$, output-input jointness or complementarity is implied. The parameter estimates for the interactions between the value of GFB animal production and labor expenses, GFB animal production and total other variable expenses, the value of GFB meat production and labor expenses, GFB meat production and total other variable expenses, and GFB meat production and fixed expenses show complementarity, leading to increased land expense. However, the parameter estimate for the interaction between the value of GFB animal production and fixed expenses shows a substitute relationship, leading to decreased land expense.

Estimated inefficiency model parameter estimates are also presented in Table 4. College education, gender, experience, operation size, percentage of annual net household income from off-farm sources, and Midwest region were efficiency drivers for U.S. GFB enterprises. As anticipated, GFB producers with 4-year college degrees were more technically efficient than farmers without 4-year college degrees. Male grass-fed beef producers were more technically efficient than female producers. Greater experience with producing GFB led to more technically efficient GFB enterprises. Producers with more farming experience are likely to have greater knowledge about their farms and farming practices; therefore, farming experience has generally had a positive impact on TE.

Large and medium-sized GFB operations were more technically efficient than small-sized operations, potentially contributing to greater economies of size in this industry. GFB producers having greater percentages of income from off-farm sources were more technically efficient than producers with lower percentages. This suggests that having off-farm employment causes producers to more efficiently utilize their inputs (including labor) in producing GFB. Midwestern GFB enterprises were more technically efficient than Southeastern GFB enterprises, while western GFB enterprises were less technically efficient than Southeastern GFB enterprises. The distribution of the estimated input-oriented TE scores is presented in Table 5. We find an average TE of 0.82, which implies that the average U.S. GFB enterprise could reduce about 18% in inputs to produce the same output as an efficient enterprise on the production frontier. The table also shows that more than 68% of the producers achieved TE levels of 80% or higher.

Featherstone et al. (1997) and Rakipova et al. (2003) found average TEs of 0.78 and 0.92 for Kansas and Louisiana beef cattle producers, respectively.

Table 5. Distribution of TE

Range of TE	Freq.	Mean	SD
TE <= 0.10	4		
0.10 < TE <= 0.40	4		
0.40 < TE <= 0.50	4		
0.50 < TE <= 0.60	5		
0.60 < TE <= 0.70	3		
0.70 < TE <= 0.80	6		
0.80 < TE <= 0.90	21		
0.90 < TE <= 1.00	35		
Total	82		
Technical Efficiency		0.82	0.21

A measure of scope economies was estimated from the IDF by taking the second cross partial output derivatives, $\partial^2 lnD^I(X,Q)/\partial lnQ_k \, \partial lnQ_l \; > 0$ (Paul et al. 2004), and was statistically significant. The positive measure of scope economies indicates that scope economies exists in U.S. GFB enterprise production. A coefficient of 0.17 suggests that joint production of both GFB animal and GFB meat outputs decreased average total cost by 17% relative to the separate production of these two outputs on U.S. GFB farms.

Overall economic indicators including marginal productive contributions (MPC) (see Morrison-Paul et al., 2004), returns to scale (RTS), scale efficiency, and scope economies for the U.S. GFB production are presented in Table 6. The estimated RTS parameter for U.S. GFB enterprises shows that a 1% increase in all outputs increased overall input use by 0.76%. This implies that an increasing RTS economy exists in U.S. GFB enterprise production. The potential productivity gains from moving to the optimal farm size is found using the scale efficiency (SEF) measure which can be estimated from the IDF (Table 6). The method for estimating SEF was introduced by Ray (1998, 2003) and Balk (2001) for multiple-input and multiple-output IDFs. Using the $SEF(X,Q) = \exp((-(1-\sum_k \partial lnD^I(X,Q)/\partial lnQ_k))^2/2\sum_k \sum_l \beta_{kl})$ equation (Ray, 2003), we estimate the SEF for U.S. GFB production. As an economic performance indicator, SEF represents the improvement in average productivity of U.S. GFB enterprises through a change in the scale of GFB production. Our results indicate that U.S. GFB enterprises, on average, are scale efficient if the scale of production is greater than 100 GFB animals.

Table 6. Input and Output MPCs, and RTS, SE and **Scope Economies**

MPCs	**Coeff.**	***t*-test**
$ln\ X_{Land}$	-0.39***	-3.92
lnX^{*}_{Lab}	-0.28**	-2.09
lnX^{*}_{Var}	-0.18**	-2.01
lnX^{*}_{Fix}	-0.14**	-2.08
lnQ_{GFBah}	0.21**	2.15
lnQ_{GFBm}	0.55***	3.55
Return to scale	0.76**	3.95
Scale efficiency	1.00***	67.27
Scope economies	0.17***	7.03

Notes: *, **, *** Significances at the 10%, 5% and 1% levels, respectively.

Summary and Conclusions

There is limited information and knowledge of the most efficient practices available for GFB producers regardless of the recent the industry growth and development. To reveal insights into the recent U.S. GFB industry growth and development, we estimated efficiency measurements including TE, scale and scope economies, and SEF for U.S. GFB enterprises using costs and returns data for a sample of U.S. GFB producers.

Cost analyses show that increased farm size in U.S. GFB production substantially decreased total, variable, labor, and fixed expenses. We determined that factors such as farm structure characteristics, farmer demographics, and production region significantly impact the efficiency of U.S GFB enterprises. Increasing RTS, scale efficiency, and scope economies are found in this study, exposing insights into the growth potential for U.S. GFB farms. The effect of operation size on the efficiency and productivity of U.S. GFB enterprises is significant. Large and medium-sized GFB enterprises were more technically efficient than small operations. Small farms have the potential to enhance their competitiveness by increasing the scale of their operations. The IDF estimates indicate along with cost analyses that there are economies of size in U.S. GFB production. In addition, increasing returns to scale for the U.S. GFB enterprise suggests that producers can increase the size of their operations, resulting in less overall input usage per unit produced. Our results suggest that U.S. GFB farms can be scale efficient if their operation size is greater than approximately 100 GFB animals.

Scope economies (which includes both GFB meat and animal production) in U.S. GFB production suggest reduced long run average cost of production via diversification. Scope economies provide U.S. GFB enterprises with a means to generate operational efficiencies and an economic incentive to diversify production. Off-farm income by producers appears to result in an increase in GFB enterprise TE, perhaps due to the investment of off-farm income on GFB enterprise operations. The inefficiency model estimates revealed that more highly educated U.S. GFB producers were more technically efficient. Experience had positive impacts on the TE of US GFB farms. Having more knowledge about farming practices, experience generally leads to greater efficiency. Overall, the research findings of this study provide significant contributions on the economics of U.S. GFB production.

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