Ownership, region, system or ? – What leads to efficiency?

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Summary

This study utilizes a production function based on costs of feed, health and reproduction, and other inputs to measure efficiency of milk solids production in New Zealand. A second function was also used to measure inefficiency and the sources of inefficiency. The results show that on average producers are reasonably "efficient" with a score of 84%, with reproduction and farming system being major influences on efficiency. Efficient producers have good control over all costs and a high percentage of cows calving early in the milking season. One component of a system that "inefficient" producers can examine is their reproduction program.
Key words: seasonal production, pasture, efficiency, stochastic frontier.

Introduction

Seasonal dairy production is undertaken in many regions of the world to take advantage of rainfall patterns that generate adequate pasture growth for milk production and allow producers to reduce the costs of feed required for milk production. Pasture based dairy production is the dominant production system in many countries such as New Zealand, Ireland, and Australia (Holmes et al., 2002), however seasonal milk production systems bring with them their own set of management challenges to ensure the profitable and economically sustainable future of the dairy business. The two main challenges in a seasonal production system are: 1) Ensuring pasture growth is adequate, which as the major feed source is critical and; 2) ensuring all cows calve within a confined period.

Maintaining milk production from pastures can be achieved through pasture alone, if rainfall provides sufficient moisture for ideal pasture growth, and pasture and grazing management, including appropriate fertilizer management, is optimal (Mayne et al., 2000). To aid in pasture management and the maintenance of lactation producers can supplement lactating cows with grain or other forage sources, such as hay or silage (Bargo et al., 2003). Supplementing lactating cows can also increase total milk production as the diet of cows is higher in energy than if on pasture alone (Leaver 1995, Bargo et al., 2003). However, supplementation of lactating cows on pasture can also increase the costs of production which can be offset by the higher milk production, and producers need to be aware of the marginal increases in costs and revenues generated by supplementary feeding (Tozer et al., 2004, McInerney 2000).

Reproductive management is also critical in a seasonal dairy system, as cows that calve late have a shorter time in milk before the end of the grazing season, therefore produce less total milk, and may have difficulty in conceiving in a shortened breeding window to ensure a 365-d calving cycle (Holmes et al., 2002, Esslemont and Peeler 1993). Ideally in a seasonal calving herd, cows should calve, have a period of anoestrus, then be mated and conceive within 80-85 days of calving (Holmes et al., 2002). Cows that calve late have less time to conceive post-partum and because of the requirement of the 365-d calving interval may be culled to ensure optimal milk production in the subsequent lactation (Esslemont and Peeler 1993). The economic consequences of later calving cows and higher culling rates due to non-pregnancy were analysed by Evans et al. (2006), the conclusion from that research was that lower reproduction rates and higher culling rates cost Irish seasonal dairy producers €1,363 per year per farm. Esslemont and Peeler (1993) showed that for a 305-d lactation, an extended calving interval cost between £1.59 and £2.17 per cow per day of extended calving interval.

To produce milk "efficiently" a dairy producer must combine all inputs (land, pastures, cows, labour, feed, health inputs, and so forth) using the available production technology to produce as much milk as possible at the lowest possible cost. The most efficient producers are those who combine all inputs to produce the maximum amount of milk possible from the given set of inputs. We also note here that dairy producers can use different combinations of inputs; i.e. all pasture, a combination of pasture and supplements, or a full TMR ration, or different milking intervals or milk technologies, to produce milk, thus producers need not be limited to a single production method, and that efficiency is only relative to the peer group included in a study. Efficiency can be measured either from an output or input perspective. Input oriented efficiency measures the minimum level of inputs required to produce a given level of output, whereas the output orientation measures efficiency as the maximum level of output that can be produced with a given set of inputs (Coelli et al., 2005). The choice of orientation is somewhat subjective and as noted by Coelli et al (2005) the orientation of a research model does not usually significantly affect the efficiency outcomes when constant returns to scale are assumed. However, the orientation of the efficiency analysis should also consider what variables a decision maker can control and typically dairy farmers can control inputs to produce a given level of output (Bogetoft and Otto 2011). Also, farmers in general as price takers have very little control over price of their output and this is especially the case in New Zealand dairying where prices are set by the dairy cooperatives prior to the beginning of the milk production season based on projected world supply and demand factors.

Typically efficiency is measured in terms of one output and one input, such as litres of milk per cow, litres of milk per full time equivalent (**FTE**) worker, or kilograms of milk solids per ha, however, all these measures are partial measures of efficiency as they do not take into account productivity of other inputs (Coelli et al. 2005, Bogetoft and Otto, 2011). There are several ways to measure the efficiency of multiple input/output firms including total factor productivity (**TFP**) analysis, data envelopment analysis (**DEA**) and stochastic frontier analysis (**SFA**) (Coelli et al. 2005). Each of these methods has its own characteristics and idiosyncrasies and provides different types of information to the analyst. For the remainder of this discussion we will focus on DEA and SFA. Data envelopment analysis is a non-parametric, linear programming based tool that estimates the relative efficiency of a group of decision making units (**DMU**), calculates the relative peer groups for non-efficient producers and is not bound by the functional form of the production function, but does not take into account statistical noise or missing observations during the estimation procedure (Coelli et al., 2005, Boegtoft and Otto, 2011). On the other hand SFA is a statistical analysis tool that measures the efficiency of each DMU relative to the estimated efficiency frontier, identifies sources of inefficiency and takes into account noise in the data, but is dependent on assumptions regarding the functional form used to estimate the production frontier (Bogetoft and Otto 2011). The selection of either SFA or DEA depends on the goals of the researcher, if the researcher is seeking a flexible approach then DEA is preferable, or one that takes into account the ability to separate noise and efficiency, in this case SFA is the better option (Bogetoft and Otto 2011).

Both efficiency measures discussed have been utilized in studying efficiency in the dairy industry, DEA has been used by researchers who focused on overall technical and or scale efficiency which can be easily measured using DEA (Jiang and Sharp 2014). Most DEA analyses of the dairy industry are regional or national models, see for example Kelly et al., (2013) (Ireland), Stokes et al., (2007) (Pennsylvania), Jaforullah and Whiteman (1999) (New Zealand), Fraser and Cordina (1999) (Victoria, Australia), Tauer (1993) (New York), or Cloutier and Rowley (1993) (Quebec, Canada). Others, such as Heinrichs et al. (2013) have utilised DEA to examine the efficiency of components of the dairy farm (heifers) or animal health impacts (lameness) on efficiency (Barnes et al., 2011). Researchers using SFA have attempted to identify reasons for (in)efficiency including scale or size of operation (Kumbhakar et al, 1989), farmer education level and scale (Kumbhakar et al., 1993), and feeding system and feed levels (Cabrera et al., 2010). Lawson et al. (2004) utilized SFA to measure the impact reproductive disorders, such as dystocia, retained placenta or uterine infection, had on milk production efficiency in Danish herds.

The objectives in this research were: 1) to examine and compare the efficiency of milk solids (**MS**) production of dairy farms in a seasonal pasture-based production system in New Zealand of owner operators and 50-50 sharemilkers; and 2) to identify potential causes of inefficiency and determine if there are differences in efficiency across business structures, so that dairy producers and their advisers may be able to develop programs to effectively overcome these inefficiencies in a manner in which the additional revenue or cost savings exceeds the costs of implementing the program developed. Given that the objective is to identify the source(s) of inefficiency SFA is utilized as the analysis method. In the context of this research inefficiency is measured as the ratio of actual MS production and predicted MS produced at the production frontier for each farm.

The efficiency of production of owner operators and sharemilkers maybe different due to the different sets of incentives in production of the two structures. In a 50-50 sharemilking operation, the sharemilker provides cows and some machinery, such as motorbikes or other vehicles, and the land owner provides land and the milking facilities, and the MS revenue, i.e. MS produced multiplied by the MS price, is split 50 per cent to each party by the dairy factory, so that each receives a check for the share of revenue due. Owner operators have control over all assets of the business; land, cows and other productive capital and receive all MS revenue.

Because of the different asset structures and revenue flows comparing efficiency of the two ownership structures using economic variables such as return on assets or net profit from farming would yield inconsistent outcomes, therefore a variable that is independent of revenue is required, but this variable must also be consistent with efficiency. Given that producers have little control over price received, it can be reasonably assumed that to maximize profit producers must generate as much yield as they can with their limited resources. Alternatively, producers can minimize costs and produce a given level of output with the inputs purchased, thus maximizing profit. Therefore, in the following analysis MS per ha is used for the measure of efficiency to allow for comparison across ownership structures.

MATERIALS AND METHODS

Model

Stochastic Frontier Model. The stochastic frontier production function was developed independently by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977). The model is similar to a standard linear regression model except for the addition of one extra parameter. The additional parameter is a stochastic error term that captures inefficiency in the system of interest. The model chosen to represent the production function is selected such that the function envelops all data observations, this in contrast to a typical regression analysis where the model is selected to best fit through the means of the data rather than the frontier or perimeter of the data. After reviewing the relationships between the variables in the data the analyst selects the functional form that best represents the input-output process. Functional forms that have been used previously include the Cobb-Douglas and transcendental logarithm (translog) functions (Coelli 1996). The Cobb-Douglas stochastic frontier model has the following form (The translog form has a similar form, but with the addition of interaction and squared terms, see Lawson et al., 2004):

$$\ln(q_i) = \beta \ln(x_i^{'}) + v_i - u_i \qquad (1)$$

where q_i is the output of the ith firm, $x_i^{'}$ is the vector of inputs used by firm i to produce q, β is a vector of unknown parameters to be estimated, v_i is a normally distributed error term with mean 0 and variance σ_v^2, i.e. $v_i \sim N(0, \sigma_v^2)$. The inefficiency component of the model, u_i, is defined as:

$$u_i = z_i\delta + w_i \qquad (2)$$

where z_i is a vector of variables that explains inefficiency of firms, δ is a vector of unknown coefficients that are to be estimated in the model, and $w_i \geq -z_i\delta$, to ensure that $u_i \geq 0$ (Battese and Coelli, 1995). The random variable w_i has a normal distribution with mean 0, but truncated at 0, and variance σ^2. Given these assumptions we can define u_i as being distributed in the non-negative truncated section of a distribution with mean $z_i\delta$ and variance σ_u^2, i.e. $u_i \sim N^+(z_i\delta, \sigma_u^2)$ (Battese and Coelli, 1995). Following from equations 1 and 2, technical inefficiency is estimated as:

$$TE_{\text{i}} = \exp(-u_i) = \exp(-z_i\delta - w_i) \qquad (3)$$

In the results that follow inefficiency is measured as the ratio of actual MS production for each firm relative to its frontier level of production predicted from equation 3, this yields inefficiency values as a ratio or percentage. Adding the variance terms for each of the error terms together yields, $\sigma_u^2 + \sigma_v^2 = \sigma_s^2$ and the value of $\gamma = \sigma_u^2 / \sigma_s^2$ measures how much of the total variance of the error term is due to the inefficiency term (Coelli et al. 2005). A high value for γ indicates that much of the variance in the error term is due to the inefficiency component. However, there is no critical value for γ that determines whether inefficiency is significant or not as it is a relative measure.

Frontier Model

The choice of model to estimate in SFA is usually between the translog function and the Cobb-Douglas function; both have some desirable properties with respect to information generated in the efficiency analysis of DMUs. Preliminary analysis of both functional forms found that the translog form, with the data used, was problematic in that the models would not converge or generated unrealistic parameter estimates, for these reasons the Cobb-Douglas technical effects model of Battese and Coelli (1995) was used. One problem that may occur with the types of data being used in this analysis was the potential for heteroscedasticity to affect the statistical efficiency of the parameters of the model due to the different sizes of operations in the data set (Kumbhakar and Knox 2003). As noted earlier the dependent variable in the model was MS per ha, using this as a variable has the added benefit that the potential effect of heteroscedasticity, if total production was used, is reduced. This conversion also has the added benefit of being able to identify the efficiency of one of the most limiting factors in New Zealand dairying, land.

In the model output is defined as MS per ha, and inputs into milk production (all on per ha basis) are supplementary feed costs (SFC) ($/ha), pasture costs (PC) ($/ha), other costs (OC) ($/ha), stocking rate (SR) (cows per ha), and labour (FTE/ha). The area variable used in the model is the milking area only, and does not include land used for dry cows and replacement rearing. Supplementary feed costs are the total costs of supplements made on farm, including fodder conservation, and purchased feed, such as palm kernel extract or grains, but do not include fertilizer costs used in fodder production. Pasture costs include fertilizer, pasture reseeding, and, if the farm used irrigation, the costs of water applied. Other costs include health, reproduction, fuel, electricity, and other dairy related expenses. These individual expense classes were included in one variable to reduce the problems of multicollinearity due to variables such as health and reproduction being highly correlated. The stocking rate variable is the milking area divided by the peak number of cows milked in the milking season, and is used as a measure of intensity of land use.

All labour, paid fulltime, part-time, and casual, and unpaid family labour was summed to define the total labour supply for a farm in FTE. However, contrary to other research (Lawson 2004, Cabrera et al., 2010) labour (FTE) or labour costs per ha which were included in the final model but the analysis showed that labour was not a statistically significant variable. A final note here is that due to the formulation of the model as shown in equation 1 all variables are in logarithmic form, therefore the final model for farm *i* took the following form:

$$\log(MS_i) = \alpha + \beta_1(\log SFC_i) + \beta_2(\log PC_i) + \beta_3(\log OC_i) + \beta_4(\log SR_i) + \beta_5(\log L_i) + v_i - u_i$$

Efficiency Model

The inefficiency component of the model included the six week calving percentage (6-Week) and a dummy variable for business type (owner operator or sharemilker. Farms are also classified by the FS they use from System 1, a fully self-contained pasture-based feeding system where the only supplements fed are conserved forage from the milking area, with a progression in the level of supplemental feeds used through to System 5, where supplemental feeds are used all year round, and at least 25 per cent of total feed is imported (Characteristics of each FS type are presented in Table 1). In the inefficiency model each FS is defined as a set of (0,1) dummy variables for each system, with System 5 as the comparison region. Given the importance of early calving in a seasonal milk production system, the percentage of cows in the milking herd that had calved by the end of the sixth week from the planned date for calving to begin was used, this variable is used as a measure of reproductive efficiency in the dairy system, other variables such as the calving rate at 3 weeks were also tested and these gave similar results to the 6-week variable. A set of regional dummy variables (0,1) were included in the inefficiency model to determine if there was a regional effect on efficiency, this variable can also be used as a means to capture regionally specific effects of climate or land value on efficiency, the regional variables and their location are presented in Table 2. Other variables that may have contributed to (in)efficiency such as breed, milking shed type (herringbone or rotary), animal health, or milk quality measures were tested in preliminary analysis and were found not to significantly affect (in)efficiency and as such are not included in the final model.Table 1: Characteristics of farming systems used in analysis.

System number	System characteristics
1	All grass self-contained, all stock on the effective dairy area, no feed is imported. No supplement fed to the herd except supplement harvested off the milking area and no cows are grazed off the milking area.
2	Feed imported either supplement or grazing off for dry cows. Approximately 4-14% of total feed is imported. Large variation in percentage of feed imported in high rainfall areas and cold climates
3	Feed imported to extend lactation (typically autumn feed) and for dry cows. Approximately 10-20% of total feed is imported.
4	Feed imported and used at both ends of lactation and for dry cows. Approximately 20-30% of total feed is imported.
5	Imported feed used all year, throughout lactation and for dry cows. At least 25% of total feed is imported.

Data

The data used in this study is for the 2013-2014 dairy production year and is sourced from the DairyNZ DairyBase data base. DairyBase is a voluntary data analysis service provided by DairyNZ to allow farmers to compare, and or benchmark themselves, to other dairy farmers in the same milk production region or the entire country. Producers in the DairyBase program must enter different types of data; 1) basic physical data, i.e. milking area, labour types and hours worked, number of cows, and types of feeding and milking systems, and 2) basic financial information, such as gross farm revenue, operating expenses, and capital value of the business, through to individual expense categories. Producers can, if they elect, enter more detailed production data including; 3) specific levels of feed from pastures and or supplements, areas of the farm cropped in winter and or summer, and cow liveweight, and 4) calving and mating data, such as planned start of calving, empty cow rate, mastitis and lameness information, or soil test information. Producers participating in DairyBase in any one year must at least enter the basic physical and financial information (1 and 2), the entry of the more detailed data (3 and 4) is not required to generate the basic reports from DairyBase.

Given that the focus of this research is on the impact of reproductive performance and feeding strategies on efficiency of milk solids production, the required data was from producers entering the more detailed information. The original data set consisted of 1,306 milk producers both owner operators (998) and sharemilkers (308), however as noted not all producers are required to enter the level of detail required, therefore due to missing data for the variables included in the models some producers were excluded from the analysis, hence the final data set consisted of 392 dairy farms, 315 owner operators and 77 sharemilkers. The regional breakup of dairy farms in New Zealand and the number of farms per region used in the analysis is shown in Table 2. From this table we can see that the percentage of observations per region is close to the actual percentage, except for Taranaki and Waikato, which are lower (-7%) and higher (+15.4%) in the analysis data set.

Summary information for all variables included in the stochastic frontier analysis is presented in Table 3. All models were estimated using the Frontier package in R (Coelli and Henningsen 2013).

Table 2: Percentage of herds in each New Zealand Dairybase region in 2013/14 and the percentage of herds in each region used in the efficiency analysis (Total number of herds in New Zealand in 2013/14 = 11,927) (DairyNZ 2014).

Region Number	Region	Percentage of herds 2013/14	Percentage of herds in analysis
1	Bay of Plenty/Eastern North Island	9.6	11.5
2	Lower North Island	8.6	10.2
3	Marlborough/Canterbury (South Island)	11.3	9.7
4	Northland (North Island)	11.3	8.2
5	Otago/Southland (South Island)	11.5	13.3
6	Taranaki (North Island)	14.4	7.4
7	Waikato (North Island)	20.3	35.7
8	West Coast (South Island)	3.1	4.1

Table 3: Summary of data used in frontier and inefficiency model (n = 392).

	Mean	SD
Technical Effects Model Variables		
Milking Cows (no.)	447.30	266.55
Effective Milking Area (ha)	150.90	85.16
SR (cows/ha)	2.99	0.56
Labor (FTE/ha)	0.0224	0.0077
Milk Solids (MS kg/ha)	1,201.57	351.61
Made and purchased supplementary feed costs (SFC) ($NZ/ha)	1,871.29	1,327.10
Pasture costs (PC) ($NZ/ha)	593.93	324.41
Other costs (OC) ($NZ/ha)	866.25	374.17
Inefficiency Model Variables [1]		
Six week calving rate (%)	83.69	8.07
Farming system type (1-5) [2]	3.32	0.96

Results and Discussion

Technical Effects Model

The parameters for the Cobb-Douglas technical effects model are presented in Table 4A, and one outcome of using this form for the production function is that the parameters can be interpreted directly as response measures or more commonly termed elasticities. Elasticity measures the response of an output to a marginal change in an input, usually 1 per cent. Therefore, from Table 4A we can determine the response of MS production to a change in each of the inputs. As expected all responses are less than one, for example a 1 per cent change in supplementary feed costs will generate a 0.1282 per cent change in MS produced, we would expect this as not all feed is converted into milk due to the maintenance or growth requirements of cows, and feed conversion efficiencies. The key outcome of the elasticities is to indicate that milk production is occurring in the region of diminishing marginal returns of the production function, or where the output response to additional inputs is less than the percentage change in inputs. Two variables, pasture costs and labour, are included in the final model, even though they are statistically insignificant. These variables are included to demonstrate the effects these variables have on MS production, in that higher pasture costs and labour contribute positively to production.

Table 4A: Estimated parameters for the technical effects production frontier model for milk solids production.

	Estimate[1]	s.e.
Constant	4.8536***	0.2057
log (Supplementary feed costs)	0.1282***	0.0132
Log (Pasture costs)	0.0070	0.0056
log(Other costs)	0.0966***	0.0245
log(Stocking rate)	0.7619***	0.0404
log(Labor)	0.0203	0.0225

[1] *** significantly different from zero at P < 0.01.

Table 4B: Inefficiency model parameters for milk solids production.

	Estimate[1]	s.e.
Constant	0.2031	0.1243
Type	-0.1574***	0.0351
System 1	0.2853***	0.0754
System 2	0.1615***	0.0455
System 3	0.1429**	0.0455
System 4	0.0796*	0.0424
6Weeks	-0.2302*	0.1179
Region 1	-0.0301	0.0600
Region 2	0.0993*	0.0552
Region 3	0.0403	0.0495
Region 4	0.1722***	0.0520
Region 5	-0.0832	0.0615
Region 6	0.0330	0.0648
Region 7	0.1205*	0.0209
σ_s^2	0.0147***	0.0029
γ	0.6973***	0.1041
σ_u^2	0.0102***	0.0025
σ_v^2	0.0044***	0.0013
log of the likelihood function	321.0974	
Mean efficiency:	0.8399	

[1] ***, **, * Significantly different from zero at P < 0.01, P < 0.05, and P <0.1, respectively

The input responses are consistent with those observed in Lawson et al. (2004) and Cabrera et al. (2010). The parameter estimates from Cabrera et al. (2010) for feed and crop variables were 0.059 and 0.082, respectively approximately the same value, when summed, as estimated in the current research. The estimates for the feed parameters in Lawson et al. (2004) were higher than in either the current study or Cabrera et al. (2010), but that may be a reflection of the units of measurement used in the Lawson et al. (2004) study. The estimated parameter value for other costs in this study was 0.0966 which is higher than, but consistent with, previous research, Lawson et al. (2004) estimated a value for other expenses of 0.085 and the value from Cabrera et al. (2010) was 0.062 for "livestock" expenses. One explanation for the higher parameter value is that more expenses are included in the OC value than in previous research models.

Inefficiency Model

Parameter values for the inefficiency model are also included in Table 4B. From this table we can see which variables are positively or negatively affecting efficiency. The interpretation of the parameter values needs to be done with care, as a negative value indicates that the variable increases efficiency and a positive value decreases efficiency. The major contributors to efficiency were the 6-week calving percentage, business structure (Owner operator or sharemilker) and the feeding system. Parameter values for reproduction and feeding system variables indicate that a higher 6-week calving percentage leads to higher MS production efficiency and similarly the increasing value of the feeding system, or in this case intensity of supplementary feeding led to higher MS production when compared to FS 5. These values are consistent with the previous discussion regarding reproduction and the value of feeding supplements to cows. The type of business structure also affects efficiency with sharemilkers being more efficient in producing MS than owner operators. In general there was some level of inefficiency due to regional factors; regions 2 (Lower North Island), 4 (Northland), and 7 (Waikato) were more inefficient compared to region 8 (West Coast, South Island). Some of this inefficiency may be attributed to the low number of observations in the comparison region, but other factors in the study year may also contribute to the inefficiency, such as differences in regional rainfall or temperature.

Overall mean efficiency estimated by the SFA model was 83.99 per cent which is slightly lower than that estimated by Cabrera et al. (2010), 88 per cent, and of Lawson et al. (2004), 92.9 per cent, but consistent with that estimated by Jiang and Sharp (2014). The estimated value of γ is 0.6973 indicates that approximately 70 per cent of the error term is due to variance in the inefficiency component of the model. It is possible to measure the difference between actual MS production and the efficient level of milk production, in this case the average actual MS production was 1,202 kg per ha (see Table 3), and the predicted average efficient level of production was 1,408 kg per ha a difference of 206 kg MS per ha. Using the 2013-14 net milk price of $7.69 per kg MS (DairyNZ 2015) the mean loss in revenue from not producing efficiently was $1,585 per ha.

To compare efficiency across business ownership structures and feeding systems to determine if there are common factors across these variables the data set was segregated based on ownership structure (Table 5) or FS (Table 6). As noted earlier sharemilkers were more efficient than owner operators (0.92 v 0.83, $P < 0.01$), in general sharemilkers milked less cows ($P < 0.01$) on a slightly smaller milking area and produced a numerically lower level of MS. From Table 5 it is possible to see where sharemilkers generated their higher levels of efficiency, through lower costs of supplementary feeds, pasture, and other costs, and although labour is not included in the efficiency model we can see that owner operators used more labour ($P < 0.05$) than did sharemilkers.

Table 5: Summary of data used in frontier and inefficiency model for owner operators and sharemilkers and efficiency score and costs of milk revenue loss due to inefficiency (n = 392).

	Owner Operator	Sharemilker	Difference[1]
n	315	77	
Cows	450.37	230.00	***
SD	270.87	515.00	
Effective Milking Area	151.67	147.79	
SD	86.68	79.11	
Stocking rate (SR) (cows/ha)	2.99	2.96	
SD	0.58	0.48	
Labour (FTE/ha)	0.0229	0.0205	**
SD	0.0081	0.0056	
Milk solids kg/ha	1205.68	1184.78	
SD	365.22	290.87	
Made and purchased supplementary feed costs (SFC) ($/ha)	2071.58	1051.91	***
SD	1377.47	612.44	
Pasture costs (PC) ($/ha)	690.76	197.78	***
SD	281.08	131.05	
Other costs (OC) ($/ha)	943.86	548.76	***
SD	368.50	179.25	
6 Week calving rate	84.13	81.91	
SD	7.98	8.24	
Efficiency Comparison			
Efficiency	0.83	0.92	***
SD	0.11	0.11	
Loss of Milk Revenue	$1,795	$731	***
SD	$1,157	$1,016	

[1] ***, ** Significantly different at P < 0.01, and P < 0.05, respectively.

Following a similar method Table 6 shows the efficiency scores, input and output variable's for the five feeding systems. From Table 6 the efficiency scores increase as FS number increases from 1 to 5, which is expected given the results presented in Table 4. The number of cows and effective milking area varies across FS, with farmers using FS 2 having the lowest average number of cows and smallest effective milking area. Comparing FS 1 to other systems generated few significant differences, this is not to say this system was similar to other systems but was due to the very small number of observations (n = 7) in this group. However, in general, costs and other variables, such as labour and stocking rate, all increased as FS number rose. One variable that did not differ significantly across all FS was that of the 6-week average calving rate, which was between 83 and 85 per cent. This does not mean that the 6-week calving rate did not affect efficiency in each group, but that the effect on (in)efficiency was similar across all FS. Also, shown in Table 6 is the loss in milk revenue due to not operating at an efficient level. The loss in milk revenue declines as FS number increases, which would be expected as producers using the higher numbered FS were more efficient and therefore would have MS production closer to the "efficient" level of production.

A slightly different way to examine the differences in efficiency is to analyse per unit costs of production. The economic rationale for using pasture as a feed input is to reduce the costs of production (Tozer et al., 2004). In Table 6 the total feed costs (supplementary plus pasture) and total costs per kg of MS produced for each FS group are also shown, from there the differences across groups can be observed. Feed costs for FS 2 are significantly lower than FS 3, 4, and 5 ($P < 0.05$), there is no difference in feed costs between FS 1 and FS 2 or FS 1 and FS 3, and there are significant differences in feed costs between the remaining FS groups. A similar but slightly different set of results can be observed in Table 6 with respect to total costs of production per kg of MS. The total costs for FS 1 are now only lower to those of FS 5 ($P < 0.1$), FS 5 has higher costs than the remaining three feeding groups ($P < 0.05$), and the total costs of FS 2, 3, and 4 are progressively higher ($P < 0.05$). Not shown in Table 6, but can be derived from this table is the other costs incurred in each FS. For FS 2, 3, 4 and 5 other costs are in the range of \$0.75 to \$0.80; however the other costs for FS 1 are \$0.96 which are higher than those for the other groups ($P <0.05$). This indicates that although producers in FS 1 produced less MS per ha than FS 2 they are incurring much higher per unit feed costs, and when total per unit costs are calculated, i.e. adding feed, health, reproduction, and other costs together, FS 1 has higher total costs of production compared to FS 2 and 3 Thus, some of the costs saved in utilizing pastures as a feed source are offset by higher expenses for other inputs into the business.

Conclusions

Stochastic frontier analysis was employed to study the efficiency of milk solids production in the seasonal milk production system of New Zealand. The production function incorporated total feed, health, reproduction, and other costs, and capital to determine the production of MS per ha. Inefficiency was captured with a subsequent model that included milking interval, feeding system and the number of cows that had calved by the third week of the milk production season. The results from the models show that production is consistent with expectations, and that a change in output due to changes in inputs occurs at a decreasing rate. The inefficiency model estimated that producers are relatively efficient as a group with a mean efficiency of 87.10 per cent. However, the range of efficiency scores was from 66 to 105 per cent, indicating that some producers are relatively inefficient compared to the mean. The main sources of relative efficiency were producers who had a high percentage of cows that had calved by the third week of the milking season or were using a higher level of supplemental feeding.

Consistent with previous research one of the keys to efficient milk production in a seasonal grazing system is the reproductive program. The results of the current research indicate that efficient producers are those with good control over all costs and have a high percentage of cows calving early in the milking season. Thus one component of the farm system that “inefficient” producers can examine is their reproduction program. Increasing the number of cows calving early in the system generates more income, through higher total milk sales in the milking year, and reduces costs, as less replacements are needed to replace cows that fail to conceive or would calve too late in the next calving period.

One note of caution is that attempting to improve efficiency through a variable, such as 6-week calving rate, will more than likely incur additional costs, so a decision maker needs to take into account the overall costs of improving the variable of interest against the expected benefits. In the context of the current study the benefits would be additional income from higher MS sales as cows would milk longer over the milking season, and extra costs may include additional feed to improve body condition prior to breeding or reproduction program needs such as CIDRs, improved AI programs, or additional labour to monitor herd for estrus activity.

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Table 6: Efficiency scores, input and output variables for the five different feeding systems[1].

System type	1	2	3	4	5
n	7	68	160	107	50
Sharemilker	1	14	35	18	9
Owner Operator	6	54	125	89	41
Efficiency	0.69[d]	0.82[c]	0.84[c]	0.87[b]	0.91[a]
SD	0.10	0.12	0.11	0.10	0.11
Cows	385.43[b]	350.46[Bb]	411.37[Aa]	516.70[a]	444.98[a]
SD	283.70	212.86	217.29	271.51	264.73
Effective Milking Area	166.14	130.37[C]	146.31[B]	164.92[A]	161.40[A]
SD	109.14	70.07	80.84	84.66	108.45
Stocking Rate (cows/ha)	2.30[B]	2.70[Ad]	2.86[c]	3.15[b]	3.49[a]
SD	0.51	0.47	0.43	0.45	0.78
Labour (FTE/ha)	0.0178[B]	0.0202[d]	0.0213[c]	0.0232[Aa]	0.0281[Aa]
SD	0.0052	0.0055	0.0062	0.0074	0.0119
Milk solids (kg/ha)	672.81[e]	953.06[d]	1106.67[c]	1337.95[b]	1625.40[a]
SD	239.28	203.64	241.94	274.36	437.13
Made and purchased supplementary feed costs ($/ha)	617.49[Be]	945.58[Ad]	1487.58[c]	2266.54[b]	3687.82[a]
SD	337.82	472.61	676.65	882.61	2227.25
Pasture costs($/ha)	543.49	489.5[b]	561.2[b]	673.7[a]	676.8[a]
SD	329.66	271.52	317.41	319.53	371.45
Other costs($/ha)	628.3[e]	752.9[de]	833.4[c]	983.8[b]	1224.0[a]
SD	201.50	202.07	229.36	271.00	346.85
6 Week calving rate	0.84	0.83	0.83	0.85	0.84
SD	0.08	0.10	0.08	0.06	0.08
Loss of Milk Revenue	$2,242	$1,703	$1,638	$1,500	$1,349
SD	$705	$1,173	$1,184	$1,116	$1,502
Cost per kg MS	$2.71[B]	$2.34[d]	$2.63[c]	$2.94[b]	$3.35[Aa]
SD	$0.89	$0.74	$0.78	$0.64	$0.85

Feed costs per kg MS	$\$1.75^{Bd}$	$\$1.54^{d}$	$\$1.87^{Ac}$	$\$2.20^{b}$	$\$2.57^{a}$
SD	\$0.85	\$0.65	\$0.71	\$0.60	\$0.81

[1] Variables in the same row with different letters are significantly different at $P < 0.1$ (upper case), and $P < 0.05$ (lower case).