IMPACT OF FEEDING SYSTEMS ON THE PROFIT AND EFFICIENCY OF NEW ZEALAND DAIRY FARMS

Sub Theme – Knowledge and Information

Peter Tozer

Massey University, Manawatu Campus, New Zealand

Abstract:

This study utilizes a production function based approach using data on milk solids, farm working expenses, labour, farm area total dairy-based assets to measure and compare the efficiency of profitability measured as returns on dairy assets of sharemilkers and owner-operators in New Zealand. A second function to measure inefficiency and the sources of inefficiency included year, feeding system, region, and other variables. The results show that on average owner operators were reasonably "efficient" with an average efficiency of 70% however average sharemilker efficiency was only 55%. Feeding system and time were major influences on efficiency for owner operators but not for sharemilkers, where the number of cows and time were the major factors influencing efficiency.

Key words*: seasonal production, pasture, efficiency, stochastic frontier, New Zealand.*

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. 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 other feed sources aid in the achievement of the goals of the business, including profitability.

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 revenue. However, producers need to be aware of the marginal increases in costs and revenues generated by supplementary feeding (Tozer et al., 2004, McInerney 2000), and the impact this may have on overall profitability of the dairy business.

To produce milk "efficiently" and profitably 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 highest amount of milk possible from the given set of inputs at the least cost. We note here that dairy producers can use different combinations of inputs; i.e. all pasture, a combination of pasture and supplements, or a full total mixed ration (TMR), 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.

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 (**MS**) 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**) via index number analysis, data envelopment analysis (**DEA**) and stochastic frontier analysis (**SFA**) (Coelli et al. 2005).

Both DEA and SFA 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, USA), Jaforullah and Whiteman (1999) (New Zealand), Fraser and Cordina (1999) (Victoria, Australia), Tauer (1993) (New York, USA), 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., 1991), 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 rate of return on dairy assets (**DROA**) of dairy farms in a seasonal pasture-based production system in New Zealand of owner operators (**OOP**) and herd owning sharemilkers (**HOSM**); 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 (in)efficiency is measured as the ratio of actual DROA to the predicted DROA from the production frontier for each farm.

The efficiency of DROA of OOP and HOSM maybe different due to the different sets of incentives in production of milk under the two ownership structures in that the owner operator owns land, machinery, and cows, but the HOSM may be using sharemilking as a method of capital accumulation as a pathway to land ownership, thus they usually own the cow herd and some machinery (Gardner and Shadbolt 2005). In a HOSM operation, the sharemilker provides cows and some machinery, such as motorbikes or other vehicles, and the land owner provides land and the milking facilities. Milk solids revenue, i.e. MS produced multiplied by the MS price, is split 50 per cent to each party. Owner operators have control over all assets of the business therefore receive all 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, we analyse the efficiency of the DROA of HOSM and OOP separately.

MATERIALS AND METHODS

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 and is estimated using maximum likelihood techniques. 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. The Cobb-Douglas stochastic frontier model has the following form:

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

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:

$$TE_i = \exp(-u_i) = \exp(-z_i\delta - w_i) \qquad (3)$$

In the results that follow inefficiency is measured as the ratio of actual DROA for each firm relative to its frontier DROA predicted from equation 3, this yields inefficiency values as a ratio. 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.

Owner Operator and Sharefarmer Frontier Models

In the OOP model output is defined as DROA, and inputs were total MS production (kg), farm working expenses (**FWE** $NZ), effective farm area (**AREA** ha), total farm labour (FTE) and average dairy assets (**DASS** $NZ). This set of variables is used as MS production and FWE generate the majority of net farm income, and labour and farm area are proxies total productive capacity and skills of the farm labour force. All economic variables were adjusted for inflation using producer price indexes for agriculture from Statistics New Zealand. For the HOSM model the area and DASS variables were dropped due to statistical insignificance as measured by a likelihood ratio test.

A final note here is that due to the formulation of the model as shown in equation 1 all variables are in logarithmic form to reduce the effects of heteroscedasticity due to the cross sectional data. Feeding system and time were included in preliminary technical effects models but, in general, the statistical fit as individual variables and sets of variables was poor, thus they were not included in the final models. Based on these preliminary analyses and likelihood ratio tests the final models for owner operators and sharemilkers on farm *i* take the following form (note that the HOSM model does not include AREA due to the lack of good statistical fit for this variable):

Owner Operator Model

$$\log(\text{DROA}_i) = \alpha + \beta_1(\log\text{MS}_i) + \beta_2(\log\text{FWE}_i) + \beta_3(\log\text{AREA}_i) + \beta_4(\log\text{FTE}_i) + \beta_5(\log\text{DASS}_i) + vo_i - uo_i$$

Herd Owning Sharefarmer Model

$$\log(\text{DROA}_i) = \phi + \theta_1(\log\text{MS}_i) + \theta_2(\log\text{FWE}_i) + \theta_3(\log\text{FTE}_i) + vs_i - us_i$$

Efficiency Model

The inefficiency component of the OOP model included binary variables for feeding system (**FS**) and production region, time (t = 0 -9 for years 2005 to 2014) and milking interval (0 = twice-a-day, 1 = once-a-day, 3 times in 48 hours or any other milking interval), with twice-a-day the base for comparison. For the HOSM model, time and a quadratic time variable, DASS, and peak cows were added to the system type and regional variables of the OOP model. Farms are 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 (see Table 1). In the inefficiency model each FS is defined as a set of (0,1) dummy variables, with System 1 as the comparison system. 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.

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 sourced from the DairyNZ DairyBase data base for the years 2006 to 2014. 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 DairyBase 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 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).

Table 2: Dairy regions of New Zealand (DairyNZ 2015).

Region Number	Region
1	Bay of Plenty/Eastern North Island
2	Lower North Island
3	Marlborough/Canterbury (South Island)
4	Northland (North Island)
5	Otago/Southland (South Island)
6	Taranaki (North Island)
7	Waikato (North Island)
8	West Coast (South Island)

The final data set consists of 1,063 OOP and 292 HOSM from the original data set of 1,471 and 412 OOP and HOSM. As noted not all producers are required to enter the level of detail required, and also due to the logarithmic dependent variable any observation with DROA ≤ 0 was excluded (approximately 20 observations were excluded). 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).

One point to note from Table 3 is the difference in DROA between OOP and HOSM is due to the different asset classes held by each business type which can be seen in the dairy assets value. As noted earlier HOSM do not own land, but own cows and machinery, hence the higher but more variable DROA compared to OOP. Another reason for the more variable DROA for HOSM may be due to the differences in time in the industry for HOSM. Some sharemilkers will be new entrants into the industry, and their knowledge and experience of production systems and management can be limited thus their ability to adapt to change or problems that arise may be limited, which in turn could reduce income or increase costs. Also, note the differences in FWE between OOP and HOSM, this is due to sharing of some costs, such as fertiliser and fertiliser application between the land owner and the sharemilker. One final point with respect to feed costs of sharemilkers, HOSM are responsible for all feed costs unless the land owner requires a particular feed to be used, but this is not very common in sharemilking operations.

Table 3: Summary of data used in frontier and inefficiency model.

	Owner Operator	Sharemilker
n	1063	292
Return on Dairy Assets (DROA)	6.19%	20.03%
SD	4.25%	13.52%
Total Milk Solids	173,841	191,720
SD	125,086	100,100
Cows	445	482
SD	287	222
Effective Milking Area	146.90	157.76
SD	87.52	69.97
Farm Working Expenses	$684,404	$426,102
SD	$519,850	$255,850
Total Labour (FTE/ha)	3.06	3.07
SD	1.66	1.21
Dairy Assets	$7,450,877	$1,206,422
SD	$5,207,459	$619,848
Milking interval (2x daily)	960	

Results and Discussion

Technical Effects Model

The parameters for the technical effects model are presented in Table 4A. One outcome of using this type of production function is that the parameters can be interpreted as response measures or more commonly elasticities. Elasticity measures the response of an output to a marginal change in an input. From Table 4A we can determine the response of DROA to a change in each of the inputs for either business type. For example for the OOP model, a 1% change in MS production will generate a 0.7976% change in DROA (i.e. if DROA = 7% then a 1% change in MS will lead to a DROA of 7.05%); conversely a 1% increase in expenses decreases DROA by 0.7574%. Also, from Table 4A we can see that there a conflict between two assets, AREA and total assets, with respect to DROA; increasing AREA leads to higher DROA, but increasing assets under management reduces DROA. Increasing area leads to higher milk revenue, a numerator effect in calculation of DROA, but increasing the value of assets under management increases the denominator of the calculation, thereby reducing DROA. The main difference between the two business types is the relative size of the parameter values, particularly for the FWE parameter, which for OOP is approximately a multiple of 3 greater than that for HOSM. This difference indicates that HOSM are attempting to reduce costs to their lowest possible level, while still maintaining milk production. The other major difference in parameter values is for the labour variable, for OOP additional labour adds to DROA by 0.2175% for each additional 1% of labour added, whereas for HOSM labour reduces DROA.

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

	Owner Operators		Sharemilkers	
Parameter	Estimate	Std. Error	Estimate	Std. Error
Constant	2.5973***	0.6115	-6.6920***	1.5836
log(MS)	0.7976***	0.1025	0.7609***	0.2586
log(FWE)	-0.7534***	0.0911	-0.2443**	0.2303
log(AREA)	0.2144**	0.0837		
log(TOTFTE)	0.2175***	0.0680	-0.3497*	0.1691
log(DASS)	-0.3670***	0.0400		

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

Inefficiency Model

Parameter values for the inefficiency model are included in Table 4B. From this table we can see which variables positively or negatively affect 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.

In the OOP model the major contributors to (in)efficiency were time and FS. Parameter values for feeding system variables indicate that efficiency increased as FS number increased; alternatively systems with higher levels of supplementary feeding were more efficient in achieving the predicted DROA of the frontier model. The time variable indicates that producers improved the efficiency of achieving the predicted DROA as years progressed. This may be due to producers developing the skills to respond to price volatility by improving cost control mechanisms. The value of the milking interval variable indicates that those producers milking at different intervals than twice-a-day were less efficient at achieving the predicted DROA, which would be somewhat expected as milk yield is reduced with lower milking frequency. There appears to be little regional impact on efficiency, with some numerical differences and only one region being statistically significant in the efficiency model. Sharemilker efficiency increased over time but at a decreasing rate, however in contrast to the OOP, there was no FS effect on HOSM efficiency. Other factors impacting efficiency for HOSM were number of cows milked, which reduced efficiency and assets under management, which had a very small positive impact on efficiency.

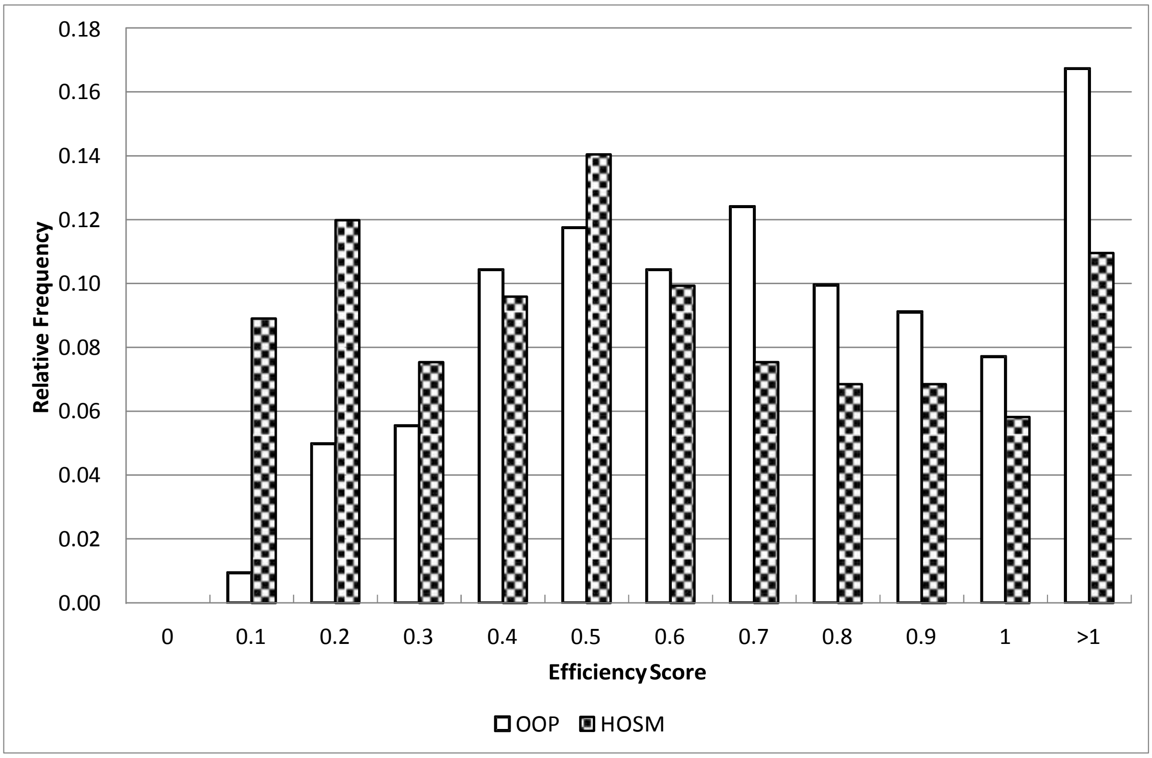
Overall mean efficiency estimated by the SFA model for OOP and HOSM was 70.38% and 55.12%, respectively. The estimated value of γ for the OOP model is 0.8419 and for the HOSM γ is 0.9731, indicating that 84% and 97% of the variance in the error term is due to the inefficiency component of the model. The actual and predicted DROA and DROA efficiency for each FS for OOP are reported in Table 5. From this table we can see that predicted DROA decreases with increasing FS number, but efficiency increases; in contrast the actual DROA increases from FS 1 to FS 3 then decreases after FS 3. Also, except for FS 1 compared to FS 3, 4, and 5 ($P < 0.1$), there is no difference between the actual DROA across FS for OOP. Conversely, when examining the predicted DROA for OOP, except for FS 1 and 2, the predicted DROA is significantly different across all other FS. The actual and predicted DROA for HOSM are reported in Table 6 and different to the OOP models, the actual and predicted DROA generally increase from FS 1 to FS 5, with the exception of the predicted DROA for FS 4 and 5.

Table 4B: Inefficiency model parameters for DROA.

	Owner Operator		Sharemilker	
	Estimate	s.e.	Estimate	s.e.
Constant	0.5537	0.4145	3.8588***	1.4668
Time	-0.1444***	0.0513	-1.8625**	0.7865
Time^2			0.1954**	0.0814
System 2	-0.4823**	0.2364	-1.6399	1.4136
System 3	-0.5653**	0.2403	-1.0708	1.3693
System 4	-0.5505**	0.2449	-1.5871	1.7008
System 5	-1.1198***	0.4058	1.9997	1.7469
Region 1	-0.2161	0.2889	-4.7024**	2.3458
Region 2	-0.3916	0.3414	-1.1336	1.3516
Region 3	-0.5911*	0.3389	-2.1955	1.5397
Region 4	0.4214	0.3239	-0.7243	1.3729
Region 5	-0.7405	0.4566	-3.4935**	1.6129
Region 6	0.3601	0.3185	-0.4781	1.0900
Region 7	0.2995	0.2621	-1.3433	1.0164
Milking Interval	0.3472*	0.1994		
Cows			0.0147**	0.0064
Dairy Assets			-0.00001**	0.0000
σ_s^2	0.9916***	0.2940	4.6783	1.8391
γ	0.8419***	0.0475	0.9731	0.0113
σ_u^2	0.8348***	0.2919	4.5524	1.8314
σ_v^2	0.1568***	0.0172	0.1259	0.0337
Mean Efficiency	0.7038		0.5512	

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

Figure 1: Relative frequency of efficiency score for Owner Operators (OOP) and Herd Owning Sharemilkers (HOSM).



For HOSM there was no difference in the actual DROA between systems. However, there were significant differences ($P < 0.05$), between most systems except for FS 1 and 2, and FS 5 and FS3 and 4. Also different to the OOP model DROA efficiency for HOSM generally increased with FS until FS 4 then dropped from FS4 to FS5.

Figure 1 presents the relative frequency for each efficiency score range. From this figure it is possible to see that owner operators tend to have relatively small number of observations in the low efficiency score ranges (0.1 to 0.3). Conversely, the distribution of relative frequency for sharemilkers appears to be at least bi-modal with over 20% of observations being in the low efficiency score ranges of 0.1 to 0.2, then a fall in relative frequency for the 0.3 range and increasing again. Also, observable is the frequency of OOP in the higher efficiency score ranges is much higher than sharemilkers, as expected from the previous discussion.

Another way to look at the differences in DROA is to consider the differences in operating profit. We know that DROA is the difference between operating profit and rental costs divided by DASS, given that we know the predicted DROA, rental costs and DASS, we can calculate the difference between actual and predicted operating profit, or the change in operating profit required to achieve the predicted DROA, assuming everything else is held constant. Using this we calculated the differences in operating profit across FS, these are shown in Table 7. One point to note from this table is that except for FS 5, there is very little variation across the differences in actual and predicted operating profit for OOP, the main reason differences across FS for DROA was due to asset value, and the efficiency of producers in each FS to achieve the frontier level of DROA.

Table 5: Actual and predicted DROA and DROA efficiency across feeding systems for owner operators.

FS	Number	Actual DROA (A)	Predicted DROA (P)	DROA Efficiency (A/P) (%)
1	50	0.0512	0.0974	52.60
2	261	0.0612	0.0937	65.36
3	384	0.0637	0.0881	72.32
4	259	0.0624	0.0844	73.87
5	109	0.0609	0.0778	78.26

Table 6: Actual and predicted DROA and DROA efficiency across feeding systems for herd owning sharemilkers.

FS	Number	Actual DROA (A)	Predicted DROA (P)	DROA Efficiency (A/P) (%)
1	12	0.1420	0.3066	48.67
2	76	0.1721	0.3186	54.56
3	129	0.1961	0.3475	55.93
4	56	0.2138	0.3669	58.10
5	19	0.1727	0.3578	47.08

The differences in actual and predicted operating profit for HOSM exhibit more variation across FS. This coupled with some significant differences in DASS values for HOSM contributes to the low efficiency of HOSM across all FS in achieving the frontier DROA.

Conclusions

Stochastic frontier analysis was employed to study the efficiency of DROA in the seasonal milk production system of New Zealand. The production function incorporated MS produced, farm working expenses, milking area, and total labour usage. Inefficiency was captured with a subsequent model that included milking interval, feeding system, region and the number of cows milked.

Table 7: Difference in operating profit calculated from the difference in actual and predicted DROA for owner operators and sharemilkers across feeding systems.

	1	2	3	4	5
Owner Operator	$200,613	$212,101	$213,809	$226,174	$152,391
Sharemilker	$93,365	$160,290	$170,123	$230,477	$257,844

The inefficiency model estimated that owner operators are somewhat efficient as a group at achieving the frontier level of DROA with a mean efficiency of 70.38 per cent, however herd owning sharemilkers are much less efficient with a mean efficiency of 48 per cent. The main factors effecting efficiency of owner operators were feeding system and a time variable, with efficiency increasing with both time and level of concentrate fed. Efficiency of sharemilkers increased over the period of study at a decreasing rate, and was marginally impacted by cows milked and total dairy assets, and contrary to the owner operator model, feeding system was not a significant factor affecting the efficiency of achieving the frontier DROA for sharemilkers.

Although the models show that producers can be efficient in achieving the frontier level of DROA not all producers are on or near the frontier. It must be remembered that DROA is a measure of profit and that not all producers would be profit maximisers, and that deviations from profit maximisation due to other goals of the farm business are not captured in the types of models used in this research. However, the technique can show producers how small changes in their business can improve the overall profitability of the business, which may enhance the ability of the business owners to achieve other defined goals.

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