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Profit efficiency among peri-urban dairy farms in Odisha: an application of the stochastic frontier function

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Abstract This study examines the profit efficiency of peri-urban dairy farms in Odisha. Inefficiencies are found, and the profit efficiency ranges from 2% to 92%; the mean is 54%. The mean profit efficiency is 76% for large farms, the highest, 64% for medium-size farms, and 60% for small farms. Concentrate price and labour wage rates affect profits significantly. Profit inefficiency is impacted positively and significantly by herd size and negatively and significantly by herd composition; decreasing the herd size and increasing the number of crossbred cows would enhance profit efficiency. Improving education and dairy farm experience would enhance the profit efficiency.

Keywords Inefficiency model, peri-urban, profit efficiency, stochastic profit frontier

JEL Codes C13, C21, D22, Q12

India is the largest milk producer in the world, producing 187.7 million tons of milk in 2018–19 (NDDB 2019). Demand is growing, however, and India needs to produce about 380–400 million tons of milk by 2050 to fulfil the growing demand (NDRI 2015). Dairy enterprises need to be profitable and efficient if this target is to be achieved, but the productivity efficiency is lower than in developed countries, and an assessment of the profit efficiency of dairy farmers will provide the context for development.

In Odisha, dairy farming has always been looked upon as a subsidiary occupation. Milk production almost doubled from 2000 to 2.31 million tons in 2019 (NDDB 2019), and production has been increasing, but the per capita availability of milk, 145 g per day on average, is much lower than the national average (394 g per day) (NDDB 2019), and the livestock potential is poor (Kale et al. 2016). The state promotes dairy entrepreneurship, and dairy farms are coming up in peri-urban areas to meet the high demand for milk in urban areas (FIAPO 2017) and take advantage of the easy access to markets (Bohra et al. 2004).

The competitiveness of a dairy enterprise depends on economic and technical decisions that influence its profitability (Calsamiglia et al. 2018). The main optimization problem of achieving enterprise objectives is identifying a combination of inputs and outputs at the given level of technological knowledge (Fandel and Lorth 2009). Efficiency is a farm's capability to produce a given level of output at minimum cost (Farrell 1957). It has been reported that in both urban and peri-urban areas farm efficiency, amid increasing competition with intensive livestock producers, is always a major concern for policymakers (Nganga et al. 2010).

The concept of profit efficiency considers the effects of the choices of production on costs and revenues. The choices of production help to provide complementary information in the analysis of farm-specific profit efficiency (Mawa et al. 2014). The concept of profit efficiency is, therefore, broader than that of cost efficiency. The measurement of farm-specific efficiency is an important area of research (Nganga et al. 2010) because profitability depends on the efficiency of an enterprise and agricultural growth is directly linked to profit (Abdulai and Huffman 2000). Efficiency can be technical, allocative, or economic; economic efficiency is a combination of technical and allocative efficiency.

Efficiency has traditionally been estimated using the production function approach (Battese and Coelli 1995; Ojo 2003), but it is now considered inappropriate because factor endowments and regional price differences are present; instead, the stochastic model approach, which considers inputs and outputs random variables, is held to be appropriate in dealing with technological uncertainties in the real world (Davtalab-Olyaie, Asgharian, and Nia 2019). The application of the stochastic profit function helps to estimate farm-specific economic efficiency directly, therefore (Ali and Flinn 1989; Rahman 2003; Kumbhakar, Biswas, and Bailey 1989).

To gain insight into the performance efficiency of peri-urban dairy farms in Odisha, we estimate the profit efficiency of the dairy farms in our sample and construct an inefficiency model to determine the socio-economic variables that cause variations in profit efficiency.

Methodology

The Centre for Environmental Studies, Forest, Environment and Climate Change Department, Government of Odisha divides the state into 10 agroclimatic zones. We conducted the study in 2019 in the east and south-eastern coastal plains zone. The state has 10 agroclimatic zones; the east and south-eastern coastal plain zone, comprising six districts, has the highest milk-producing potential. We randomly selected two districts, Khorda and Cuttack, from these six districts.

On the basis of the peri-urban dairy farms available, we selected an urban area from each district—Bhubaneswar from Khorda district and Cuttack from Cuttack district (Figure 1). We randomly selected 60 peri-urban dairy farms from each urban area and formed our sample of 120 peri-urban dairy farms in 2019. We collected the cross-sectional primary data of this sample.

Farmers are officially classified by landholding, but dairy farms are not categorized by their number of

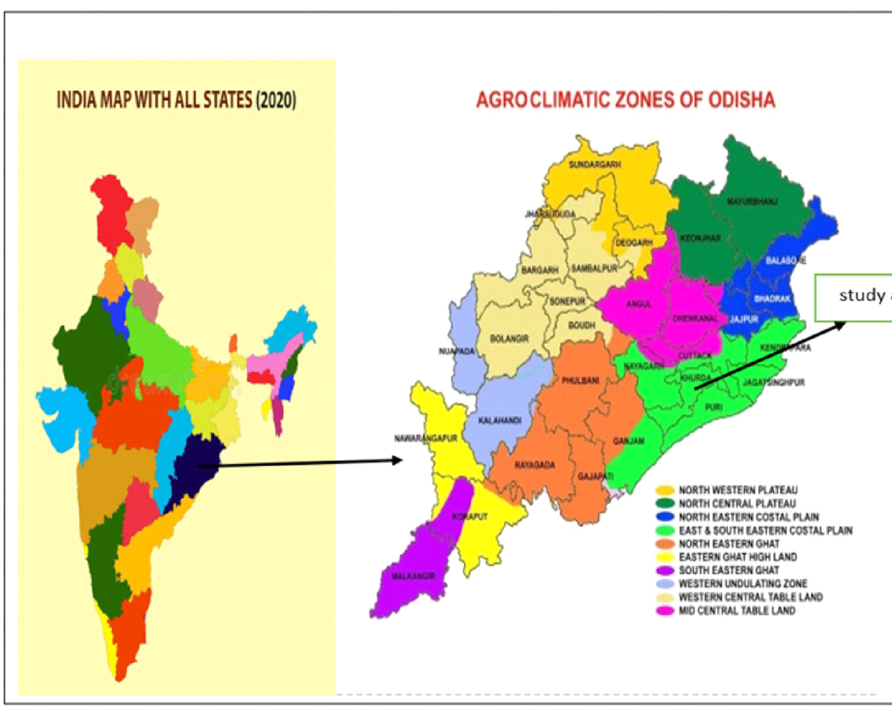

Figure 1 Location of the study area

animals because the animal density varies by region. Complete enumeration was carried out in the study area and the dairy farms were categorized into small (up to 18 milch animals), medium (18–24 milch animals), and large (above 24 milch animals) categories using the cumulative square root frequency method (Singh and Mangat 2013). Herds have several different types of animal; to make the estimation easier, we converted a herd into standard animal units (SAU) (Feroze et al. 2015). Following the approach of Trivedi and Pareek (1963), we calculated the mean educational score in our sample by assigning scores: 0 for illiterate, 1 for primary education, 2 for middle education, 3 for secondary education, 4 for senior secondary education, and 5 for graduate and above.

We estimated the profit efficiency using farm- and animal-level cross-sectional household data (Ali and Flinn 1989; Mawa et al. 2014; Adamu and Bakari 2015; Lalrinsangpuii et al. 2016; Kumari, Chandel, and Lal 2020). Several econometric models estimate profit efficiency, but all make some assumptions and errors in measurement. Data envelopment analysis (DEA) assumes that all the deviation from the frontier is inefficiency, but we can not assume it, because variability is inherent in dairy products—due to factors like temperature, disease, and natural hazards, like a cyclone in the study area. Poor farmers in Odisha, a low-income state, are not able to keep accurate records of every animal; there may be errors in measurement in the data collected from farmers, and these errors may influence the positioning and shape of the frontier if it is estimated using DEA. Therefore, we chose a stochastic frontier model to estimate the profit efficiency across the herd size categories.

We conducted this study in two stages. In the first stage, we assumed that inefficiency effects are identically distributed (Battese and Coelli 1995) and used a stochastic frontier approach to obtain profit inefficiencies. The second stage contradicts the identical distribution of inefficiency effects in the stochastic frontier (Battese and Coelli 1995) and we used the ordinary least squares (OLS) approach to regress these inefficiencies on farm-specific factors. The behaviour of this profit function is consistent with the concept of the stochastic frontier:

$$\pi i = f(P_{ij}, Z_{ik}).\ \exp(\xi_i) \qquad \ldots(1)$$

where,

π_i is normalized profit of the ith farm, defined as gross revenue less variable cost, divided by farm-specific output price;

P_{ij} is the price of jth variable input faced by the ith farm, divided by output price;

Z_{ik} is the level of the kth fixed factor on the ith farm;

ξ_i is error term; and

I is 1, …, n, number of farms in the sample.

The error term ξ_i is assumed to behave in a manner consistent with the frontier concept:

$$\xi_i = v_i - u_i \qquad \ldots(2)$$

where,

v_i is assumed to be independently and identically distributed with N $(0, \sigma_v^2)$ two-sided error terms and independent of u_i.

u_i represents non-negative random variables associated with inefficiency in production.

The profit efficiency of farm 'i' in the context of the stochastic frontier profit function is:

$$EFF_i = E[\exp(-u_i) \mid \xi_i] = E[\exp(-\delta_0 - \Sigma_{d=1}^{D} \delta_d W_{di})|\xi_i] \qquad \ldots(3)$$

where,

E is the expectation operator.

We calculated the profit efficiency by obtaining the expressions for conditional expectation u_i upon the observed value of ξ_i. We used the maximum likelihood method to estimate the unknown parameters; we estimated the stochastic frontier and inefficiency effects function simultaneously. The likelihood function is expressed in terms of the variance parameters $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2 / \sigma^2$ (Battese and Coelli 1995).

The explicit Cobb–Douglas functional form of the stochastic frontier profit function in Equation 1 is

$$\ln\pi_i = \ln \beta_0 + \ln \beta_{1i}P_{1i} + \ln \beta_{2i}P_{2i} + \ln \beta_{3i}P_{3i} + \ln \beta_{4i}P_{4i} + \ln Z_{5i} + v_i - u_i \qquad \ldots(4)$$

where,

π_i is normalized profit (INR);

P_{1i} is normalized green fodder price (INR);

P_{2i} is the normalized dry fodder price (INR);

P_{3i} is the normalized concentrate price (INR);

P_{4i} is the normalized wage of labour (INR);

Z_{5i} is the fixed cost (INR); and

v_i-u_i is the error term.

Now, the inefficiency model u_i is defined as

$$\mu_i = \delta_0 + \Sigma_{d=1}^{5} \delta_{di} W_{di} \quad \ldots(5)$$

where,

W_1 is the age of the dairy farm owner (in years);

W_2 is the education of the dairy farm owner;

W_3 is the herd size (in numbers);

W_4 is the herd composition; and

W_5 is the experience in dairy farming (in years).

The herd composition is indicated by the ratio of the total number of crossbred to the total herd size. We used FRONTIER 4.1 to obtain the maximum likelihood estimates of the stochastic frontier profit function and inefficiency model (Coelli 1996).

Results and discussion

The decision-making process in a dairy enterprise influences its profitability; therefore, we need information on the peri-urban dairy farms in our sample (Table 1).

The dairy farmers were 41 years old on average. The household heads of large farms were better educated than the heads of medium-size and small farm; the mean education score was 3.26. The availability of green fodder was limited—only 5.25 kg of green fodder, and 8 kg of dry fodder, was available per SAU per day on average—and the animals depended on concentrate, around 5.77 kg per SAU per day.

The farmers sold milk directly to consumers. The profit per litre was highest for large farms, followed by small and medium-size farms. The fixed cost was higher for medium-size farms, and it accounted for their low profitability. The demand in urban areas was high, and the price of milk was reasonable. Cow milk is used to make traditional sweets; the demand for cow milk is higher than for buffalo milk, and so is the profit per litre. Cow milk farms of all herd size categories contribute an almost equal percentage of the supply but small buffalo milk farms have fewer buffaloes and, therefore, contribute a smaller percentage of the supply (Figure 2).

Maximum likelihood estimates of profit frontier function

The OLS function provided the estimates of the average production function; the maximum likelihood estimation (MLE) model provided the estimates of the stochastic production frontier. On the basis of the stochastic production frontier, we used the MLE technique to estimate the farm efficiency. The parameter estimates obtained are the elasticities of profit with respect to the different input prices (Table 2).

Concentrate prices and labour wages affected profits significantly overall. Concentrate prices had a negative effect on profits for medium-size and large farms but a positive effect for small farms. A positive effect is possible if when prices rise, farmers reduce the quantity of concentrate they feed their herd so much that the overall cost falls or if they purchase higher quantities

Table 1 Peri-urban dairy farms in our sample

Particulars	Small	Medium	Large	Overall
Age	42	41	39	41
Education	3.22	2.82	3.93	3.26
Green fodder (kg per SAU per day)	5.49	5.19	5.08	5.25
Dry fodder (kg per SAU per day)	8.51	7.93	7.62	8.02
Concentrate (kg per SAU per day)	6.00	5.79	5.51	5.77
Profit per litre of cow milk (INR)	9.23	8.09	13.21	9.84
Profit per litre of buffalo milk (INR)	6.46	4.55	9.10	6.47

Source Authors' own calculation

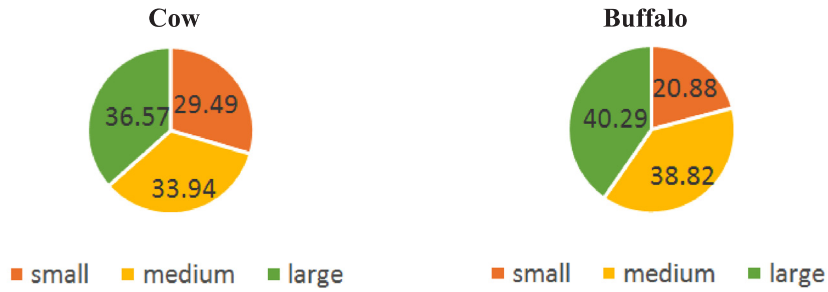

Figure 2 Dairy farms' share (%) of cow milk and buffalo milk

Table 2 Estimate of maximum likelihood estimate of parameters of stochastic Cobb–Douglas profit frontier function

Variables	Small	Medium	Large	Overall
Intercept	0.124	0.634	15.62	0.122
	(0.921)	(1.560)	(9.28)	(0.449)
Green fodder price	–0.212	0.907**	–1.15**	0.0304
	(0.548)	(0.305)	(0.059)	(0.470)
Dry fodder price	–0.609**	0.193	0.47	0.0751
	(0.120)	(0.451)	(0.940)	(0.672)
Concentrate price	0.247	–0.204	–2.91	0.150*
	(0.117)	(0.630)	(2.95)	(0.011)
Labour wage	–0.339	–0.324**	–3.84	–0.217**
	(0.830)	(0.058)	(3.48)	(0.015)
Fixed cost	0.167	0.869**	–0.184	0.230
	(0.730)	(0.339)	(0.935)	(0.294)
ó^2	0.760**	0.167**	0.211	0.941*
	(0.092)	(0.050)	(0.157)	(0.155)
Ò	0.999**	0.393	0.622**	0.958**
	(0.00004)	(0.544)	(0.007)	(0.025)
Log likelihood	–0.364	–0.105	–0.115	–0.1005
LR test of the one"sided error	0.353	0.625	0.169	0.280

Note Figures in parentheses indicate standard error; * significant at 5%; **significant at 1% level of significance
Source Authors' own calculation

of concentrate. But the average quantity of concentrate farmers fed animals did not decrease (Table 1); so, farmers continued their purchase. Many studies (Gupta and Raj 1993; Meena et al. 2012; Kumari and Malhotra 2018) suggest that animals yield more milk if fed concentrate and, therefore, profit increases; the cost of concentrate may be growing slower than the increase in revenue from the improved milk yield. The cost of labour rises as the labour hours increase, reducing the profit; therefore, profit has a negative relationship with labour.

Mostly unchaffed rice straw, without any pre-treatment, is easily available in the study area and at low cost; it is used as dry fodder by farmers, but it reduces the yield of milk (Aquino et al. 2020) and, therefore, the profit. Feeding animals mineral mixture and concentrate would raise their productivity and yield; therefore, reducing the prices of concentrate would increase their use and, in turn, yield and profit. Developing infrastructure would help increase profits. Reducing the number of labour hours would raise the profits of medium-size farms.

Little green fodder is available in the study area. Large farms produce their own green fodder to reduce procurement cost and increase profits; so, green fodder costs large farms less than other feeds, and only the price of green fodder significantly affected the profits of large farms. Overall, all the feed coefficients are positive; a rise in prices would increase profits, and so the farmers should use more of the feeds and increase their demand despite rising prices. The coefficients of the Cobb–Douglas function are treated as elasticities; and if the price rise by 1.0% for dry fodder, green fodder, and concentrate, the profit would increase, respectively, by 3.0%, 7.5%, and 15.0%.

The value of γ must be bounded between 0 and 1 such that if $\gamma=0$ inefficiency is not present and if $\gamma=1$ there is no random noise. The estimated value of γ is close to 1 and, significantly, different from 0 across all the herd size categories, establishing that inefficiencies exist among dairy farmers. The value of γ was significant for all farm sizes except medium-size farms. The estimate of γ was 0.958 overall, or differences in farmer practices, rather than random variability, explain 95% of the variation in the profit. The value of γ^2 indicates the fitness and correctness of the specified distributional assumptions of the composite error term. The estimated across all herd size categories except large farms was significant, indicating a good fit. The milk yield per SAU was positively related to profit efficiency: an increase in the milk yield will ultimately improve the profit efficiency of farmers (Figure 3).

Profit inefficiency model

Inefficiency existed in the study area. We fitted an inefficiency model using values obtained from the stochastic frontier model and regressed the model—on factors like age, education, herd size, herd composition, and experience in dairy farming—to see the effects of the factors on inefficiency (Table 3).

We expected that the risk-bearing ability of farmers decreases with an increase in age, thereby increasing profit efficiency (Adamu and Bakari 2015). The sign is negative overall and for large farms but positive for small and medium-size farms; age significantly affects adoption on medium-size farms. More of younger farmers than older ones adopt profitable, but costly, technologies probably because they have more time to reap the benefits (Lalrinsangpuii et al. 2016).

For small, medium-size, and large farms, education was significant, and it had a negative coefficient: better education improves farmers' knowledge of dairy management practices and chances for increasing profit. The coefficient of herd composition is negative, or the yield potential of crossbred cows is high, and farmers are likely to raise yield if they increase the number of crossbred cows in their herd. Herd size and composition significantly affect profit inefficiency overall. Farming experience negatively impacts profit inefficiency, or adopting better technologies lets an experienced dairy farmer reduce profit inefficiencies (Rahman 2003).

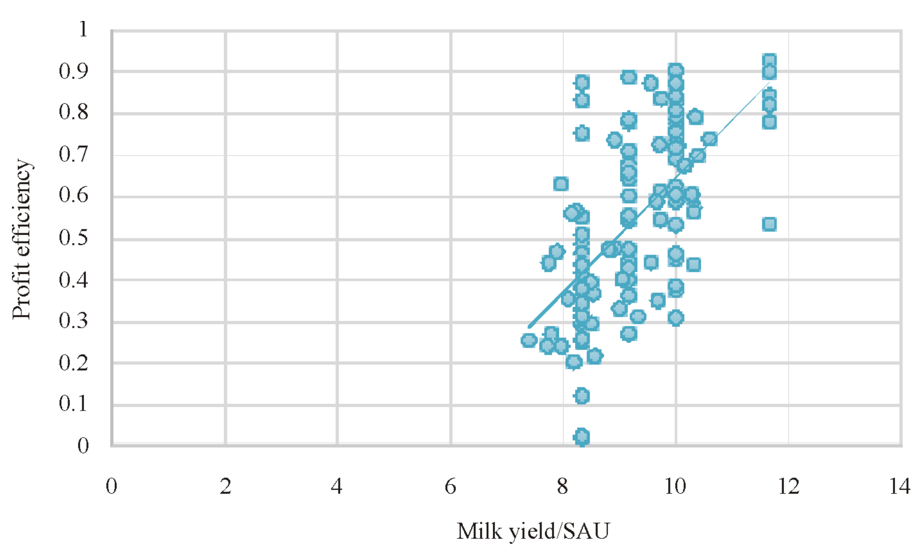

Figure 3 Relationship between profit efficiency and milk yield/ SAU

Table 3 Determinants of dairy farm–specific profit inefficiency

Variables	Small	Medium	Large	Overall
Intercept	0.553	0.450	0.433	0.507
	(0.425)	(0.702)	(0.331)	(0.179)
Age	0.013	0.009**	-0.00089	-0.01
	(0.003)	(0.005)	(0.0029)	(0.002)
Education	-0.051*	-0.038*	-0.026**	-0.048
	(0.023)	(0.019)	(0.014)	(0.012)
Herd size	0.003	0.0054	0.007*	0.0048*
	(0.014)	(0.019)	(0.003)	(0.002)
Herd	-0.405	-0.284	-0.03	-0.311*
composition	(0.246)	(0.310)	(0.328)	(0.129)
Experience	-0.007	-0.10*	-0.004	-0.0049
	(0.0098)	(0.012)	(0.0064)	(0.004)
R^2	0.6743	0.7416	0.7268	0.6820
Number of observations	49	41	30	120

Note Figures in parentheses indicate standard error;
* significant at 5%; **significant at 1% level of significance
Source Authors' own calculation

Frequency distribution of dairy farms by profit efficiency

We used the stochastic Cobb–Douglas profit frontier to obtain the profit efficiency of farms and the frequency distribution (Table 4). The profit efficiency ranged from 2% to 92%, averaging 54%. Inefficiency in the study area accounted for 46%. The distribution of profit efficiency was uneven. The mean profit efficiency was 76% for large farms, the highest, 64% for medium-size farms, and 60% for small farms. Profit inefficiency caused a loss of profit: 40% in small farms, 36% in medium farms, and 24% in large farms. The profit efficiency ranged from 18% to 99% in small farms, 24% to 99% in medium-size farms, and 46% to 88% in large farms.

We conducted a box plot analysis of dairy farms by herd size category (Figure 4). The cross in the box plot shows the mean score of profit efficiency, the horizontal line at the middle the median, and the vertical length the standard deviation. The vertical length of the box and whisker shows that small farms experienced the highest variation in the efficiency score and large farms the least. The profit efficiency of most farms ranges from 40% to 80%.

Table 4 Frequency distribution of peri-urban dairy farms by profit efficiency

Efficiency estimate (%)	Small	Medium	Large	Overall
0–10	0	0	0	2
				(1.67)
10–20	1	0	0	1
	(2.04)	(0)	(0)	(0.83)
20–30	5	2	0	14
	(10.20)	(4.87)	(0)	(11.67)
30–40	3	4	0	18
	(6.12)	(9.75)	(0)	(15.00)
40–50	6	7	1	19
	(12.24)	(17.07)	(3.33)	(15.83)
50–60	11	4	0	13
	(22.44)	(9.75)	(0)	(10.83)
60–70	8	3	4	16
	(16.32)	(7.31)	(13.33)	(13.33)
70–80	1	11	15	21
	(2.04)	(26.82)	(50)	(17.5)
80–90	6	2	10	13
	(12.24)	(4.87)	(33.33)	(10.83)
90–100	8	8	0	3
	(16.32)	(19.51)	(0)	(2.50)
Minimum	18	24	46	2
Maximum	99	99	88	92
Mean	60	64	76	54
Total number of farms	49	41	30	120

Note Figures in parentheses indicate percentage of the total sampled dairy farm
Source Authors' own calculation

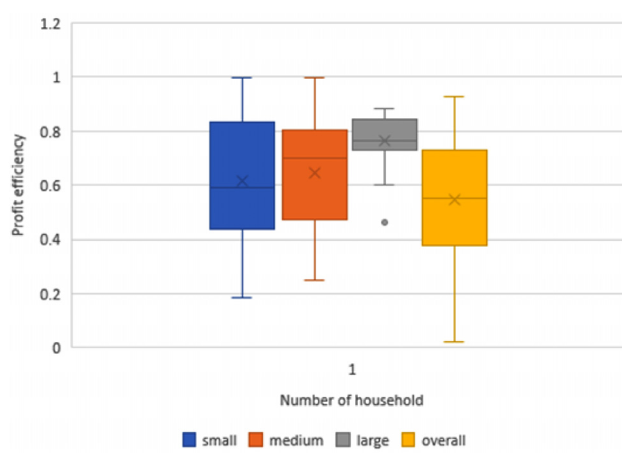

Figure 4 Box plot of frequency distribution of households by herd size and profit efficiency

Conclusions

The study used a stochastic profit frontier to analyse the profit efficiency of the peri-urban dairy farms in our sample. The mean profit efficiency was estimated at 54%. The profit efficiency varied from 2% to 92%, indicating inefficiency in all the farms; the profit efficiency can be improved by increasing technical and allocative efficiency.

Concentrate price and labour wages significantly affected profits. Surprisingly, the concentrate price had a positive impact on profit for small farms, probably because small farmers feed their herd animals concentrate to raise milk yield and production, and the resulting increase in revenue is so high that profits increases too. Also, the parameters of the profit frontier suggest that a 1.0% increase in the price of dry fodder, green fodder, and concentrate would increase profits, respectively, by 3.0%, 7.5%, and 15.0%. Profit inefficiency is impacted positively and significantly by herd size and negatively and significantly by herd compositionl; farmers can improve profit efficiency by decreasing the herd size and increasing the number of crossbred cows in the herd.

Better education and dairy farming experience improves the efficiency of dairy farms; therefore, inefficiencies among farmers can be reduced by improving the level of education and providing the animals better feed at a subsidized rate.

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