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Evaluating Yield Gap and Yield Improvement Potential in the Dairy Sector of Pakistan

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A survey data of 600 dairy farms obtained from the largest dairy cluster in Pakistan's Punjab was used to provide new evidence on the yield gap and yield improvement potential of dairy farms producing milk and meat. The yield gap was estimated by the frontier-based input distance function analysis. The results indicated that a large yield gap exists in the sample where an average dairy farm has a yield improvement potential of 55 percent. By closing the gap, an average dairy farm can increase yearly production of fat-corrected milk (FCM) by 120,036 kg and non-milking herd for meat by 25 heads. The evidence also shows that small farms (< 25 herd-size) are technically more efficient than those of medium (26 ≤ herd-size ≤ 50) and large farms (> 50 herd-size). The study finds clear evidence of an efficiency boost for keeping a higher share of non-milking to milking herd, a greater proportion of exotic cows to local breeds, and a higher farm-gate price of milk, which can all trigger efficiency gains. Policymakers hence have room to provide adequate intervention strategies that can help in enhancing efficiency.

JEL Classification: D24, L25, Q12, Q13, Q18
Keywords: Yield Gap, Yield Potential, Input Distance Function, Technical Efficiency, Dairy Farms

1. INTRODUCTION

The world human population is projected to exceed 9 billion by 2050; a continuing population and consumption growth means the need for more processed food, meat, dairy, and fish to meet the global demand (Godfray, et al. 2010). Higher production targets, without converting additional agricultural land and water resources into dairy production, will require increased productivity. Thus, exploring

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this potential is necessary to formulate intervention strategies. Although extensive literature available about yield gap in the crop sector (e.g., van Ittersum, et al. 2013; FAO, 2015; Fischer, 2015; Silva, et al. 2017), there is a dearth of knowledge on the yield gap in dairy sectors of developing countries where yields are low and thus have large potential of increasing.

The scant literature on the dairy yield gap tends to examine mixed crop and livestock farmers in Sub-Saharan Africa (Henderson, et al. 2016), cross-bred cattle in the North-Eastern state of India (Paul and Chandel, 2010), milk production in the Indian Himalayan state of Meghalaya (Kemboi, et al. 2021), attainable bovine milk yields in Ethiopia and India (Mayberry, et al. 2017) and genetic yield potential of milk in Pakistan (Iqbal & Ahmad, 1999).

Pakistan is one of the five major milk producers in the world producing 65.5 billion kg of milk/per year from ninety-seven million cattle and buffaloes (GoP, 2022). Milk is easily the largest agricultural produce in the country with a market worth US$20 billion, valued at a dairy farm-gate price of PKR 50/kg. Most of the cattle population consists of indigenous breeds, which have low milk yield. Nearly 62 percent of milk comes from buffaloes and 38 percent from cows with average lactation yields of less than 2300 kg, which is far less than average lactation yields of more than 6000 kg in the developed world (Burki & Khan, 2019).

Gross milk production in Pakistan has increased over the past decades mainly due to the growth in the population of dairy animals (Burki & Khan, 2019). Due to the growth in human population, increased incomes, and urbanisation, demand for milk and meat will increase in the near future (Herrero & Thornton, 2013). To meet the demand, increasing the production of low-yielding cattle by cross-breeding offers the greatest potential, however, genetic improvement is a long-term strategy spanning decades (Burki & Khan, 2019). A short-term strategy is to close the yield gap to ensure a potential increase in yields.

The objective of this paper is to evaluate and provide new evidence on the yield gap and yield improvement potential in Pakistan's largest dairy cluster by estimating the yield gap by the frontier-based input distance function. The paper uses a sample survey of 600 dairy farms drawn from five districts located near Lahore metropolitan city. The dairy farms in this largest cluster share many common characteristics of dairy farms in other dairy clusters of the region Therefore, the analysis will have many similarities in outcomes to give the findings wider applicability.

2. LITERATURE REVIEW

The yield gap refers to the difference between realised yields and the best that can be achieved using available genetic material, technologies, and management (Godfray, et al. 2010). Yield gap analysis identifies growth potential and constraints in existing production systems for future yield improvement with the adoption of better management practices and implementation of improved production technologies (Nin-Pratt, et al. 2011). Iqbal & Ahmad (1999) provide evidence of milk yield gap in Pakistan indicating that productivity in the dairy sector is far below than its genetic potential. Their findings suggest that by overcoming the yield gap, milk production can go up by 50 percent to 100 percent.

Actual yield generally refers to the average observed yield of sampled farmers in a particular area. The potential yield has several definitions, e.g., the yield obtained from experimental stations, economically feasible yield, maximum yield observed by farmers, and yield obtained from mathematical crop simulation models (Singh, et al. 2009). Agronomists often study yield gaps from crop simulation models (van Ittersum, et al. 2013; Silva, et al. 2017), which commonly assume that optimal conditions always prevail on farms, which is a moot question. Neumann, et al. (2010) and Nin-Pratt, et al. (2011) have noted that crop simulation models often end up getting over- or under-estimated potential yields. That is why such models have received less attention in yield gap analysis in the livestock and dairy sector.

Recent studies have used the frontier efficiency approach to calculate the yield gap in the livestock and dairy sector (Henderson, et al. 2016; Mayberry, et al. 2017). This approach has strong theoretical underpinning due to which it has been extensively used in several technical efficiency and yield gap assessments in agriculture, dairy, and livestock sectors (Parik, et al. 1995; Abdulai and Tietje, 2007; Neumann, et al. 2010; Nin-Pratt, et al. 2011; Henderson, et al. 2016; Mayberry, et al. 2017; Silva, et al. 2017, and Ahmad, et al. 2021).

Henderson, et al. (2016) have used the stochastic frontier analysis to examine the yield gap in mixed crop and livestock farmers operating in six Sub-Saharan African countries to increase food production and reduce greenhouse gas emissions. Based on a cross-section survey data they find a substantial yield gap at all survey locations and evaluated determinants of technical inefficiency to apprise policymakers to devise intervention strategies. Similarly, Mayberry, et al. (2017) have studied the yield gap in Ethiopia and India to quantify attainable bovine milk yields based on survey data. They also find a huge yield gap in milk production in both countries and propose intervention strategies to increase milk yields.

3. DATA

The data from dairy farms from five districts of Pakistan's Punjab province, *viz.*, Lahore, Kasur, Okara, Pakpattan, and Sheikhupura was used in the study. The data was collected through a survey conducted from June to August 2020. The study area represents one of the largest dairy clusters in Pakistan, where individual dairy farms supply raw milk to households, milk shops, manufacturers of traditional and modern dairy products, and more than two dozen UHT and pasteurised milk plants.[1] Milk is a perishable good that cannot be easily transported from far-off places without a cold chain that is largely missing in the raw milk market, except milk collection network of UHT and pasteurised milk plants. Most raw milk supplies to Lahore metropolitan city come from nearby districts. Therefore, sample farms share many common features of dairy farms in other dairy clusters in the region. The present study focuses on the analysis of five districts considering that the similarities in the outcomes will give the findings of this paper much wider applicability.

[1]Two unique properties of supply of dairy products in developing countries are that milk is perishable, and it is produced during a short-period. These properties require middlemen into the dairy supply who specialise and collect small quantities of milk from several dairy farms to provide efficient delivery to the end users by reaping economies of scale in transportation (Jung, et al. 2012).

A multi-stage sampling technique was used to draw a representative sample of the dairy farms. Firstly, five districts from one of the major dairy clusters in the country were selected based on a purposive sampling plan.[2] The selected districts had a 200 km radius consisting of Lahore and its surrounding districts (although not all of them border it). Secondly, a *mouza* level list of dairy farms provided by the Punjab Livestock and Dairy Development Department (L&DD) served as the total population, which helped to obtain *mouza* level concentration of farms and dairy animals. Thirdly, a cluster sampling method (Lahiri, 1951) was used to sample 15 *mouza*s of each district (Annexure-1). The *mouza* census was done to determine the population of eligible farms in selected *mouzas*. Thereafter, a random sampling plan was used to draw a sample of 8 dairy farms from each *mouza*. Finally, a sample of 600 dairy farms was obtained consisting of 120 farms each from each district.

A ten-page structured questionnaire was used to record information related to the period from 1st January 2019 to 31st December 2019. The questionnaire was pre-tested, revised, and restructured based on responses from the farms. The survey was delayed due to the first wave of the Covid-19 pandemic and was finally carried out between June to August 2020 through in-person interviews with respondents.

4. METHODOLOGY

The frontier efficiency approach was employed to calculate the yield gap from technical efficiency scores obtained from the maximum likelihood estimates of the stochastic frontiers. More specifically, the paper uses the stochastic frontier input distance function approach, which can effectively deal with the effects of data noise arising from measurement and reporting errors and data anomalies often hard to avoid in developing countries.[3] Since dairy farms have more discretionary control over the use of inputs, rather than outputs, it is more appropriate to use input orientation of the distance function (Coelli & Perelman, 2000). Shephard (1970) introduced the input distance function, which is defined in the input requirement set, $L(y)$. It represents the set of all input vectors, $x \in \Re_+^J$, which can produce the output vector, $y \in \Re_+^M$, given by

$$L(Y) = \{x \in \Re_+^J : x \text{ can produce } y\} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

We can express a multiple-input and multiple-output input distance function defined in the input set, $L(y)$, and written as

$$D_I(x, y) = \max_{\theta} \left\{\theta \middle| \left(\frac{x}{\theta}\right) \in L(y)\right\} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

where $D_I(x, y)$ is decreasing in each output level and non-decreasing, homogenous of degree 1 and concave in input vector x (Kumbhakar, et al. 2015). Moreover, $D_I(.) \geq 0$ if $x \in L(y)$. Imposing homogeneity, the input distance function is expressed as

$$\frac{D_I}{x_1} = f\left(\frac{x_2}{x_1}, \dots, \frac{x_j}{x_1}, y\right) \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

[2]Other districts in this cluster includes Sahiwal, Bahawalnagar, Vehari, Khanewal, Mandi Bahauddin, Hafizabad, Chiniot, Faisalabad, Nankana Sahib, Sargodha and Toba Tek Singh.

[3]The distance functions also help avoid the limitations associated with the conventional cost or production frontier approaches, e.g., limited price variation and simultaneous equation bias (Kumbhakar, et al. 2015).

The functional form for the distance function should ideally be flexible, easy to calculate, and should permit the imposition of linear homogeneity (Coelli & Perelman, 2000). A translog function fulfills these properties and is commonly used in such applications. However, it can run into problems by violating monotonicity and curvature properties while multicollinearity is a common obstacle in some datasets, including the data used in this paper. Therefore, a Cobb-Douglas input distance function is chosen as the most appropriate functional form representing underlying technology as it is easy to calculate and allows the imposition of homogeneity. While the transformation function in not concave in the output dimension, this should not be a serious concern as the primary interest of this paper is not the optimisation behaviour, but to obtain technical efficiency measures (Coelli & Perelman, 2000). With this background, the stochastic frontier Cobb-Douglas input distance function for two outputs and five inputs is given below:

$$\ln D_{Ii} = \alpha_0 + \sum_{j=1}^{J} \beta_j \ln x_{ji} + \sum_{m=1}^{M} \gamma_m \ln y_{mi} \quad \dots \quad \dots \quad \dots \quad (4)$$

where $i = 1, 2, \dots, N$ denotes *i*th dairy farm in the sample, y_{mi}, is *m*th output quantity of *i*th farm, x_{ij} is *j*th input quantity of *i*th dairy farm and α, β and γ are unknown parameters to be estimated. Imposing linear homogeneity conditions and rewriting the distance function $D_I(x, y)$ as;

$$\ln D_{Ii} - \ln x_{ji} = \alpha_0 + \sum_{j=2}^{J-1} \beta_j \ln \frac{x_{ji}}{x_{Ji}} + \sum_{m=1}^{M} \gamma_m \ln y_{mi} \quad \dots \quad \dots \quad \dots \quad (5)$$

Given the nature of dairy farming in Pakistan, certain dummy variables are added. Grazing is part of green roughages; however, it cannot be easily quantified in the data of input variables. The paper includes a dummy variable for grazing farm (GR) as a control variable in the base model. The herd size (HS), and district dummy variables, which allow technologies to differ in levels due to the peculiar nature of the dairy farms, were also included. To make this a stochastic function, we added a random error term, v_i, and denote $\ln D_{Ii} = u_i > 0$ and move it to right-hand side of the equation as

$$-\ln x_{ji} = \alpha_0 + \sum_{j=2}^{J-1} \beta_j \ln \frac{x_{ji}}{x_{Ji}} + \sum_{m=1}^{M} \gamma_m \ln y_{mi} + \beta_1 GR_i + \sum_{k=1}^{3} \theta_k HS + \sum_{m=1}^{5} \rho_m District + v_i - u_i \quad \dots \quad \dots \quad \dots \quad \dots \quad (6)$$

where $v_i - u_i$ is the composite error term; v_i is for the stochastic error component, which captures the exogenous shocks due to reasons beyond the control of the dairy farms and are assumed to be independently and identically distributed or $iid\ N(0,\ \sigma_v^2)$; and u_i is a non-negative random variable measuring farm-specific technical inefficiency. A higher value of u_i indicates increase in technical inefficiency and when u_i is zero, it indicates that the farm is perfectly technically efficient.

To explore the impact of farm attributes on technical inefficiency a vector of observable explanatory variables included by assuming that the stochastic term u_i is independently distributed and is obtained by truncation at zero. It implies that the technical inefficiency of each farm can be replaced by a linear function of a vector of explanatory variables specified by;

$$u_i = \delta z_i + \varepsilon_i \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (7)$$

where z_i is a vector of explanatory variables for technical inefficiency, δ is a vector of unknown parameters to be estimated, and ε_i is an unobservable random variable obtained by truncation of the normal distribution with mean zero and variance σ^2 and the truncation point occurs at $-\delta z_i$ or $\varepsilon_i \geq -\delta z_i$.

Two output variables (FCM and non-milking herd) and five input variables (labour, animal capital, concentrate, roughages, and other farm expenses) are used in the estimation. Table 1 provides definition of variables. To construct FCM variable, data of 14,813 milking buffaloes and cows at an average of 25 animals per farm was recorded

Table 1

Definition of Variables

Variable Name	Definition
Input Distance Function	
Labour (Number)	The number of hired, family, and part-time workers measured in full-time equivalents by taking total hours divided by 40 hours for a full-time work week.
Animal Capital (Number)	Animal capital is measured in cow equivalents to account for the quality of a breed. The number is obtained by dividing the value of all milking and dry animals on a farm by average price of Sahiwal cow in the full sample.
Concentrate (PKR '000 per Year)	The concentrate input variable is constructed using the Lowe input aggregator function based on an x-vector measuring 22 concentrate ingredients consumed on each farm and the average price ($\overline{w}_c$) of each ingredient in the full sample written as $X_{ci} = \overline{w}_{c1}x_{c1i} + \overline{w}_{c2i} + \ldots + \overline{w}_{cn}x_{cni}$.
Roughages (PKR '000 per Year)	Roughages input variable is constructed using the Lowe input aggregator function based on actual input quantities (x_r) consumed (in kg) of various purchased and homegrown dry (straws) and green (fodders) roughages and average prices ($\overline{w}_r$) in the full sample written as $X_{Ri} = \overline{w}_{r1}x_{r1i} + \overline{w}_{r2}x_{r2i} + \ldots + \overline{w}_{rn}x_{rni}$.
Other Farm Expenses (PKR '000 per Year)	Simple sum of all expenditures on structures and machinery, expenses on veterinary services, and other direct dairy expenses.
Fat Corrected Milk (kg '000 per Year)	Milk yield is measured in kilograms corrected to 4 percent fat using 6.5 percent fat content for Nili-Ravi and non-descript buffaloes, 4.2 percent for Sahiwal cows, 3.9 percent for Friesian-cross and Jersey cross, 3.7 percent for Friesian pure and 3.5 percent for non-descript cows.
Non-milking Herd (Numbers)	Measures the number of heifers, young stock, and bulls by the end of the year.
Grazing Farm (Yes=1, No=0)	Dummy equals 1, if the farm is feeding on grasses or agricultural grazing, but has feed supplements, and 0 otherwise.
Small Herd-size: ≤ 25	Dummy equals 1, if herd size is less than or equal to 25, 0 otherwise.
Medium Herd-size: 26 ≤ HS ≤ 50	Dummy equals 1, if herd size is greater than or equal to 26 but less than or equal to 50, 0 otherwise.
Large Herd-size: HS > 50	Dummy equals 1, if herd size is more than 50, 0 otherwise.
District Effects	Includes five district dummy variables, where Lahore district is excluded.
Technical Inefficiency Effects	
Time to Metaled Road (Minutes)	Travel time on motorcycle from the farm to the nearest metaled road in minutes.
Small Herd-size: ≤ 25	Dummy equals 1, if herd size is less than or equal to 25, 0 otherwise.
Medium Herd-size: 26 ≤ HS ≤ 50	Dummy equals 1, if herd size is greater than or equal to 26 but less than or equal to 50, 0 otherwise.
Large Herd-size: HS > 50	Dummy equals 1, if herd size is more than 50, 0 otherwise.
The proportion of Exotic Cows to the Milking Herd	The ratio of pure Friesian or Jersey cows to the total milking herd on the farm.
The proportion of Non-milking to Milking Herd	The ratio of the non-milking herd (including calves, heifers, and bulls) to the milking herd on the farm.
Milk Price (PKR)	Average farm gate price of milk in PKR.
Lahore District	Dummy equals 1, if the farm is in Lahore district, 0 otherwise.
Kasur District	Dummy equals 1, if the farm is in Kasur district, 0 otherwise.
Okara District	Dummy equals 1, if the farm is in Okara district, 0 otherwise.
Pakpattan District	Dummy equals 1, if the farm is in Pakpattan district, 0 otherwise.
Sheikhupura District	Dummy equals 1, if the farm is in Sheikhupura district, 0 otherwise.

Table 2

Summary Statistics of Variables in Input Distance Function and Technical Inefficiency Model

Variables	Mean	SD	Min	Max
Input Distance Function				
Labour (Number)	7	4	2	42
Animal Capital (Number)	27	20	6	175
Concentrate (PKR ‘000 per Year)	1212070	1295480	2387	19558614
Roughages (PKR ‘000 per Year)	2675245	7989197	42179	145927857
Other Farm Expenses (PKR ‘000 per Year)	133432	120094	24800	1596250
Fat Corrected Milk (kg ‘000 per Year)	67137	58829	13974	580578
Non-milking Herd (Numbers)	16	12	4	168
Grazing Farm (Yes=1, No=0)	0.27	0.45	0	1
Small Herd-size: ≤ 25	0.27	0.44	0.00	1.00
Medium Herd-size: 26 ≤ HS ≤ 50	0.55	0.50	0.00	1.00
Large Herd-size: HS > 50	0.18	0.39	0.00	1.00
Lahore District (Yes=1, No=0)	0.20	0.40	0	1
Kasur District (Yes=1, No=0)	0.20	0.40	0	1
Okara District (Yes=1, No=0)	0.20	0.40	0	1
Pakpattan District (Yes=1, No=0)	0.20	0.40	0	1
Sheikhupura District (Yes=1, No=0)	0.20	0.40	0	1
Technical Inefficiency Effects				
Time to Metaled Road (Minutes)	9	8	0	40
Small Herd-size: ≤ 25	0.27	0.44	0.00	1.00
Medium Herd-size: 26 ≤ HS ≤ 50	0.55	0.50	0.00	1.00
Large Herd-size: HS > 50	0.18	0.39	0.00	1.00
The Proportion of Exotic Cow to Milking Herd	0.12	0.25	0	1
The Proportion of Non-milking to Milking Herd	0.73	0.43	0.10	3.18
Milk Price (PKR)	71.85	19.32	40	120
Lahore District (Yes=1, No=0)	0.20	0.40	0	1
Kasur District (Yes=1, No=0)	0.20	0.40	0	1
Okara District (Yes=1, No=0)	0.20	0.40	0	1
Pakpattan District (Yes=1, No=0)	0.20	0.40	0	1
Sheikhupura District (Yes=1, No=0)	0.20	0.40	0	1
Sample Size	600	–	–	–

during the period from 1st January to 31st December 2019. The unadjusted milk yield was used to convert it into 4 percent FCM to compare the milk yield of different breeds of cows and buffaloes on the farms as this is what the farmers in Pakistan get paid for. The method suggested by Gaines (1928) was used to convert milk into 4 percent FCM

$$FCM = [(0.4*\text{kg milk}) + (0.15*\text{kg milk}*\text{fat }\%)]$$

Using information gathered from industry sources, raw milk of different breeds was converted into 4 percent FCM (Table 1). Non-milking herd output was measured by the number of other adults and young stock, e.g., heifers, calves, and bulls, on a farm by end of the year. The Lowe quantity index, which is a member of the class of fixed weight indices, was used to aggregate both concentrate and roughage inputs (O'Donnell, 2012). The Lowe index satisfies all index number axioms including transitivity, which allows to make multilateral comparisons across farms at a given point in time (Hill, 2010). Determinants of technical inefficiency include a z-vector of variables (Table 1). Table 2 presents summary statistics of the variables.

5. RESULTS

The average yearly milk yield (arithmetic mean) per farm was 58.7 MT that ranged from 10.8 MT to 500 MT (Table 3). Farm yield in Sheikhupura averaged 90.7 MT farm^{-1}, ranging from 15.7 to 490 MT farm^{-1}, which was the highest of the five districts.[4] The average yield was 60.3 MT farm^{-1} in Pakpattan (10.8 MT farm^{-1} to 500 MT farm^{-1}), 50 MT farm^{-1} in Kasur (14.9 MT farm^{-1} to 180.3 MT farm^{-1}), and 49.1 MT farm^{-1} in Lahore (16.4 MT farm^{-1} to 269.5 MT farm^{-1}). Similarly, the lowest mean farm yields were observed in Okara, averaging 43.7 MT farm^{-1} (15.9 MT farm^{-1} to 234.7 MT farm^{-1}).

Table 3

Descriptive Statistics of Surveyed Dairy Farms in Five Districts of Punjab

	Sample	Milk yield MT farm^{-1}						
Farms	Size	Mean	SD	Minimum	25%Q	Median	75%Q	Maximum
All Farms	600	58.7	55.1	10.8	29.0	43.1	68.0	499.8
Kasur	120	49.7	33.7	14.9	25.7	38.7	61.8	180.3
Lahore	120	49.1	35.8	16.4	24.7	39.7	62.7	269.6
Okara	120	43.7	27.3	15.9	28.6	37.0	49.6	234.7
Pakpattan	120	60.3	69.8	10.8	29.0	42.0	60.8	499.8
Sheikhupura	120	90.7	76.3	15.7	47.9	72.6	104.4	490.1

Note: MT farm^{-1} indicates milk yield in metric tons per farm per year.

Table 4 reveals that the yield improvement potential of FCM varies across breeds, which is highest for non-descript cows (61 percent), but more uniform for buffaloes, Sahiwal, Cholistani and Friesian crossbred cows, ranging from 41 to 45 percent. This is consistent with the results of Iqbal and Ahmad (1999) who reported a yield gap between 50 and 100 percent of dairy animals' genetic yield potential in Pakistan. Despite comparing current milk yields with genetic yield potential, the findings of Iqbal and Ahmad (1999) are not far from the present study. The breed comparison indicated that Friesian pure cow potential milk yield was highest (8.61 MT head^{-1}) than buffaloes (2.99 MT head^{-1}), Friesian crossbred (2.79 MT head^{-1}), and Sahiwal cows (2.34 MT head^{-1}). A similar pattern of yield gap also emerged when raw milk yields were compared, however, the results are not reported here for brevity.

[4] The difference in yield is numeric, not statistically.

Table 4

Actual Yields of Breeds and Yield Gap at 4 Percent fat Corrected Milk: The Benchmarking Analysis

		Milk Yield MT head^{-1}		Yield Gap MT head^{-1}	
Animal Breed	Sample Size	Maximum Potential Yield (top 10 Percent Farms) Mean (SD)	Current Yield (Average All Farms) Mean (SD)	Potential Minus Current	% Increase
All Buffaloes	8873	4.33 (265)	2.99 (754)	1.33	45
Sahiwal	3124	3.29 (341)	2.34 (535)	0.95	41
Cholistani	1004	2.48 (241)	1.73 (420)	0.75	43
Friesian Crossbred	1222	3.99 (785)	2.79 (796)	1.20	43
Friesian Pure	25	9.87 (45)	8.61 (608)	1.26	15
Non-descript Cows	465	2.72 (494)	1.69 (562)	1.03	61

5.1. Estimating the Distance Functions and Technical Inefficiency Effects

The maximum likelihood parameter estimates of the input distance function (Equation 6) and technical inefficiency effects (Equation 7) assuming a truncated normal distribution for the technical inefficiency are presented in Table 5. Caudill & Ford (1993); and Hadri (1999) have reported that the presence of heteroscedasticity can have serious implications on technical inefficiency estimates in such models. Therefore, robust standard errors corrected for heteroscedasticity are used (Abedullah, et al. 2015). The null hypothesis, that herd size has no differential impact was accepted at a 1 percent level (LR test = 6.36, χ_2^2 =9.21). Farm location might be a constraint limiting the capability of dairy farms to make the best use of available inputs, which could potentially be a reason for estimating a separate frontier for each district, but due to the small sample size, this was not an option (also see, Ahmad, *et al*. 2021). Alternatively, we introduce district effects but null was strongly rejected at 1 percent level (LR test= 19.35, χ_4^2 =13.28). Thus, district effects are important variables in this application. Hence, model 2 is selected based on the tests and its results are explained. The null hypothesis that technical inefficiency effects are absent, i.e., $H_0: \gamma = \delta_0 = \cdots = \delta_9 = 0$, was strongly rejected indicating that most of the dairy farms are operating below the frontier. A large value of γ parameter (γ = 0.330; t = 10.34) also confirms that most of the deviations from the input requirement set are due to inefficiency instead of random shocks.

The estimated coefficients of inputs and outputs denote elasticities as the data on inputs and outputs is divided by respective sample means. The result shows that the input distance function is non-increasing in outputs since the estimated coefficients of two outputs are negative and highly significant (Table 5, model 2). The absolute value of two output elasticities is less than one (0.85), indicating increasing returns to scale at the sample means. In economic terms, a 10 percent increase in joint production decreases total cost by 8.5 percent (Coelli, et al. 2003). A 10 percent increase in FCM production results in a 3.9 percent increase in total cost. However, a similar increase in the production of non-milking herd leads to 4.7 percent increase in total cost. The estimates show a dominance of production of the non-milking herd along with milk production. Elasticities of the distance function with respect to input quantities are equal to cost shares, showing the importance of each input in dairy production. The elasticities are either positive or statistically equal to zero. The elasticity with respect to animal capital is the largest, which is corroborated by some past studies reporting similar findings (Burki & Khan, 2011; Irz & Hadley, 2003).[5]

Table 5

Estimated Parameters of the Input Distance Functions

	Cobb-Douglas Function	
	Model 1	Model 2
Input Distance Function	0.043***	0.042***
Labour (Number)	(4.20)	(4.23)
Animal Capital (Number)	0.921***	0.922***
	(65.01)	(66.42)
Concentrate (PKR '000 per Year)	0.007	0.006
	(1.18)	(1.13)
Roughages (PKR '000 per Year)	–0.007	–0.008
	(–1.42)	(–1.57)
Other Farm Expenses (PKR '000 per Year)	*0.036*	*0.038*
Fat Corrected Milk (FCM) (kg '000 per Year)	–0.389***	–0.388***
	(–14.35)	(–14.45)
Non-milking Herd (Numbers)	–0.466***	–0.465***
	(–14.06)	(–13.54)
Grazing Farm (Yes=1, No=0)	0.017*	0.017*
	(1.88)	(1.84)
Medium Herd-size: 26 ≤ HS ≤ 50	–	0.039
		(0.68)
Large Herd-size: HS > 50	–	0.027
		(0.39)
District Fixed-effects included (Yes=1, No=0)	Yes	Yes
Technical Inefficiency Effects		
Time to Metaled Road (Minutes)	–0.001	–0.001
	(–1.35)	(–1.16)
Medium Herd-size: 26 ≤ HS ≤ 50	0.062***	0.102*
	(5.55)	(1.69)
Large Herd-size: HS > 50	0.174***	0.203***
	(6.93)	(2.84)
Proportion of Exotic Cow to Milking Herd	–0.032**	–0.033**
	(–2.06)	(–2.11)
Proportion of Non-milking to Milking Herd	–0.805***	–0.792***
	(–16.30)	(–15.26)
Milk Price (PKR)	–0.001***	–0.001***
	(–2.73)	(–2.65)
Kasur District (Yes=1, No=0)	0.149**	0.084
	(2.24)	(1.36)
Okara District (Yes=1, No=0)	0.175***	0.094
	(2.65)	(1.36)
Pakpattan District (Yes=1, No=0)	0.180***	0.140**
	(2.72)	(2.36)
Sheikhupura District (Yes=1, No=0)	0.04	–0.046
	(0.67)	(–0.70)
Log-likelihood	628.12	630.36
Mean Technical Efficiency	0.647	0.632
Sample Size	600	600

Note: z-values are reported in parentheses as robust standard errors have been used to correct for heteroscedasticity.

[5]There may be some concern that the Cobb-Douglas function might have imposed unnecessary restrictions. For comparison, we also estimated the translog function, but most of the first-order coefficients were statistically insignificant, indicating presence of multicollinearity in this data (see also, Newman & Mathews, 2006). However, the translog results were qualitatively similar to the Cobb-Douglas model especially the signs and significance of technical inefficiency effects were consistent.

Turning to technical inefficiency effects, Table 5 also shows that increased herd-size increases the technical inefficiency of dairy farms. Relative to small dairy farms, large and medium farms are 20.3 and 10.2 percent more inefficient, respectively. These results suggest that an average dairy farm may reduce average cost by decreasing the scale. The cost-reducing effects are also relevant to medium dairy farms (i.e., $26 \leq HS \leq 50$) which could also reduce their production cost by operating at a lower scale.

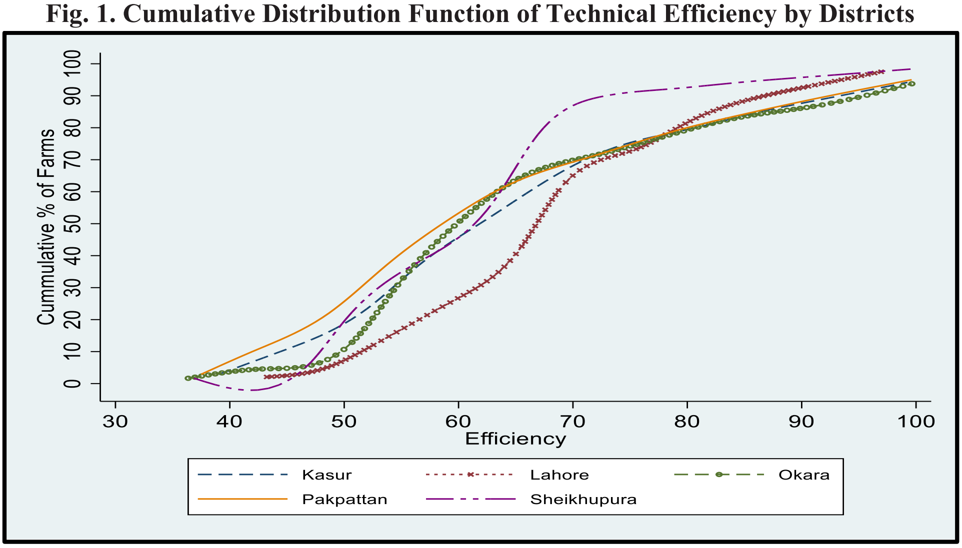
Similarly, dairy farms having a higher proportion of non-milking to milking herds operate closer to the technological frontier. The coefficient of the proportion of non-milking to milking herd is negative and significant (–0.792, t = –15.26), which indicates that the increased presence of heifers and calves decreases technical inefficiency. The proportion of exotic cow to milking herd variable is negative and statistically significant (–0.033, t = –2.11), which indicates that an increase in the proportion of high-yielding exotic cow varieties decreases technical inefficiency (or improvement in technical efficiency). Hence, these farms operate much closer to the technological frontier.

As one would expect, the farm-gate price of milk has a negative and significant effect on the technical inefficiency of dairy farms, indicating that higher milk prices provide an incentive to improve farming practices and get closer to the technological frontier. However, the coefficient measuring the time to metaled road turns out to be statistically insignificant.

5.2. Finding Yield Gaps with the Frontier Analysis

The mean technical efficiency is 63.2 percent ranging between 32.3 percent and 99.9 percent, while the average standard deviation is 16.1 percent (Table 6). Dairy farms in Lahore, Kasur, and Okara have relatively higher mean technical efficiency than other districts, however, the differences are rather small. The data on cumulative distribution functions (CDFs) of technical efficiency scores of five districts (Figure 1) revealed that

Fig. 1. Cumulative Distribution Function of Technical Efficiency by Districts



no district has a clear edge in efficiency scores over the other districts. However, dairy farms from the Lahore district are technically more efficient than the farms from other districts. The CDF of Lahore depicts this, which is mostly to the right of the CDFs of other districts. Of all the dairy farms in Lahore, efficiency scores of some 95 percent of them fall in 45 to 95 percent intervals. By contrast, of all the farms in Sheikhupura, 90 percent of them fall in the efficiency range of 35 to 72 percent intervals, indicating a relatively large average yield gap. Although, mean yield gaps are relatively small, yet the standard deviations indicate that large yield gaps are present within the districts (see Table 6).

Table 6

Mean Technical Efficiency and Yield Gap by Districts

District	Technical Efficiency Scores Mean	SD	Min	Max	Yield Gap (%)	CV (%)
Kasur	0.652	0.173	0.366	0.998	53	26.5
Lahore	0.681	0.131	0.397	0.992	47	19.2
Okara	0.656	0.172	0.342	0.999	52	26.2
Pakpattan	0.635	0.184	0.323	0.999	57	29.0
Sheikhupura	0.612	0.127	0.362	0.996	63	20.8
Full Sample	0.647	0.161	0.323	0.999	55	24.9

Note: Yield gap equals [(1-TE)/TE]*100. The coefficient of variation (CV) equals standard deviation over mean. The coefficient of variation (CV) equals standard deviation over mean.

The regional patterns in the FCM yield gap range from 47 to 63 percent, whereas the average yield improvement potential, from better use of existing resources, is 55 percent (Table 6). Significant differences in yield gap also exist within districts as shown by the higher coefficient of variation (CV). Closing the yield gap can accrue substantial benefits that are highest in Sheikhupura, followed by Pakpattan, Kasur, Okara, and Lahore districts. Several factors may be blamed for putting constraints on dairy production resulting in a large yield gap, therefore, a single intervention may not work.

The output targets, which the dairy farms can potentially realise by closing the yield gap are presented in Table 7. For instance, the farms could increase yearly production of FCM by 72,022 MT (178.8 percent) and non-milking herds by 14,851

Table 7

Potential Growth in Dairy Production by Closing the Yield Gap

District	FCM Quantity (MT)	FCM Increase (%)	Non-milking Herd Quantity (Heads)	Non-milking Herd Increase (%)
Kasur	12561.55	179.11%	3203	158.33%
Lahore	12074.09	165.51%	2316	153.68%
Okara	10863.82	170.81%	2896	147.53%
Pakpattan	16223.20	189.07%	3553	162.09%
Sheikhupura	20299.19	183.97%	2884	167.67%
Full sample	72021.85	178.79%	14851	157.91%

Note: Yield gap target quantities are calculated by dividing farm-level FCM quantities and non-milking herds by their respective technical efficiency scores.

heads (157.9 percent). More precisely, an average dairy farm could increase yearly FCM production by 120,036 kg (i.e., 329 kg/farm/day) and non-milking herd by 25 heads/farm by simply closing the existing yield gap. The growth potential is highest in Sheikhupura where an average dairy farm could increase production of FCM by 463 kg per day and non-milking herd by 24 heads per annum. A large potential for output growth also exists in other districts.

It is important to mention that technical inefficiency (efficiency) of the dairy farms monotonically increased (decreased) with the herd- size (Table 8). Farms maintaining small herd size have clear efficiency gains over medium and large herd sizes, implying that the average potential of yield gap improvement is highest for large farms (73.3 percent), followed by medium (53.4 percent) and small farms (45.8 percent). Therefore, intervention strategies to close the yield gap of dairy farms should particularly focus on medium and large farms.

Table 8

Technical Efficiency and Yield Gap by Herd-size

Herd-size	Mean Technical Efficiency	Yield Gap (%)
Small Herd-size: ≤ 25	0.686	45.77%
Medium Herd-size: 26 ≤ HS ≤ 50	0.652	53.37%
Large Herd-size: HS > 50	0.577	73.31%

Farms with a higher share of exotic cows (pure Friesian or Jersey cows) to milking herds operate closer to the frontier and thus face a lower yield gap. Average milk yields of pure Friesian are three to four times more than other breeds while its milk yield relative to non-descript cows is five times more. Culling of less productive stock and cross-breeding of cattle with high-yielding exotic breeds offers the largest potential as a long-term strategy because there are more than 15 million breedable cattle in the country (Burki & Khan, 2019). The government can realize the potential of increasing milk yields by extending the crossbreeding program. Present artificial insemination facilities are insufficient as they cover a limited stock of dairy animals. Restructuring the entire breeding program can put it on a fast-track to achieving desired results.

6. CONCLUSIONS AND POLICY IMPLICATIONS

This paper evaluated the nature and causes of the yield gap in one of the largest dairy clusters in Pakistan and find evidence of a sizable yield gap. Considering frontier efficiency as upper bound of what can be achieved with available technology and management, we find an average yield improvement potential of 55 percent, which translates into an average yearly production improvement of FCM by 120,036 kg per farm and non-milking herd for meat by 25 heads per farm. Productivity differentials are widespread across districts that are geographically not far from each other and share common characteristics of the dairy farms in the cluster. The best-performing farms indicate a capacity to use locally available information and knowledge to their advantage but less-performing farms face technical constraints in raising productivity.

Technical inefficiency monotonically increases with herd size where small dairy farms are more efficient. Thus, policies aimed at promoting small and medium dairy farms through loans or splitting the large dairy farms into smaller units can trigger major efficiency gains. The econometric results highlighted the importance of raising calves and heifers for meat as an important by-product. The dairy farms that have a higher proportion of non-milking to milking herds operate closer to the technological frontier. We find strong evidence that the increased presence of heifers and calves decreases technical inefficiency. This is hardly a surprising result due to the presence of a lucrative market for the meat and sacrificial animals all over Pakistan, especially on the occasion of Eid-ul-Adha. This is contrary to the business model of corporate dairy farms which keep exotic cow breeds but sell male calves within the first month of calving and cull excess cattle to maintain herd sizes that support the limited capacity of milking parlours (Burki & Khan, 2019). Thus, multi-output dairy farms that produce optimal quantities of both milk and meat have significantly lower yield gaps, and promoting joint production of milk and meat can yield handsome returns.

The yield gap also exists for dairy farms that face low returns to increased production, which makes it hard to raise production to full potential. As they face high risks in investment, not investing is a more rational decision. The results indicate that a higher farm-gate price of milk decreases the yield gap because a higher milk price provides an incentive to farmers to improve farm practices to get closer to the frontier. The raw milk price offer in the upstream milk market by bulk buyers who possess large market share, e.g., UHT/pasteurised milk processing companies, has a significant impact on milk price. Besides poor transport infrastructure and farm-to-market roads raise the price of moving raw milk to high-demand urban centres. Improved networks of highways, motorways, and farm-to-market roads reduce these price differentials and provide much-needed incentives to farmers from far-off places.

Breaking away from traditions is a major challenge in designing strategies to close the yield gap in developing countries like Pakistan. The households who are into the dairy business for generations dominate most of the dairy production and for them change is painfully slow. For example, silage-making equipment is readily available in the market, but there is a lack of demand as only 2 percent of the farms in the dairy survey were using silage for their dairy herd. This is alarming because on-farm silage preparations can reduce the cost of fodder/concentrate, improve nutritional levels in the dairy herd and increase milk yields. It will be particularly helpful if policymakers adopt measures that promote the use of on-farm silage making and the availability of high-quality silage in the market. Similarly, milk removal from hand milking of animals is dominant in the sample dairy farms, which is not only a slow process often marred by seasonal labour shortages, but it also results in lower average yield per lactation (Burki & Khan, 2019). Improvements in labour productivity, milking performance, and hygiene can be achieved by making small capital investments in bucket milking systems or mobile milking machines, which offer a cheaper alternative to hand-milking. Social media, training programs, and extension visits are the tools that policy-makers can use to achieve positive results. Demonstrating the production practices of best-performing dairy farms to less-performing dairy farms can also pay dividends.

ANNEXURE-1

Lahiri's Method

For each district, two random numbers were generated: first between 1 and *N* (the total number of *mouzas* in that district) and second between 1 and *M* (the largest farm size in the district). The sampling was carried out in three steps given below:

(1) A random number was drawn between 1 and *N*. For instance, in Kasur district, the first random number was generated between 1 and 356 while the number drawn was 3 indicating that *mouza* 3 will be considered for data collection.

(2) We draw a random number between 1 and *M*. If this random number is less than or equal to M_i (the total number of farms in i^{th} *mouza*), then include i^{th} *mouza* in the sample; otherwise go back to step 1. For instance, the second random number generated for Kasur was between 1 and 40. Suppose for *mouza* 3 second random number was 16 and the total number of secondary sampling units in *mouza* 3 were 30 then this *mouza* will be included in the sample. On the other hand for *mouza* 2, the second random number was 31 which is less than the total number of farms in *mouza* 2 therefore it was rejected.

(3) Repeat until desired sample size is obtained.

The table below shows the example of two accepted and two rejected PSUs of the Kasur district. The process was repeated to obtain a list of 15 *mouzas* from each district

Table A1

Example of Accepted and Rejected Mouzas

Serial No.	*Mouza*	Farms	First Random Number	Second Random Number	Accept
2	Deo Sial	30	2	31	0
3	Deena Nath	30	3	16	1
4	Orara Nau	27	4	18	1
9	Ellahabad	17	9	39	0

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