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Formal Participation in a Milk Supply Chain and Technical Inefficiency of Smallholder Dairy Farms in Pakistan

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This paper provides empirical evidence on the impact on technical inefficiency of smallholder dairy producers when they formally participate in a milk supply chain. Here the stochastic production frontier and technical inefficiency effects model are estimated based on the data gathered from 800 smallholder dairy farms in Pakistan. The results suggest that the technical inefficiency of the participating farms is significantly reduced. A strong impact of the supply chain is also detected in reducing technical inefficiency of farms that are located in remote areas and on those that have larger herd-size. Experienced farmers upto the age of 36 years have the advantage of reducing technical inefficiency. The remaining differences in relative inefficiency of dairy farms are accounted for by severe long-term depressive disorders.

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1. INTRODUCTION

Agri-food supply chain systems have undergone dramatic transformation lately in many developing countries. Urbanisation, in conjunction with rapid growth in incomes, has caused the character of urban diets in these countries to shift away from low quality staple grains towards high quality cereals, then to livestock and dairy products, and vegetables and fruits [Pingali (2006)]. A combination of these factors have forced many developing countries to re-orient their production and marketing systems by linking local producers with the organised commodity networks and super markets to meet the increasing domestic and global consumer demands. Hence numerous supply chains of agricultural and food products have been formed by agents engaged in production, processing, marketing and distribution of these products. The consequences of linking smallholder producers with the organised supply chain networks catering to domestic or

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international markets are not fully known: Who are the winners and who the losers in an integration of this kind; how participation in these supply chains affects the relative inefficiency of smallholder producers; and how does the buyer-side market structure affects the sustainability of the participating farms? This paper attempts to answer these questions.

Much of the research into supply chain networks continues to rely on agribusiness theory [e.g., Dolan and Humphrey (2000); Islam (2008); Sartorius and Kirsten (2007)]. A vast literature also examines production and distribution planning of supply chains [see, among others, Ahumada and Villalobos (2009)], while many others address issues related to public health as in Jevsnik, *et al.* (2008). A few papers such as Gow and Swinnen (1998) and Key and Runsten (1999) show that foreign direct investment in developing nations helps in enforcement of contracts and adoption of new technologies, yet others [e.g., Dolan and Humphrey (2000) and Weatherspoon and Reardon (2003)] conclude that FDI negatively affects small local suppliers. Gow and Swinnen (2001) and Dries and Swinnen (2004) show that FDI related vertical and horizontal integration contributes to increased access to finance, inputs and productivity growth while Gorton, *et al.* (2006) illustrate how asymmetric information between dairy farmers and milk processors leads to market failure. Some recent studies have voiced concerns about exclusion of small-scale farmers in developing countries from profitable niche markets due to tighter alignment of supply chains producing for international super markets [e.g., Reardon and Barrett (2000); Stanton (2000); Unneveher (2000); Sartorius and Kirsten (2007)]. Yet there is no empirical evidence on the effects of participation of smallholder producers in supply chain network on their productive efficiency.

This paper provides evidence from the supply chain of milk processing industry in Pakistan and evaluates how participation of commercial dairy farms in milk supply chain network, also known as milk district, affects technical inefficiency of the participating dairy farms, especially in comparison with the record of their rival, traditional milk collectors or *dodhis*. Milk supply chain functions on the basis of: (a) self-collection of farmers' milk by the milk plants, e.g., Nestlé's milk collection model; (b) third-party milk collection on behalf of processing units, e.g., Haleeb, Nirala, Noon, etc.; and (c) farmer cooperatives, e.g., HALLA (Idare-e-Kisan).[1]

Pakistan is the fourth largest producer of milk in the world where three-fourth of the total milk supply is produced in the Punjab province. The hallmark of the dairy economy in Pakistan is the dominance of subsistence dairy households that keep buffalos and cows in small herd-sizes [Burki, *et al.* (2004)]. Punjab is also home to one of the largest milk supply chains in Asia. Punjab has the unique feature of having more than 20 private milk processing companies competing to collect farmer milk, including global giant Nestlé, Haleeb Foods, and Halla. Nestlé Pakistan has, this year, completed 23 years of milk collection from rural Punjab while other milk processing units have also made significant inroads over the last 15 years. While commercial dairy farms are evenly spread, the milk supply chain mostly consists of central and southern districts of the Punjab province where population density is relatively low and milk is surplus. However,

[1]Nestlé Pakistan is the biggest processing industry of the sector, collecting 1040 tons of milk daily from over 140,000 farmers in about 3500 villages. Other major industry players include Haleeb, Nirala, Halla, Noon, Millac, Dairy Bell, Dairy Crest, Premier, Army Dairies and Engro Foods.

this is not the case in northern districts of Punjab, where a vast informal network of traditional milk collectors, known as *dodhis*, is still collecting milk from dairy farmers, as was the case in southern Punjab before the emergence of the milk supply chain. Gains in technical efficiency of participating dairy farms are expected on account of better decision-making.

The milk supply chain creates favourable production conditions in the form of modern milk storage facilities, better and dependable transportation even to remote areas, regular payment schedules and buyer-side competition leading to higher farm-gate prices.[2] In effect it is expected that the presence of milk supply chain would lead to gains in technical efficiency of the participating dairy farms.

This paper uses a rich data set of 800 smallholder dairy producers to examine the extent to which participation in milk supply chain contributes to reducing the technical inefficiency of these farms. The results suggest that dairy farms in milk supply chain improve their long term viability by establishing a steady and secure link with the processing industry. In general, while technical inefficiency of dairy farms located in the milk supply chain is significantly reduced, the stronger power of the supply chain is detected in further reducing technical inefficiency of farms situated in remote areas or those with relatively large farm size.

The paper is organised in six sections. Section 2 outlines the survey of dairy households and sampling methods; Section 3 describes the empirical framework; Section 4 data and variables; Section 5 analyses the estimation results and examines the impact of milk supply chain on dairy efficiency; Section 6 presents the conclusions of this study.

2. SURVEY OF DAIRY HOUSEHOLDS AND SAMPLING METHODS

A survey namely, the LUMS[3] Survey of Dairy Households in Rural Punjab 2005, was designed to draw a representative sample of 800 dairy households from rural Punjab, who owned at least one milching animal (buffalo or cow), sold milk for at least 6 months, and did not share ownership of farm resources with other households during the calendar year 2005.[4] Punjab is the most populous of the four provinces, which produces nearly 70 percent of total fresh milk supplies in the country. While the dairy farms are evenly spread in Punjab, the milk supply chain is mostly concentrated in central and southern Punjab. The dairy survey was conducted between January and April 2006.

The authors used a probability sampling plan where sampled area (rural Punjab) was divided into sections according to agro-climatic (crop) zones, *mouzas*/villages and target groups. To accommodate the different environmental production conditions faced by the dairy households, Pinckney (1989) was followed and the districts were classified into five agro-climatic (or crop) zones consisting of (1) wheat-rice, (2) wheat-mix, (3) wheat-cotton, (4) low intensity barani (rain-fed), and (5) barani regions.

[2]For instance, Nestlé's milk supply chain model generally functions by setting-up rural milk collection centres, which provide access to chillers in remote rural areas. Some milk collection networks also provide dairy extension services.

[3]LUMS is short for the Lahore University of Management Sciences.

[4]The authors organised and supervised the survey, which was carried out by a three-member team of trained professional surveyors. A 26-page survey questionnaire was developed and appended by the WHO's self reporting questionnaire (SRQ-20), meant for measuring prevalence of depressive disorders in the surveyed dairy farmers.

In stage 1, ten districts were randomly picked (two from each agro-climatic zone) from 34 districts of Punjab.[5] In stage 2, four *mouzas*[6]/villages were randomly drawn from each selected district based on the list obtained from *Pakistan Mouza Statistics 1998* [Pakistan (1999)]. Out of 40 *mouzas*/villages sampled, 26 had at least one player from milk processing industry collecting milk. In stage 3, lists of commercial dairy households in selected *mouzas*/villages were prepared in consultation with notables of the areas and local milk collection units of the processing industry. Based on the lists, 20 dairy households were randomly selected from each mouza/village, with equal probability. Five replacement dairy households were also selected from each *mouza*/village to replace those who could not be interviewed. Of the 800 dairy households sampled, 160 were drawn from each agro-climatic zone. Around 77 percent of the farms owned up to 4 milching animals, 21 percent owned 5–10 animals and only 2 percent owned 11–30 animals. Thus small and subsistence dairy farms, which are the hallmark of Pakistan's dairy economy, were well represented in the survey design.

3. ESTIMATION PROCEDURES

The empirical framework employed in this paper involves the stochastic frontier approach, first introduced by Aigner, *et al.* (1977) and Meeusen and Van den Broeck (1977), which postulates the existence of technical inefficiency in the production process. This approach uses the concept of a frontier that depicts maximum output obtainable from given inputs, where technical inefficiency of a farm is estimated by deviations from the frontier. To illustrate, let the milk production technology be represented by

$$y_i = f\,(x_i\,;\,\beta)\; e^{v_i - u_i}$$

where y_i is the output of the ith dairy farm, x_i ($i = 1,\ldots,n$) is a $1 \times k$ vector of values of known functions of inputs for the ith dairy farm, β is a $k \times 1$ vector of unknown parameters to be estimated, and $f\,(x_i\,;\,\beta)$ is the frontier production function (usually assumed as Cobb-Douglas). As usual in frontier literature, the stochastic composite error term in Equation (1) is decomposed into v_i and u_i where v_i is typically the symmetric error term taken as normal, independently and identically distributed (iid) as $N\,(0,\;\sigma_v^2)$, which captures the random effects of measurement errors in output, external shocks and events outside a farm's control, while $u_i \geq 0$ is the asymmetric technical inefficiency measure (usually assumed as half-normal, exponential, gamma or truncated normal distribution) representing farm-specific inefficiency effects reflecting the extent of the stochastic shortfall of the ith dairy farm output from the frontier. Following Battese and Coelli (1993, 1995), technical inefficiency is related to a vector of farm specific attributes Z_i in such a way that $u_i = Z_i\,\delta + w_i \geq 0$, where δ represents a vector of parameters to be estimated, and w_i is distributed as $N\,(0,\;\sigma_w^2)$, which is obtained by truncation from below where the point of truncation occurs at $-\,Z_i\,\delta$, or $w_i \geq -\,Z_i\,\delta$.

[5]The sample districts were Hafizabad and Narowal in wheat-rice zone, Sargodha and Okara districts in mixed-cropping zone, Pakpattan and Khanewal districts in wheat-cotton zone, Muzaffargarh and Layyah in low-intensity zone, and Jhelum and Attock in barani zone.

[6]*Mouza* is the smallest administrative unit under the revenue department which may consist of one big village or few small villages. Punjab province has 23385 *mouzas* with an average of 600 *mouzas* in each district.

The start is taken with the translog specification for the stochastic production frontier,[7] which offers the advantage of being a second-order Taylor series expansion to an arbitrary technology, written as

$$\ln y_i = \beta_0 + \sum_i \beta_i \ln x_i + 0.5 \sum_i \sum_j \beta_{ij} \ln x_i \ln x_j + v_i - u_i \qquad \ldots \qquad \ldots \qquad (2)$$

where the technical inefficiency effects, u_i, are assumed to be defined by a linear function of explanatory variables given by

$$u_i = \sum_{j=1}^{N} \delta_j Z_{ij} + \eta_k + w_i \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots \qquad (3)$$

where y and x are the indicators of output and inputs for the ith dairy farm, and the Cobb-Douglas technology is nested within the translog production technology, i.e., when all $\beta_{ij} = 0$. Moreover, Z_{ij} is a set of environmental or managerial variables influencing technical inefficiency, u_i, of dairy farms, while η_k captures unmeasured determinants of u_i that are fixed within a district (district fixed-effects).

4. THE DATA AND VARIABLES

Table 1 presents descriptive statistics of the relevant variables. The dependent variable in the production function is the estimated gross value of milk,[8] and other dairy products sold during the year. The value of milk income is calculated at the price quoted by the dairy farms. The average value of production of milk and other dairy output is Rs 88,520 per farm, which translates into around Rs 243 per day per farm. Based on the size, dairy production varies across dairy farms ranging from only Rs 900 to around Rs one million.

Seven input variables used in the frontier production function are (1) shed and structure capital, (2) animal capital, (3) fodders, (4) straws and concentrates, (5) molasses, (6) feed water, and (7) hired and family labour. Shed and structure capital measures the user cost of sheds, structures and electricity costs, etc. The average shed and structure capital is Rs 5,713, which is highly variable ranging from only Rs 20 to Rs 66,000 because subsistence farms do not use shed or structures for their dairy animals. The animal capital variable is calculated by taking user cost of each animal worked out on the basis of price and remaining life-span of the dairy animals. Prices of dairy cattle and buffaloes significantly vary depending upon, among other things, on their breed, genetic endowments and age, etc. Animal capital turns out to be a major component of dairy cost with an average amount of Rs 12,583 per farm. Two other major inputs in dairy production are fodders, and straw and concentrate with average use of 0.81 acres for fodders and 2,520 kg (63 × 40 kg) of straw and concentrate.

[7]For a recent review of studies that have used the stochastic frontier model in farming sector, see Bravo-Ureta, *et al.* (2007).

[8]Due to long recall period (i.e., one-year), milk production reported by dairy farms is subject to large measurement error. To avoid the obvious measurement problem in a key variable, we adopt a procedure, due to Khan (1997, 2000), and predict daily milk production of each dairy animal in our sample. We obtain estimates of daily milk production by using the parameter estimates from Khan (2000) for the respective lactation length of each animal separately for first calves, later calves, and for the summer and winter months together with (i) the reported milk production for each animal on the interview day, and (ii) reported peak time daily milk production of each animal.

Table 1

Descriptive Statistics for the Variables of the Frontier Production Function and Inefficiency Model

Variables	Mean	Std. Dev	Min	Max
Frontier Production Function				
Output				
Milk Production and other Dairy Outputs (Rs)	88517.9	87053.1	900.2	958176
Inputs				
Shed and Structure Capital (Rs)	5713	5486.3	19.6	66220.8
Animal Capital (User Cost)	12583	10709	720	131850
Fodders (Acres)	0.81	0.7693	0.0085	9.1882
Straws and Concentrates (40kg)	62.81	118.797	5.13	2811.50
Molasses (Yes=1, No=0)	0.025	0.156	0	1
Feed Water (No. of Times Feed Water to Animals)	2.34	0.51	1	4
Family and Hired Labour (Hours)	2097	1380.70	104	7488
Technical Inefficiency Model				
Farm Characteristics				
Herd-size (Number)	3.51	2.73	1	30
Head Age (Years)	49.25	13.58	17	95
Depression (if SRQ≥8=1, Otherwise=0)	0.119	0.324	0	1
Head Literate (Yes=1, No=0)	0.447	0.497	0	1
Location Variable:				
Distance *Pucca* Road (km)	0.861	1.06	0	8
Milk Supply Chain				
Milk Supply Chain (Yes=1, No=0)	0.525	0.499	0	1
No Player (No Industry Player in *Mouza*, Yes=1, No=0)	0.425	0.495	0	1
One-player (One Player in *Mouza*, Yes=1, No=0)	0.250	0.433	0	1
Two-players (Two Players in *Mouza*, Yes=1, No=0)	0.225	0.418	0	1
Three-players (Three Players in *Mouza*, Yes=1, No=0)	0.10	0.300	0	1
District				
Sargodha (Yes=1, No=0)	0.1	0.300	0	1
Narowal (Yes=1, No=0)	0.1	0.300	0	1
Hafizabad (Yes=1, No=0)	0.1	0.300	0	1
Pakpattan (Yes=1, No=0)	0.1	0.300	0	1
Okara (Yes=1, No=0)	0.1	0.300	0	1
Muzafargarh (Yes=1, No=0)	0.1	0.300	0	1
Layyah (Yes=1, No=0)	0.1	0.300	0	1
Khanewal (Yes=1, No=0)	0.1	0.300	0	1
Jhelum (Yes=1, No=0)	0.1	0.300	0	1
Attock (Yes=1, No=0)	0.1	0.300	0	1
Sample Size	800	–	–	–

Source: LUMS Survey of Dairy Households in Rural Punjab, 2005.

Feeding molasses to dairy animals is expected to have a positive impact on productivity. Molasses is a dummy variable that equals one for farms who feed molasses and zero otherwise. Only 2.5 percent of farms feed molasses to their animals. It is generally believed that if milching animals are fed sufficient water they yield more milk. But conventionally, most cows and buffaloes are tied all day due to which they are not free to drink water at will. Therefore, to gauge the effects on productivity, the frequency of feeding water to animals is used, which ranges from 1 to 4 times per day with mean value of 2.34. The labour input includes hired and family labour expressed in hours. The average use of family and hired labour is 2097 hours, which translates to 40 hours per week ranging from only 2 hours per week to 144 hours per week. In one sense this is hardly a surprising result for a country like Pakistan where small dairy households rarely employ full-time dedicated workers for day-to-day management of dairy animals. Therefore, family and hired labour is measured in hours worked per day rather than person-days. In this way, the likely underemployment of family labour is also discounted for.

Several features of the technical inefficiency model in Equation (3) should be highlighted. The milk supply chain is the variable of interest, which reflects the status of a dairy farm and is equal to 1 if the farm is located in the milk supply chain region of the processing industry, and 0 otherwise. It is noted that 52.5 percent of the sample area is located in the milk supply chain. In the rest of the sample area, the processing industry is not present due to which only traditional milk collecting agents are buying farmer milk. The coefficient on milk supply chain identifies the differential effects of farm location in the milk supply chain and the non-milk supply chain district on technical inefficiency of the dairy farms.

Another set of important explanatory variables included in the specification of the technical inefficiency model captures the differential effects on technical inefficiency attributable to the buyer side market structure. The number of milk processors competing for farmer milk in a village indicates the extent of imperfect competition in farmer milk market.[9] To this end, four dummy variables are introduced. No-player is a dummy variable indicating that no industry player is present in the *mouza* due to which the traditional milk collecting agent (*dodhi*) enjoys the monopsony power in buying farmer milk. In the study data, 42.5 percent of the respondents sell milk directly to *dodhi* or other traditional milk collecting agent. One-player, two-players and three-players indicate presence of one, two or three industry players (or their agents), respectively competing in a village for the farmer milk. Roughly, 25 percent of the respondents are located in *mouzas* where one-player is present, 22.5 percent where two-players are present and 10 percent where three-players are present.

The variable, distance from *pucca* (metalled) road, is taken as an indicator of location of *mouza*. The average distance of dairy farms from *pucca* road is 0.86 km where the maximum distance from a farm is 8 km. Because distance from *pucca* road is roughly common to all dairy farms in a *mouza*/village, it also captures some location-specific unobserved heterogeneity in the sample. Two interactive terms are incorporated in the model i.e. (milk supply chain × distance *pucca* road, and milk supply chain × herd-size) to capture additional effects on technical inefficiency associated with presence of milk supply chain with distance from *pucca* road, and herd-size.

Control variables are also introduced to capture variation in technical inefficiency across farms on account of differences in farm characteristics. Here the relevant variables are herd-size, head age, depressive disorder and head literate. For the measure of depressive disorder, an index of depressive disorder is used. The psychiatric epidemiological studies show that anxiety and depressive disorder is not only common occurrence in Pakistan, but is also associated with disability [Mirza and Jenkins (2004)]. It is expected that farmers with major depression to operate at much less than their full potential. Therefore, the degree of long-term major depression is measured from the number of yes answers to the 20 questions in WHO's self-reporting questionnaire (SRQ-20). In the present sample, 12 percent of dairy farmers suffer from major depression measured by 8 or more yes answers to SRQ-20.

[9]The market structure is said to be a monopsony when there is a single buyer of fresh milk, e.g., traditional rural milk collecting agent. This monopsony market structure closely resembles the picture prevailing in the non-milk supply chain in Pakistan. When there are two buyers of fresh milk a duopsony is said to exist; if there are several buyers oligopsony is the proper title.

Dairy farms located in various districts differ in many characteristics (e.g. differences in climate, soil conditions, temperature, rainfall and water availability). These factors might independently affect relative technical inefficiency of dairy farms across districts and thus bias the estimate of the coefficients in this study. Therefore, a complete set of all district dummy variables is also taken to control for district fixed-effects.

5. ESTIMATION RESULTS

The frontier production function, Equation (2), and the inefficiency effects, Equation (3), models are simultaneously estimated using the procedure in computer programme FRONTIER 4.1 [Coelli (1996)]. The hypothesis testing regarding functional forms and specifications is conducted on the basis of generalised likelihood ratio tests,[10] which have approximately a χ^2 distribution, except cases where the null hypothesis also involves the restrictions of $\gamma = 0$. In such cases, the asymptotic distribution of the likelihood ratio test statistic is a mixed – χ^2 distribution and therefore the appropriate critical values are drawn from Kodde and Palm (1986). The hypothesis tests are conducted on the basis of empirical specification in model 1.

An important null hypothesis of interest is whether the Cobb-Douglas production frontier is an adequate representation of the dairy sector data versus the translog production frontier model. Table 2 presents the results of the hypothesis test, which shows that the translog production frontier is rejected in favour of the Cobb-Douglas production frontier at the 1 percent level of significance. Table 2 also reports the generalised likelihood ratio test that technical inefficiency effects are absent, or $\gamma = \delta_0 = \ldots = \delta_{19} = 0$, which is strongly rejected at the 1 percent level of statistical significance; it confirms that most of the dairy farms are operating below the production frontier due to which the estimated inefficiency of these farms is high. Continuing, the null hypothesis, $\gamma = 0$, implies that the inefficiency effects are not stochastic, which is rejected at the 1 percent level of statistical significance. Finally, the null hypothesis, $H_0 : \delta_0 = \delta_1 = \ldots = \delta_{19} = 0$, entails that all the explanatory variables in the inefficiency model are jointly zero is also rejected. This result suggests that the linear explanatory variables accounting for the sources of technical inefficiency are significant even though the individual parameters of some variables may not be significant.

Table 2

Generalised Likelihood Ratio Hypothesis Tests

Null Hypothesis	Critical Value ($\alpha = 0.01$)	Test Statistics	Decision
H_0 : Cobb-Douglas vs. Translog Production	30.58	21.79	Fail to Reject H_0
$H_0 : \gamma = \delta_0 = \delta_1 = \ldots = \delta_{19} = 0$	41.02[a]	512.7	Reject H_0
$H_0 : \gamma = 0$	6.63[a]	281.21	Reject H_0
$H_0 : \delta_0 = \delta_1 = \ldots = \delta_{19} = 0$	40.29	315.42	Reject H_0

[a] Critical values are taken from Table 1 of Kodde and Palm (1986) using 1 percent level of significance.

[10]The generalised likelihood-ratio test is defined by $LR = -2\ \{\ln[L(H_0)/L(H_1)]\} = -2\{\ln[L(H_0)] - \ln[L(H_1)]\}$ where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null and alternative hypothesis, respectively [Coelli, *et al*. (1998)]. Under the null-hypothesis the test statistic has approximately chi-square distribution with parameters equal to difference between the parameters involved in the null and alternative hypothesis.

(a) Production Frontier Results

The estimated parameters of the stochastic frontier and the technical inefficiency effects models are presented in Table 3. We begin with model 1 as a parsimonious model

Table 3

Estimation Results for the Frontier Production Function and Inefficiency Model

Variables	Model 1	Model 2	Model 3
Frontier Production Function			
Constant	2.933***	2.899***	2.93***
	(13.32)	(11.81)	(13.49)
Shed and Structure Capital	–0.003	–0.003	–0.003
	(–0.29)	(–0.29)	(–0.30)
Animal Capital	0.886***	0.892***	0.885***
	(30.35)	(29.89)	(29.32)
Fodders	0.042**	0.044**	0.039*
	(2.01)	(2.13)	(1.85)
Straws and Concentrates	0.039*	0.031*	0.045*
	(1.76)	(1.17)	(1.74)
Molasses (Yes=1, No=0)	0.053	0.052	0.048
	(0.94)	(0.96)	(0.87)
Feed Water (No. of Times)	–0.029	–0.033	–0.027
	(–1.23)	(–1.40)	(–1.19)
Family and Hired Labour	0.010	0.012	0.009
	(0.56)	(0.70)	(0.55)
Technical Inefficiency Model			
Constant	2.246**	1.901***	2.283***
	(4.41)	(3.76)	(4.14)
Herd-size (Number)	–0.156***	–0.050	–0.160***
	(–13.15)	(–1.52)	(–13.75)
Head Age	–0.071***	–0.063***	–0.075***
	(–3.32)	(–3.12)	(–2.99)
Head Age^2	0.001***	0.000**	0.001***
	(2.83)	(2.48)	(2.63)
Depression (if SRQ≥8=1, Otherwise=0)	0.629***	0.611***	0.620***
	(4.17)	(3.42)	(3.78)
Head Literate (Yes=1, No=0)	0.035	0.038	0.038
	(0.38)	(0.43)	(0.40)
Distance *Pucca* Road (km)	0.169***	0.200***	0.188***
	(3.83)	(3.57)	(3.05)
Milk Supply Chain (Yes=1, No=0)	–0.515***	–0.054	–
	(–3.41)	(–0.34)	
Milk Supply Chain × Distance *Pucca* Road	–	–0.262**	–
		(–2.22)	
Milk Supply Chain × Herd-size	–	–0.117***	–
		(–3.51)	
One-player (Yes=1, No=0)	–	–	–0.751***
			(–3.26)
Two-players (Yes=1, No=0)	–	–	0.115
			(0.66)
Three-players (Yes=1, No=0)	–	–	–1.304***
			(–2.94)
District Fixed-effects	Yes	Yes	Yes
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.882***	0.769***	0.903***
	(5.85)	(5.20)	(4.35)
γ	0.962***	0.958***	0.963***
	(126.139)	(116.89)	(107.01)
Log-likelihood	–253.57	–250.69	–249.93
Sample Size	800	800	800

*, ** and *** indicate statistically significant at the 90 percent, 95 percent and 99 percent confidence level, respectively.

in which the milk supply chain is included as a key variable along with control variables included in all models. In model 2, it is shown how technical inefficiency of farms participating in milk supply chain is influenced when they are located in remote areas, i.e., interaction term "milk supply chain × distance *pucca* road", or they have large herd-size, i.e., "milk supply chain × herd-size". Model 3 explores how increased competition among the buying networks affects technical inefficiency of dairy farms. The extent of competition is introduced by four dummy variables ranging from "no industry player" to "three players" present in *mouza*/village.

The estimated coefficients of the Cobb-Douglas frontier production function model indicate that all input elasticities possess expected signs and the estimated coefficients are similar in magnitude in all the specifications. Animal capital, fodder, and straw and concentrate continue to be the most important determinants of raising output in smallholder dairy operations, while molasses, feed water, family and hired labour, and shed and structure capital do not significantly increase dairy output. To illustrate, the coefficient of animal capital is large, positive and statistically significant indicating that every 1 percent increase in the value of animal capital results in about 0.89 percent increase in dairy output.

Similarly, dairy output is statistically significantly correlated with fodder and straw and concentrate. The estimated fodder, and straw and concentrate elasticities are relatively much smaller (at approximately 0.042 and 0.039, respectively) and marginally significant suggesting that these inputs are not much of a limitation. By contrast, shed and structure capital, molasses, feed water and family and hired labour are not a constraint in raising dairy production, as suggested by their statistically insignificant coefficients. While the observed pattern for family and hired labour is explained by disguised unemployment of family labour, these results suggest that excess supply of straws and concentrate, and family labour can be used more productively by further expanding the capacity of the dairy farms (e.g., by purchasing more dairy animals). The policy makers can help by devising simpler and dairy-friendly credit policies, which may have substantial potential for dairy development in the country.

The estimated scale elasticity is measured by the sum of all the input elasticities. The estimated returns to scale is less than one (0.998), and the null hypothesis of constant returns to scale by using the Wald test is not rejected. In other words, a proportionate increase in the use of all inputs brings about a proportionate growth in dairy output.

(b) Milk Supply Chain Effects on Dairy Inefficiency

In the technical inefficiency model (Table 3), the dependent variable is measured in units of inefficiency ranging over the $(0, \infty)$ interval so that a score of zero indicates full efficiency and scores of more than zero indicate inefficiency. Likewise, coefficients with positive signs indicate increase in inefficiency, and vice versa. The estimated relationships between technical inefficiency and its correlates are qualitatively similar and robust in all regressions.

It may be noted that model 1 takes milk supply chain as a combined variable capturing milk supply chain effects plus other control variables. The estimate for γ parameter is significantly greater than zero, which suggests that the production frontier model is a significant improvement over the standard OLS regression model. In model 1, the parameter for herd-size indicates that, *ceteris paribus,* keeping one additional milch animal significantly decreases technical inefficiency of dairy farms. The negative and positive coefficients for head-age and age-square predict that, on average, technical inefficiency of farmers continues to decrease until they reach the age of 36 years and increases thereafter. The significantly positive coefficient on the dummy variable for depression indicates higher inefficiency of farmers who suffer from severe long-term depression.

Farms located in remote areas do not face favourable operating conditions. It makes intuitive sense when it is found that distance from *pucca* road is positive and highly significant. For example, in model 1, the parameter (0.169, t = 3.83) indicates that technical inefficiency significantly increases with an additional kilometre distance of dairy farm from *pucca* road. In other words, we detect that remoteness of dairy farms clearly has unfavourable effect on technical inefficiency.

The primary interest in this paper is to explore the differential impact of milk supply chain on technical inefficiency of dairy farms, holding all else as constant. It is clear from the results that the presence of milk supply chain indeed decreases technical inefficiency of smallholder dairy farms. The milk supply chain variable[11] has a negative estimated coefficient; this effect is statistically significant at the 1 percent level in model 1. The results suggest that it is important to build supply chains in rural areas if the policy makers are really interested in increasing productivity and growth of smallholder producers.

In model 2, the results suggest that while distance from *pucca* road increases technical inefficiency (0.200, t = 3.57), building of milk supply chain clearly benefits dairy households in remote *mouzas*. For example, the negative and statistically significant coefficient of the interaction term (–0.262, t = –2.22) reveals that building of milk supply chain tends to decrease inefficiency of dairy farms with their increasing distance from the *pucca* road. This is an interesting result since remoteness of rural communities remains a key feature in many developing countries including Pakistan. Given that local population in remote rural areas is partially or completely excluded from the facilities available to the rest of the population, building of milk supply chain in these *mouzas* enables producers to reap such benefits as fair prices, weekly payments, transparent milk-grading, and training in farm management. These services, in turn, help dairy producers to decrease relative technical inefficiency.

The question arises whether location of dairy farms in milk supply chain influences their technical inefficiency on the basis of small vs. large herds. The interaction term (milk supply chain × herd-size) in model 2 also allows the differential effects of milk supply chain to vary by herd-size, holding all else as constant. From the parameter of the interaction term (–0.177, t = –3.51) we further predict that the inefficiency reducing effect of large herd-size becomes even stronger when farms are located in the milk supply chain, as suggested by the difference in the two delta coefficients (–0.050 –0.177), which is –0.227 and in the same direction. The combined effect of the two interaction terms suggests that milk supply chain benefits sample dairy

[11]Here milk supply chain variable accounts for the possibility that if differential effects associated with milk supply chain are indeed present then predicted inefficiency should vary across farms in milk supply chain and non-milk supply chain.

producers disproportionately more when they are located at a distance from *pucca* road, and they maintain relatively larger herds.

Finally, as conditions become more competitive with entry of other industry players, farmers look for better prices, improved dairy extension services, and more economical ways to manage their dairy farms. To this end, three dummy variables (one-player, two-players, and three-players) are introduced in model 3 indicating the number of milk processors competing for fresh milk in a *mouza*, while no industry player is the excluded category. With increase in number of industry players, technical inefficiency of dairy farms decreases in this sample. The estimated coefficients for one-player (–0.751, t = –3.26) and three-players (–1.304, t = –2.94) are large, negative and statistically significant at the 1 percent level, which indicates that, on average, dairy farms located in *mouzas* where one industry player and three industry players are present are relatively less inefficient than the excluded category. The difference in the estimated delta coefficient (–0.751 –1.304) is –2.055, predicting that improvement in technical inefficiency of farms dealing with three players is much higher than those dealing with one-player. These results clearly show that increase in the number of industry players tends to decrease technical inefficiency of dairy farms. It appears that industry players pay higher prices where they have more competition in villages. While the statistically insignificant coefficient for two-players (0.115, t = 0.66) is surprising; it may be blamed on high collinearity between two-players and district fixed-effects.

(c) Cross-sectional Properties of Technical Efficiency

Table 4 reports summary statistics of the predicted mean technical efficiency scores derived from the stochastic frontier and technical inefficiency effects models.[12] It is worth noting that the mean and the median technical efficiency in this sample is 73 percent and 81 percent, respectively, which is comparable to the averages presented by Bravo-Ureta, *et al.* (2007) for the stochastic frontier models in the dairy sectors of other countries. This suggests that an average dairy farm loses about 37 percent of dairy output due to being technically inefficient.

Farms that participate in formal milk supply chain appear to be far more efficient than those in non-milk supply chain. Moreover, the standard deviation of technical efficiency is also relatively lower in a milk supply chain. It shows that farms located in milk supply chain cluster closely to the production frontier than farms in non-milk supply chain.

Superior efficiency performance of dairy farms in milk and non-milk supply chain is also indicated in Figure 1 where the empirical cumulative distribution functions of the estimated technical efficiency scores are plotted. Further insights are provided in Figure 2 where the frequency distribution of mean technical efficiency of dairy farms in milk and non-milk supply chain is compared. For the milk supply chain sample, a relatively large number of dairy farms cluster closely to the higher-end of technical efficiency than at the lower-end, which is in sharp contrast to the efficiency levels of farms in non-milk

[12]The relationship between efficiency (Eff) and inefficiency (u_i) is given by Eff = 1/(1+u). Thus a score of 0 on u implies 100 percent or full-efficiency, and a score of 1 means 50 percent efficiency. Alternatively, u = (– Eff)/Eff. In other words, the 70 percent (or 0.70) efficiency entails 42.86 percent inefficiency.

Table 4

Descriptive Statistics of Estimated Efficiency of the Dairy Farms

Estimated Efficiency of Farms by	Mean	Median	Std. Dev	Min	Max	N
Milk Supply Chain Effects						
Milk Supply Chain	0.794	0.846	0.145	0.096	0.949	420
Not in Milk Supply Chain	0.662	0.727	0.228	0.016	0.961	380
No Industry Player	0.658	0.725	0.231	0.016	0.961	340
One Industry Player	0.783	0.840	0.156	0.263	0.949	200
Two Industry Players	0.776	0.839	0.164	0.096	0.933	180
Three Industry Players	0.809	0.852	0.116	0.332	0.939	80
Farm Characteristics						
Herd-size						
Herd-size 1-2	0.679	0.753	0.219	0.219	0.961	369
Herd-size 3-4	0.757	0.824	0.178	0.016	0.959	243
Herd-size 5-6	0.779	0.848	0.168	0.024	0.949	108
Herd-size 7-10	0.825	0.879	0.123	0.394	0.955	63
Herd-size 11-15	0.805	0.890	0.204	0.200	0.925	12
Herd-size 16 or More	0.907	0.893	0.028	0.885	0.952	5
Farmers' Long-term Stress Levels						
With Major Depression	0.681	0.769	0.218	0.016	0.961	95
Without Major Depression	0.738	0.821	0.197	0.024	0.959	705
Full Sample	0.731	0.813	0.200	0.016	0.961	800

Source: Authors' estimations.

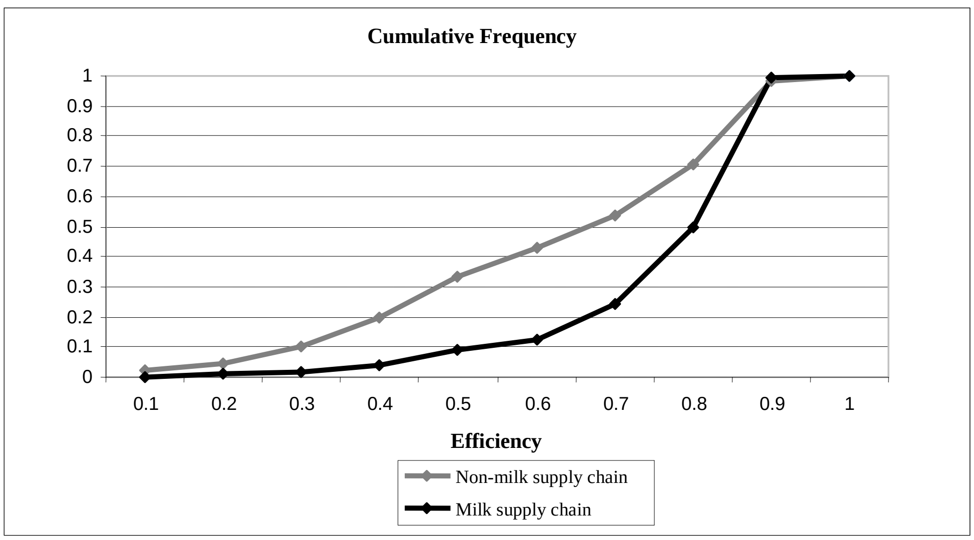


Fig. 1. Cumulative Distribution Function for Estimated Technical Efficiency

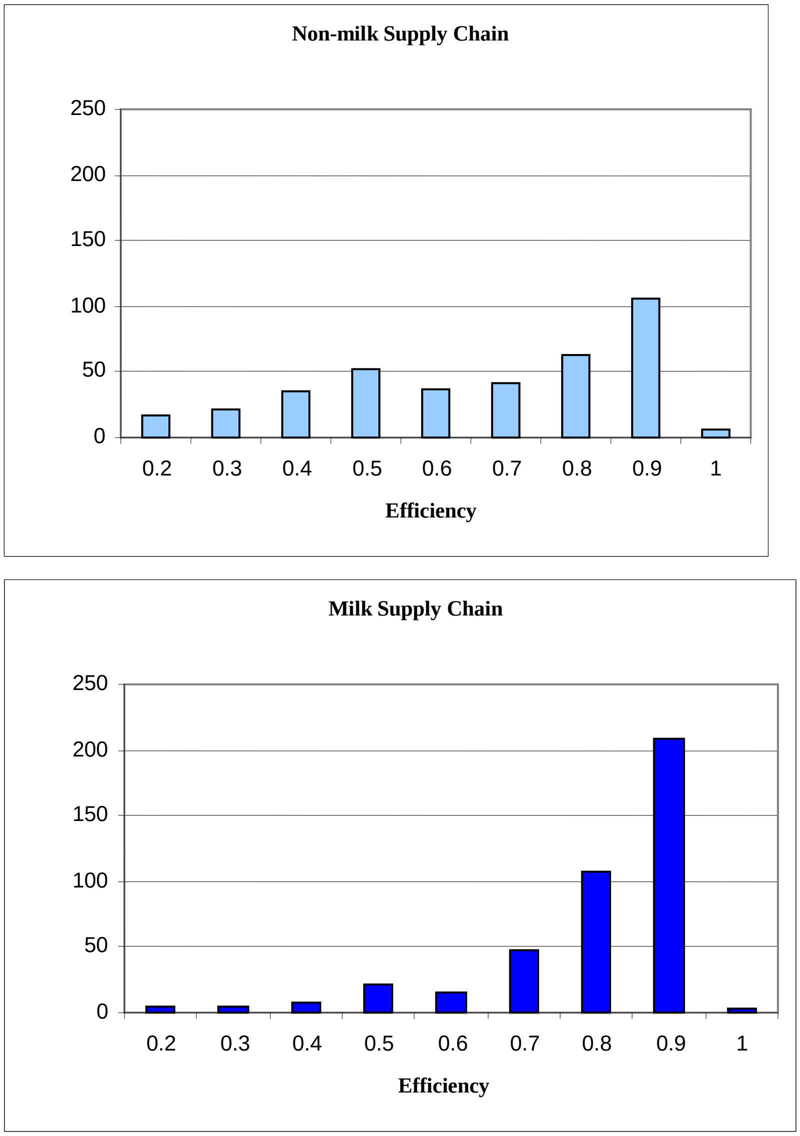


Fig. 2. Frequency Distribution of Mean Technical Efficiency Levels

supply chain sample. Very few dairy farms in milk supply chain have mean technical efficiency scores of less than 70 percent. On the contrary, a large number of dairy farms in non-milk supply chain sample have mean efficiency scores in the range of 20 to 70 percent.

Figure 3 presents the distribution of mean efficiency by *mouzas* or villages where *mouzas* are ranked from best performers to worst performers. It can be seen that 15 of the top 20 *mouzas* in our sample are from milk supply chain districts, whereas 13 of the bottom 20 *mouzas* are from the non-milk supply chain districts. In general, these findings tend to corroborate the positive contribution and efficacy of milk supply chain districts in contributing to increased productive efficiency of smallholder dairy producers.

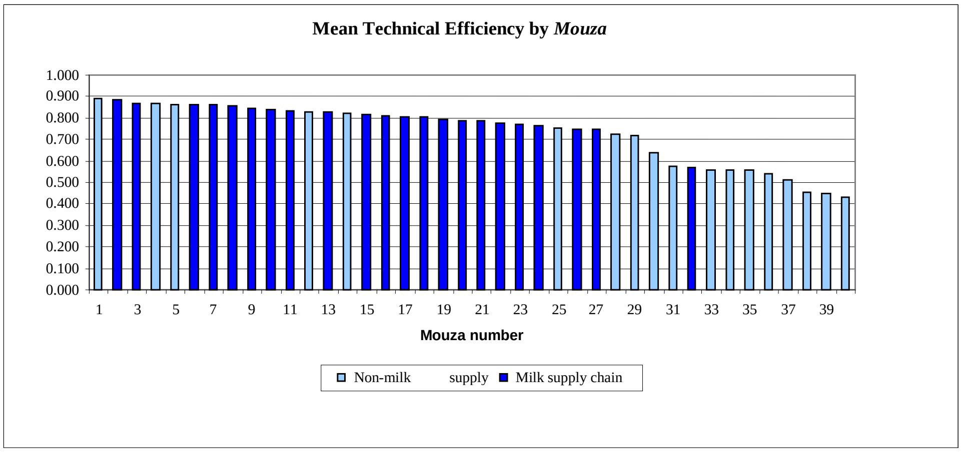
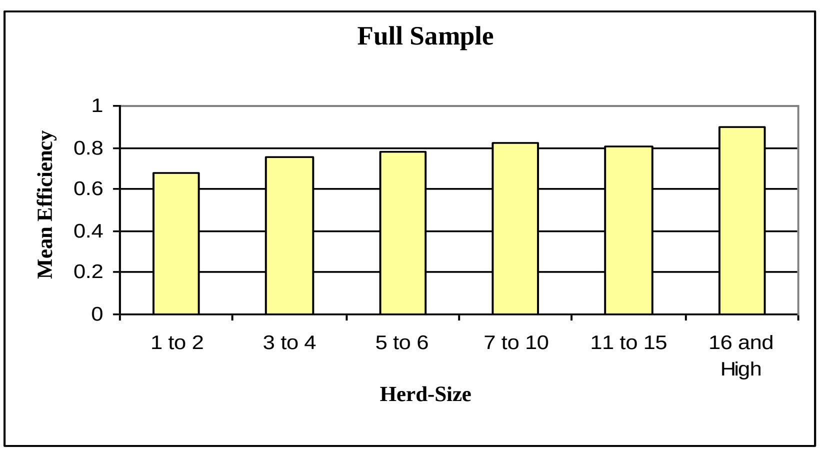


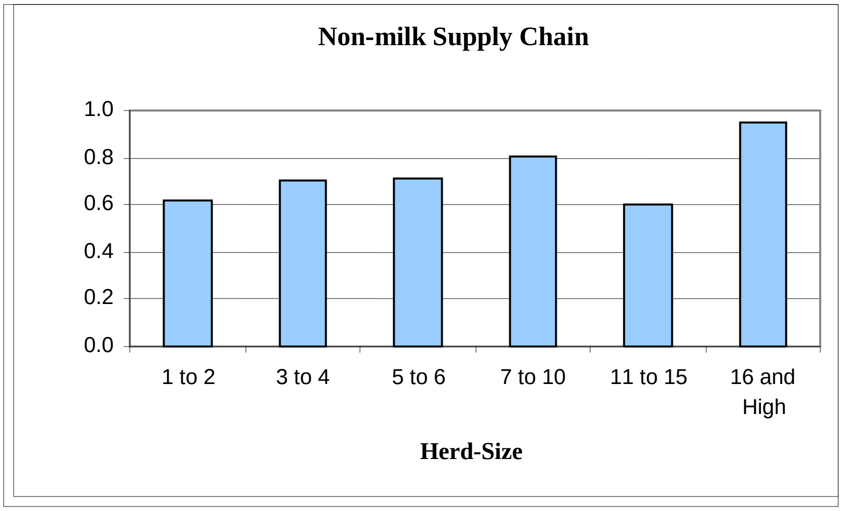
Fig. 3. Mean Technical Efficiency Levels by *Mouza*

Table 4 also shows that technical efficiency of the dairy farms is positively correlated with the number of industry players in a *mouza*. The highest mean technical efficiency is achieved when market structure resemble oligopsony (three players) while the lowest mean technical efficiency is achieved when market structure resembles monopsony (no-player). Furthermore, the difference in mean and median technical efficiency between two-players and no-player is statistically significant at the 1 percent level, which corroborates the view that statistically insignificant coefficient for two-players in Table 3 is indeed explained by the suspected collinearity between two-players and the district fixed-effects.

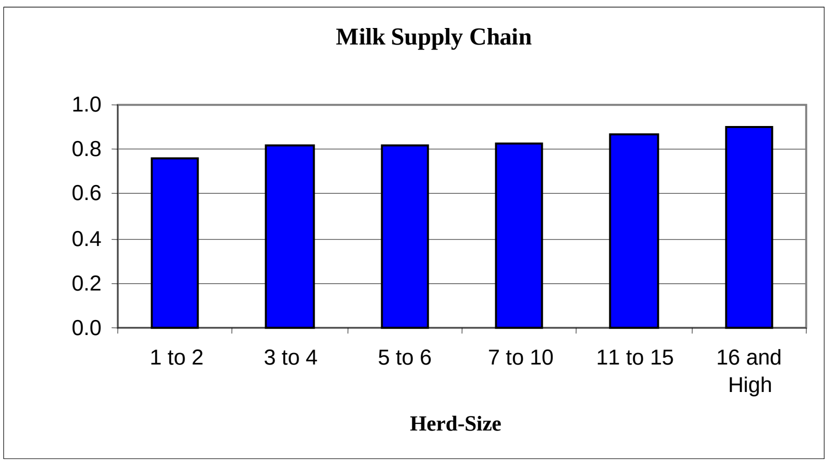
Table 4 and Figure 4 (panel A) show that in general technical efficiency is positively correlated with herd-size. Technical efficiency estimates are more fat-tailed for larger farms. Major efficiency gains occur when we move from herd-size 1–2 to herd-size 3–4. Stacked up against each other, panels B and C depict efficiency estimates by herd-size for farmers who participate or do not participate in a milk supply chain. In the milk supply chain, the mean technical efficiency levels for herd-size 1–2, 3–4 and 5–6 are much higher than otherwise.



Panel A



Panel B



Panel C

Fig. 4. Mean Technical Efficiency Levels by Herd-size

That mental depression is a common occurrence in the dairy sector of rural Punjab is confirmed by the prevalence of long-term depression in 11.8 percent of the sample respondents, and the estimated efficiency differentials between those with and without major depression also corroborates how this disability can cause economic adversity. Table 4 depicts that the mean and median efficiency index significantly falls for farmers who report major depression (68 percent and 76 percent) as compared with respondents with no major depression (74 percent and 82 percent). These results suggest that farmers without major depression cluster much closer to the frontier compared with those with major depression.

6. CONCLUSIONS

This paper provides empirical evidence on how formal participation in a milk supply chain affects smallholder technical inefficiency. This relationship has been examined on the basis of survey data of 800 smallholder commercial dairy farmers taken from milk supply chain and non-milk supply chain districts in Punjab, Pakistan. The frontier inefficiency effects model and the Cobb-Douglas production technology has been used to examine the differential impact on relative inefficiency of smallholder dairy producers. The results show that animal capital, fodder, and straw and concentrate continue to be most important determinants of raising dairy output, while labour, shed and structure capital, feeding of water and molasses do not significantly increase dairy output in our sample. The marginal significance attached to hired and family labour is attributed to the disguised unemployment of family labour. The scale elasticity estimates in this study show that if the present trends continue, dairy producers are expected to bring about a proportionate increase in dairy output with proportionate increase in inputs.

While the location of the dairy households is exogenously determined, the building of milk supply chain network indeed decreases technical inefficiency of smallholder dairy households in this sample. Evidence in the present case suggests that dairy farms located in milk supply chain districts employ fewer resources relative to those located in non-milk supply chain districts to produce the given output levels. In considering the mechanism through which a milk supply chain affects technical inefficiency, the results of this study suggest that it benefits disproportionately those farms more that are located away from *pucca* road and are relatively large in size. In general, remoteness of rural communities remains a key feature in Pakistan where local population is often excluded from the basic facilities. For the same reason, distance of a farm from *pucca* road clearly has unfavourable effect on their technical inefficiency. Likewise, we find that farms away from *pucca* road are technically more inefficient, but this disadvantage tends to decrease significantly when farms are located in a milk supply chain area. Similarly, it is shown that sample farms with larger herds are less inefficient than those with smaller herds, yet the inefficiency reducing effect of herd-size becomes stronger when large farms are located in milk supply chain regions. The study also shows that increase in the number of industry players buying farmer milk in the supply chain leads to decrease in technical inefficiency of dairy farms. From the results it is concluded that technical inefficiency is highest where the market structure resembles monopsony and lowest where the market structure resembles oligopsony.

If policy makers are indeed interested in increasing productivity and growth of smallholder dairy producers then they should promote building of supply chains in rural areas. However, efficiency and productivity gains are far greater if the supply chains also bring into their fold medium and relatively large farmers based in remote rural areas. The results in this article further suggest that the buyer-side market structure holds the key for the success or failure of the emerging agro-food supply chain systems in developing countries. If anything, the advice to policy makers from these results conforms to the standard economic view that market competition, which is long viewed as key to economic development, leads to enhanced levels of technical efficiency of smallholder producers. Without government intervention in the milk supply chain, profit motive alone provides incentives to dairy farms to move toward greater efficiency.

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