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Milk Supply Chain and Efficiency of Smallholder Dairy Producers in Pakistan

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Abid A. Burki and Mushtaq A. Khan[1]

I. Introduction

Agro-food supply chain systems have observed a dramatic transformation in many developing countries in recent years. Urbanization, 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 organized commodity networks and supermarkets to meet increasing domestic and global consumer demands. Numerous supply chains of agricultural and food products have been formed by the agents responsible for production, processing, marketing and distribution of these products. However, the existing literature is silent on the effects of such integration on relative inefficiency of smallholder producers. This paper analyzes the affects of such supply chains using survey data from the dairy sector of Pakistan.

Much of the research into supply chain networks continues to rely on agribusiness theory [e.g., Dolan and Humphrey (2000), Islam (2007), Sartorius and Kirsten (2007)]. A vast literature also examines production and distribution planning of supply chains [see, among others, Ahumada and Villalabos (2008)], 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 FDI 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 in the existing literature on the effects of producer participation in supply chain networks on productive efficiency.

This paper provides evidence from the supply chain of milk processing industry in Pakistan. Thanks to a natural experiment that took place in the dairy sector where one can empirically evaluate how participation of commercial dairy households in milk supply chain network of local milk processing industry, also known as milk district, affects cost inefficiency of the participating dairy farmers, especially in comparison with the record of their rival, traditional milk collectors or *dodhis*. Milk district functions on the basis of: (a) self-collection

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of farmer milk by the milk plants, e.g., Nestlé milk collection model; (b) third-party milk collection, e.g., Haleeb, Nirala, Noon, etc.; and (c) farmer cooperatives, e.g., HALLA (Idare-e-Kisan)[2]. Milk district creates favourable production conditions in the form of modern milk storage facilities, better and dependable transportation networks, regular payment schedules and buyer-side competition[3]. In effect, milk district makes rural production system viable where smallholder dairy producers employ mostly family labour, and rely on roughages, grasses and crop residue as fodder.

While Pakistan is the fourth largest producer of milk in the world, three-fourth of its total milk is produced in the Punjab province. The hallmark of the dairy economy of Pakistan is the dominance of poor subsistence dairying households who keep buffalos and cows in small herd-sizes. Punjab is also home to one of the largest milk district in Asia, which has the unique feature of having 15 private companies competing to collect farmer milk for processing, including global giant Nestlé, Haleeb Foods, and Halla. Nestlé Pakistan has, this year, completed 20 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 district consists of regions in southern Punjab. The northern part of Punjab has been left alone by the industry 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 building of the milk district.

We study this natural experiment by employing a cross section survey of 800 smallholder dairy households taken from rural Punjab in 2005. The results suggest that dairy farms in milk district 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 district is significantly reduced, we detect stronger power of milk district in further reducing technical inefficiency if the farms are located in remote areas, or if their size is relatively large. As the number of economic agents who compete for rural milk supplies increases, a relatively efficient private milk market develops. The layout of the paper is as follows. Section 2 outlines the survey of dairy households and sampling methods. Section 3 describes the empirical framework. Section 4 analyses the estimation results and examines the impact of milk district on dairy efficiency. Section 5 presents our conclusions.

2. Survey of Dairy Households and Sampling Methods

A survey namely, the LUMS 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

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[2] 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.

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

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 dairy farms are evenly spread in Punjab, milk district is concentrated in southern Punjab. The dairy survey was conducted between January and April 2006.

We used cluster sampling as a probability sampling plan where sampled area (rural Punjab) was divided into sections according to agro-climatic (crop) zones, *mouzas*/villages and target groups. Districts in Punjab have significant differences in climate (arid vs. non-arid), soil conditions, temperature, rainfall, and water availability. Otherwise identical dairy producers may produce different quantities of milk if faced with different temperature, rainfall and water availability. Therefore, to accommodate different environmental production conditions faced by the dairy households, we followed Pinckney (1989) and classified districts into five agro-climatic (or crop) zones consisting of (1) wheat-rice, (2) wheat-mix, (3) wheat-cotton, (4) low intensity *barani*, and (5) *barani* (rain-fed) regions.

In stage 1, we randomly picked 10 districts (two from each agro-climatic zone) from 34 districts of Punjab[5]. In stage 2, *mouza*/village was used as the basic geographical unit due to its convenient and divisible nature[6]. Four *mouzas*/villages were randomly drawn from each selected district based on the list of *mouzas*/villages obtained from *Pakistan Mouza Statistics 1998* [Government of Pakistan (1999)]. Out of the 40 *mouzas*/villages sampled, 26 had at least one industry player involved in milk collection. In stage 3, lists of commercial dairy farmers operating in each selected *mouza*/village were first prepared in consultation with the notables of the villages and local milk collection units of the dairy industry where applicable. On the basis of these lists, 20 dairy farms were randomly selected from each *mouza*/village with equal probability. Five replacement dairy households were also selected from each *mouza*/village in case the selected dairy households could not be interviewed. Of the 800 dairy households sampled, 160 dairy households were drawn from each agro-climatic zone, 10 districts and 40 *mouzas*/villages. The hallmark of the dairy economy of Pakistan is the dominance of small and subsistence dairying households, which is well represented by our sample of dairy households, which where 76.5 percent own up to 4 milching animals, 21.4 percent own 5–10 animals and only 2 percent own 11–30 animals.

3. Estimation Procedures

The empirical framework employed in this paper involves a stochastic production frontier 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 the maximum output obtainable from

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[4]The authors organized and supervised the survey, which was carried out by a 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.

[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.

given inputs, where technical inefficiency of a firm/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 *i*th dairy farm, $x_i\,(i = 1,...,n)$ is a $1 \times k$ vector of values of known functions of inputs for the *i*th 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. As usual in frontier literature, the stochastic composite error term in Eq. (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 *i*th dairy farm output from the frontier.

Sometimes, a two-stage approach is adopted where in the first stage the parameters of interest of the stochastic frontier are estimated by the maximum likelihood, assuming that the inefficiency effects in the composite error term are identically distributed. Then in the second stage, the estimated inefficiency index is related to a set of managerial/environmental variables in the OLS or Tobit type regression framework. However, a problem with this approach, as noted by Battese and Coelli (1993), is that this technique is inconsistent because using the estimated inefficiency index as the dependent variable implies that, contrary to the assumption, technical inefficiency is in fact not identically distributed.

To overcome this potential problem, some studies suggest joint estimation of the stochastic frontier and technical inefficiency effects [Kumbhakar et al. (1991), Reifschneider and Stevenson (1991), Huang and Liu (1994), Battese and Coelli (1993, 1995)]. We follow this suggestion and adopt the approach of joint estimation of the stochastic frontier and technical inefficiency effects models[7]. Following Battese and Coelli (1993), we relate technical inefficiency 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 where 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 $w_i \geq -Z_i \delta$. The log-likelihood function for the *i*th farm incorporating all the information given above takes the form

$$\ln L_i = -\frac{1}{2}\left[\ln(2\pi) + \ln(\sigma^2)\right] - \frac{1}{2\sigma^2}\left[y_i - f(x_i;\beta) + Z_i\,\delta\right]^2 - \ln\left[\Phi(m_i)\right] + \ln\left[\Phi(m_i^*)\right] \qquad (2)$$

where β, δ, γ and σ^2 are the estimated parameters, $f(x_i;\beta)$ is the stochastic production frontier, $m_i = Z_i\,\delta / (\gamma\,\sigma^2)^{1/2}$, $m_i^* = \left\{(1-\gamma) Z_i \delta - \gamma\left[\left(y_i - f(x_i;\beta)\right)\right]\right\} / \left[(\gamma(1-\gamma)\sigma^2)\right]^{1/2}$, $\Phi(.)$ denotes the cumulative standard normal distribution function, $\gamma = \sigma_u^2 / [\sigma_u^2 + \sigma_v^2]$, and $\sigma^2 = \sigma_u^2 + \sigma_v^2$.

[7]Sherlund et al. (2002) and Gonzalez and Lopez (2007) are other examples where this model has been adopted to the farm sector.

We use the translog specification for the production frontier, which offers the advantage of being a second-order Taylor series expansion to an arbitrary technology, written as

$$\ln y_i = \beta_0 + \sum_i \beta_i \ln x_i + 0.5 \sum_i \sum_j \beta_{ij} \ln x_i \ln x_j + v_i - u_i \qquad (3)$$

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

$$u_i = \sum_{j=1}^{N} \delta_j Z_{ij} + \eta_k + w_i \qquad (4)$$

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 households, 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 Eq. (3) is the estimated gross value of milk[8] and other dairy products sold during the year. We calculate the value of milk income at the price quoted by the dairy farms. The average value of production of milk and other dairy output is Rs.88520 per household, which translates to about Rs.243 per day per household. Based on the size, dairy production varies across dairy households ranging from only Rs.900 to around Rs.1 million.

Five input variables used in the frontier production function are shed & structure capital, animal capital, fodder, straws & concentrates, and hired & family labour. Shed & structure capital measures the user cost of sheds, structures and electricity costs, etc. Average shed & structure capital is Rs.5713, which is highly variable ranging from only Rs.20 to Rs.66000 because subsistence farms do not use shed or structures for their dairy animals. Prices of dairy cattle and buffaloes significantly vary depending upon, among other things, on their breed, genetic endowments and age, etc. We calculate animal capital variable by taking user cost of each animal on the basis of their value and age. 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 & concentrate with average use of 0.81 acres for fodders and 2520 kg (63 x 40 kg) of straw & concentrate. Labour input includes hired & family labour expressed in hours. 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 surprising result for a country like Pakistan

[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 & other dairy outputs (Rs.)	88517.9	87053.1	900.2	958176
Inputs:				
Shed & 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
Family & 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
Feed water (no. of times fed water to animals)	2.34	0.51	1	4
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
Molasses (yes=1, no=0)	0.025	0.156	0	1
Location variable:				
Distance *pucca* road (km)	0.861	1.06	0	8
Milk supply chain:				
Milk district (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
Jehlum (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 where small dairy households rarely employ full-time dedicated workers for day-to-day management of dairy animals. Therefore, we measure family and hired labour in hours worked per day rather than person-days. In this way, we also discount for likely underemployment of family labour.

Several features of the technical inefficiency model Eq. (4) should be highlighted. Milk district 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. We note that 52.5 percent of the sample area is located in milk district. In rest of the sample area, processing industry is not present due to which only traditional milk collecting agents are buying farmer milk. The coefficient on milk district identifies the differential effects of farm location in milk- and non-milk 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 X-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 we introduce four dummy variables. No-player is a dummy variable indicating that no industry player is present in the *mouza* due to which traditional milk collecting agent (*dodhi*) enjoys the monopsony power in buying farmer milk. In our 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.

We take the variable, distance from *pucca* (metalled) road, as an indicator of location of *mouza*. 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 our sample. We incorporate into the model two interaction terms (milk district × distance *pucca* road, and milk district × herd-size) to capture additional effects on technical inefficiency associated with presence of milk supply chain with distance from *pucca* road, and herd-size.

We also introduce control variables to capture variation in technical inefficiency across farms on account of differences in farm characteristics. Here the relevant variables are herd-size, head age, number of times animals are fed water, depression, head literate, and molasses. It is generally believed that if milching animals are fed sufficient water they yield more milk. But conventionally, most cows and buffaloes are tied with a rope all day long due to which they are not free to drink water at will. Therefore, to gauge the effects on technical inefficiency, we use frequency of feeding water to animals, which ranges from 1 to 4 times per day with mean value of 2.34. For the measure of depression, we use an index of depressive disorder. The psychiatric epidemiological studies show that anxiety

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[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 with the picture prevailing in the non-milk district in Pakistan. When there are two buyers of fresh milk a doupsony is said to exist; if there are several buyers oligopsony is the proper title.

and depressive disorder is not only common occurrence in Pakistan, but is also associated with disability [Mirza and Jenkins (2004)]. We expect farmers with major depression (or depressive disorder) to operate at much less than their full potential. Therefore, we measure the degree of long-term major depression from the number of yes answers to the 20 questions in WHO's self-reporting questionnaire (SRQ-20). In our sample, 12 percent of dairy farmers suffer from major depression measured by 8 or more yes answers to SRQ-20.

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 our estimate of the coefficients. Therefore, we also take a complete set of all district dummy variables to control for district fixed-effects.

5. Estimation Results

The maximum likelihood estimates of the parameters of the production function (Eq. 3) and the inefficiency effects (Eq. 4) models are estimated by maximizing the likelihood function given in Eq.(2). Hypothesis testing regarding functional forms and specifications is conducted on the basis of generalized 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). Table 2 presents the results of the hypothesis tests and 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. Generalized likelihood ratio hypothesis tests

Null Hypothesis	Critical value (α = 0.01)	Test statistics	Decision
H_0 : Cobb-Doublas vs. translog production	30.58	19.66	Fail to reject H_0
$H_0: \gamma = \delta_0 = \delta_1 = ... = \delta_{19} = 0$	41.02[a]	514.9	Reject H_0
$H_0: \gamma = 0$	6.63[a]	282.10	Reject H_0
$H_0: \delta_0 = \delta_1 = ... = \delta_{19} = 0$	40.29	317.64	Reject H_0
$H_0: \delta_1 = \delta_2 = ... = \delta_{19} = 0$	38.93	211.1	Reject H_0

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

We begin with model 1 as a parsimonious model in which we include as covariates, milk district as a key variable, along with control variables that are included in all models such as (i) farm characteristics, (ii) distance from *pucca* road to control for location-specific effects, and (iii) district fixed-effects. We then go on to show how exogenous inefficiency of dairy farms is influenced when we add other covariates in model 1. This includes model

[10]The generalized likelihood-ratio test is defined by $LR = -2\left\{\ln\left[L(H_0)/L(H_1)\right]\right\} = -2\left\{\ln\left[L(H_0)\right]-\ln\left[L(H_1)\right]\right\}$ 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.

2 in which we enter two interaction terms (milk district distance *pucca* road), and (milk district herd-size), and model 3 where we replace milk district variable of model 1 with three dummies to capture the extent of competition measured by the number of industry players present in a *mouza*.

A. Production frontier results

Our estimates of the coefficients for the Cobb-Douglas frontier production function and the technical inefficiency model in Table 3 indicate that all input elasticities possess expected signs and the estimated coefficients are similar in magnitude in all the specifications. Our estimates suggest that animal capital, fodder, and straw & concentrate continue to be the most important determinants of raising output in smallholder dairying, while labour and shed & structure capital do not significantly increase dairy output. To illustrate, the coefficient of animal capital in each case is large, positive and statistically significant indicating that the elasticity of output with respect to animal capital is highest. These estimates show 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 also statistically significantly correlated with fodder and straw & concentrate. The estimated fodder, and straw & concentrate elasticities are relatively much smaller (at approximately 0.04 and 0.05, respectively) and marginally significant suggesting that these inputs are not much of a limitation. By contrast, shed & structure capital, and hired & family labour are not a constraint in raising dairy production, as suggested by their statistically insignificant coefficients. While the observed pattern for family & hired labour is explained by disguised unemployment of family labour, these results suggest that excess supply of straws & 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 carry great 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 at the point of approximation is less than one (0.98), and we fail to reject the null hypothesis of constant returns to scale by using the Wald test. 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 efficiency

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.

Note that model 1 takes milk district as a combined variable capturing milk supply chain effects plus a complete set of other control variables that are included in all models. The estimate for γ parameter in model 1 is significantly greater than zero (0.959, *t*-value=84.88), which indicates that most of the residual variation is on account of inefficiency effects. In other words, the production frontier model is a significant improvement over the standard

Table 3. Estimation results for the frontier production function and inefficiency model

Variables	Model 1	Model 2	Model 3
Frontier Production Function:			
Constant	2.817***	2.807***	2.843***
	(12.18)	(12.21)	(13.39)
Shed & structure capital	-0.001	-0.001	-0.001
	(-0.15)	(-0.20)	(-0.19)
Animal capital	0.888***	0.889***	0.884***
	(29.29)	(31.08)	(33.19)
Fodders	0.037*	0.038*	0.035*
	(1.74)	(1.79)	(1.69)
Straws and concentrates	0.050**	0.044*	0.054**
	(1.99)	(1.66)	(2.16)
Family & hired labour	0.010	0.012	0.010
	(0.64)	(0.79)	(0.65)
Technical Inefficiency Model:			
Constant	2.88***	2.434***	2.979***
	(4.52)	(4.00)	(4.64)
Farm characteristics:			
Herd-size (number)	-0.096***	-0.044	-0.103***
	(-3.39)	(-1.26)	(-3.60)
Head age	-0.068***	-0.062***	-0.067***
	(-2.73)	(-2.71)	(-3.03)
Head age^2	0.00049**	0.00045**	0.00049**
	(2.25)	(2.13)	(2.41)
Feed water (no. of times fed water)	-0.372***	-0.269**	-0.395***
	(-2.63)	(-2.36)	(-3.00)
Depression (if SRQ≥8=1, otherwise=0)	0.659***	0.632***	0.592***
	(3.50)	(4.09)	(3.89)
Head literate (yes=1, no=0)	0.076	0.069	0.071
	(0.80)	(0.72)	(0.72)
Molasses (yes=1, no=0)	-1.333*	-0.947	-1.319*
	(-1.78)	(-1.21)	(-1.70)
Location effect:			
Distance *pucca* road (km)	0.161***	0.198***	0.161***
	(2.91)	(2.90)	(3.68)
Milk supply chain effects:			
Milk district (yes=1, no=0)	-0.647***	-0.242	---
	(-3.18)	(-1.39)	
Milk district × distance *pucca* road	---	-0.245*	---
		(-1.79)	
Milk district × herd-size	---	-0.074*	---
		(-2.08)	
One-player (yes=1, no=0)	---	---	-0.872***
			(-3.71)
Two-players (yes=1, no=0)	---	---	0.032
			(0.18)
Three-players (yes=1, no=0)	---	---	-1.196***
			(-3.45)
District fixed-effects	Yes	Yes	Yes
$\sigma^2 = \sigma_u^2 + \sigma_v^2$	0.845***	0.755***	0.787***
	(3.94)	(5.22)	(5.70)
γ	0.959***	0.956***	0.956***
	(87.88)	(105.16)	(114.08)
Log-likelihood	-252.20	-250.50	-247.94
Sample size	800	800	800

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

OLS regression model. This result is also supported by the second hypothesis in Table 2 where we test that technical inefficiency effects are absent from the model, or $\gamma = \delta_0 = ... = \delta_{19} = 0$. Generalized likelihood ratio test results based on model 1 indicate that this hypothesis is rejected at the 1-percent level of 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 third null hypothesis, $\gamma = 0$, implies that the inefficiency effects are not stochastic, which is rejected at the 1-percent level of statistical significance. The fourth null hypothesis, $H_0 : \delta_0 = \delta_1 = ... = \delta_{19} = 0$, entails that all the explanatory variables in the inefficiency model are jointly zero is rejected, which indicates 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. Finally, the fifth null hypothesis, $H_0 :\ \delta_1 = \delta_2 = ... = \delta_{19} = 0$, implies that the effects of all the explanatory variables in the inefficiency model are zero is also rejected.

In model 1 the parameter for herd-size indicates that, *ceteris paribus,* keeping one additional milch animal significantly decreases technical inefficiency of dairy farms, which points toward potential benefits of economies of scale. The estimated negative coefficient for head-age predicts that, on average, older and experienced farmers are less inefficient than the younger ones. The positive age-square coefficient further reveals that the advantage to experienced farmers in reducing inefficiency remains until they reach the age of 69-years. Timely feeding of water to milch animals is important. Farmers who feed more water to their milch animals are less inefficient than those who don't. The significantly positive coefficient on dummy variable for depression in all the specifications could be interpreted as indicating relatively higher inefficiency of farmers who suffer from severe long-term depression than those who don't. From the estimated coefficients in different specifications we can see that molasses has a negative effect on technical inefficiency and that in each case this effect is large and statistically significant suggesting potential benefits of feeding adequate amounts of concentrate to the milch animals.

Farms located in remote rural areas signal that they do not face favourable exogenous operating conditions due to their location specific heterogeneity. Therefore, it makes intuitive sense when we find that distance from *pucca* road is positive and highly significant in all the specifications. For example, in model 1, the parameter $(0.161, t = 2.91)$ indicates that technical inefficiency significantly increases with an additional kilometer distance of dairy farm from *pucca* road. In other words, we detect that remoteness of dairy farms clearly has unfavourable effect on their technical inefficiency.

Our primary interest in this paper is to explore the differential impact of milk supply chain on X-inefficiency of dairy farms, holding all else as constant. It is clear from the results that presence of milk supply chain indeed decreases technical inefficiency of smallholder dairy households. Milk district variable[11] has negative estimated coefficient in all the specifications; this effect is statistically significant at the 1-percent level in model 1. These 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.

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

In model 2 we analyze the sources of decline in technical inefficiency of farms in milk district by introducing two interactive effects of milk district with (a) farm location, and (b) herd-size. Our results suggest that while distance from *pucca* road increases technical inefficiency $(0.198, t = 2.90)$, building of milk supply chain clearly benefits dairy households in remote *mouzas*. For example, the negative and statistically significant coefficient of the interaction term $(-0.245, t = 1.79)$ reveals that building of milk district tend 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 populations in remote rural areas are frequently 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 their relative technical inefficiency.

Then we ask whether location of dairy farms in milk district influences their technical inefficiency on the basis of small vs. large herds. The interaction term (milk district $\times$ herd-size) in model 2 also allows the differential effects of milk district to vary by herd-size, holding all else as constant. From the parameter of the interaction term $(-0.074, t = -2.08)$ we predict further that the inefficiency reducing effect of large herd-size becomes even stronger when farms are located in milk district, as suggested by the difference in the two delta coefficients,$(-0.044 - 0.074)$ which is -0.118 and in the same direction.The combined effect of the two interaction terms suggests that milk supply chain benefits sample dairy producers disproportionately more when they are located at a distance from *pucca* road, and they maintain relatively larger herds.

Finally, we envisage that 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, we introduce three dummy variables (one-player, two-players, and three-players) in model 3 indicating the number of milk processors competing for fresh milk in a *mouza*, while no industry player is the excluded category. According to the predictions of the theory of the firm, efficiency and productivity of firms is expected to be higher and technical inefficiency lower when there is more competition; the sign of these parameters is then expected to be negative. As expected, with increase in the number of industry players, technical inefficiency of dairy farms decreases in our sample. The estimated coefficients for one-player $(-0.872, t = -3.71)$ and three-players $(-1.196, t = -3.75)$ are large, negative and statistically significant at the 1-percent level, which indicate 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 deltais $(-0.872 - 1.196)$, predicting that improvement in technical inefficiency of farms that deal with three-players is much greater than those who deal with only one-player. These results clearly show that increase in the number of industry players tends to decrease technical inefficiency of dairy farms. This is hardly a surprising result if seen in the light of the theory of the firm where monopsony/duopsony power allows firms to reap extra profits. While the statistically insignificant coefficient for two-players $(-0.872 - 1.196)$ is surprising, it may be blamed on the high collinearity between two-player and district fixed-effects.

C. Cross-sectional properties of X-efficiencies

To better understand the separated effects on production efficiency, next we consider mean predicted efficiency[12] to make cross-sectional comparison. Predicted mean technical efficiency scores from model 1 are presented in Table 4 to indicate the separated cross-sectional effects. Averaging over the full sample, the mean and the median estimated efficiency are 73.1 percent and 81 percent, respectively. The mean efficiency results suggest that, on average, dairy farms in our sample loose about 37 percent of their dairy output due to being technically inefficient.

The mean and median efficiency of farms in milk district is 79 percent and 85 percent, respectively; on the contrary, these numbers are much lower for farms that are not in the milk district at 66 percent and 73 percent, respectively. These results seem to suggest that farms in non-milk district fail to adapt to better management practices to dairy farming. This result is further supported by the standard deviation of 0.144 and 0.227 in milk and non-milk district, respectively, which reveals that farms located in milk district cluster relatively much closer to the production frontier than farms in non-milk district. Superior efficiency performance of dairy farms in milk- and non-milk districts is also indicated in Figure 1 where we plot the empirical cumulative distribution functions of the estimated technical efficiency scores. Further insights are provided in Figure 2 where we compare the frequency distribution of mean technical efficiency of dairy farms in milk and non-milk district. For the milk district sample, a relatively large number of dairy farms cluster closer to the high-end of technical efficiency than at the low-end, which is in sharp contrast to the efficiency levels of farms in non-milk district sample. Very few dairy farms in milk district have mean technical efficiency scores of less than 70 percent. On the contrary, a large number of dairy farms in non-milk sample have mean efficiency scores in the range of 20 to 70 percent.

To single out the performance effects by regions, we present the distribution of mean efficiency by *mouzas* in the histograms of Figures 3 where *mouzas* are ranked from the best performers to the worst performers. An important result emerging from Figure 3 is that 15 of the top 20 *mouzas* in our sample are from the milk district, whereas 13 of the bottom 20 *mouzas* are from the non-milk district. In general, these findings also tend to corroborate positive contribution and efficacy of milk district in increasing productive efficiency of smallholder dairy producers.

Next, we examine the differential effects on dairy efficiency incurred by the evolving market structure. In general, Table 4 shows that technical efficiency of dairy farms is positively correlated with the number of industry players present in a *mouza*. Mean technical efficiency is lowest when the market structure resembles monopsony (no-player), but building of milk supply chain network significantly increases technical efficiency. For example, we note an overall increase of 12.6, 11.7 and 14.7 percentage points in mean estimated efficiency of dairy farms when respectively one-player, two-players and three-players are present in the *mouza*. The highest level of mean efficiency (80.6 percent) and lowest standard deviation is achieved when the market structure resembles oligopsony (three-players). These results show that farms located in *mouzas* where three-players are present as a group cluster closer to the frontier. Furthermore, the difference in mean and median technical efficiency between two-players and no-player is statistically significant at the 1-percent level; it corroborates our conjecture that statistically insignificant coefficient for two-players in Table 3 was indeed explained by the suspected collinearity between two-player and the district fixed-effects .

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 district	0.794	0.85	0.144	0.10	0.95	420
Not in milk district	0.662	0.73	0.227	0.02	0.96	380
No industry player	0.659	0.72	0.230	0.02	0.96	340
One industry player	0.785	0.84	0.153	0.26	0.95	200
Two industry players	0.776	0.84	0.164	0.10	0.94	180
Three industry players	0.806	0.85	0.114	0.33	0.94	80
Farm Characteristics:						
Here size:						
Herd-size 1-2	0.681	0.75	0.218	0.04	0.96	369
Herd-size 3-4	0.757	0.82	0.177	0.02	0.96	243
Herd-size 5-6	0.776	0.85	0.170	0.02	0.95	108
Herd-size 7-10	0.821	0.88	0.125	0.39	0.95	63
Herd-size 11-15	0.804	0.89	0.204	0.20	0.92	12
Herd-size 16 or more	0.900	0.89	0.031	0.87	0.95	5
Feeding of water to milch animals:						
Feed water once a day	0.583	0.83	0.471	0.04	0.88	3
Feed water two times a day	0.742	0.82	0.197	0.02	0.96	534
Feed water three times a day	0.705	0.78	0.198	0.10	0.95	252
Feed water four times a day	0.820	0.86	0.130	0.45	0.92	11
Feeding of concentrates:						
Feed molasses	0.882	0.89	0.039	0.78	0.92	20
Don’t feed molasses	0.727	0.81	0.200	0.02	0.96	780
Farmers’ long-term stress levels:						
With major depression	0.681	0.76	0.216	0.02	0.96	95
Without major depression	0.738	0.82	0.195	0.02	0.96	705
Full sample	0.731	0.81	0.199	0.02	0.96	800

Source: Authors’ estimations

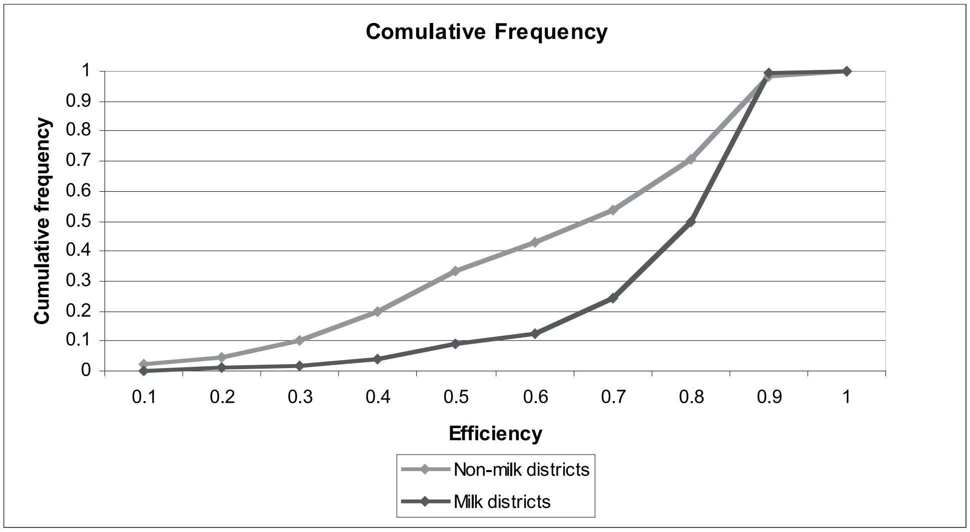


Figure 1. Cumulative distribution function for estimated technical efficiency

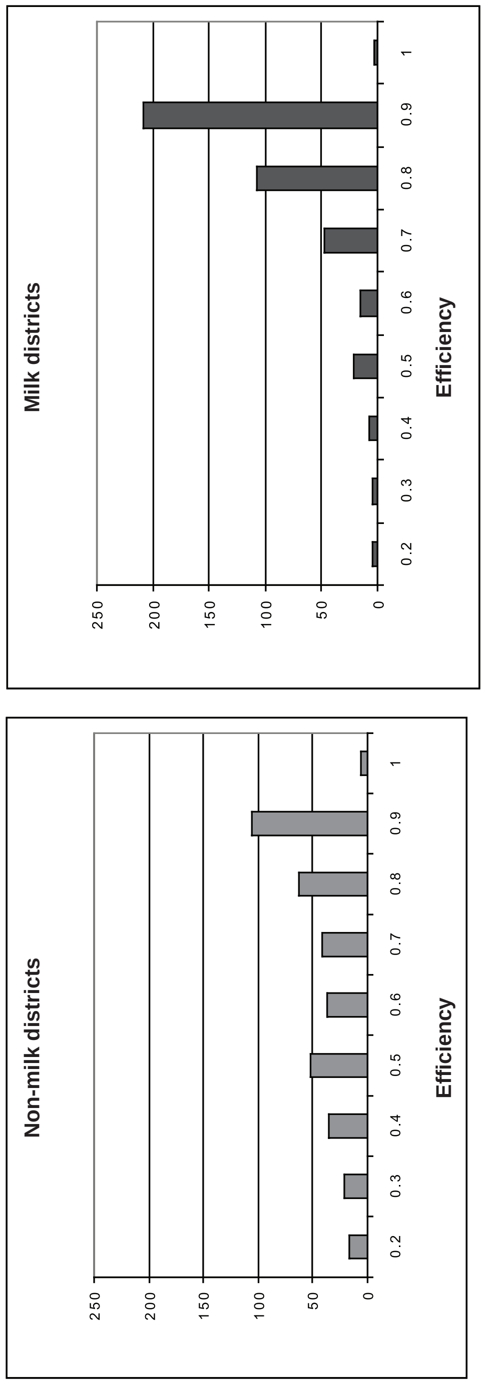


Figure 2. Frequency distribution of mean technical efficiency levels

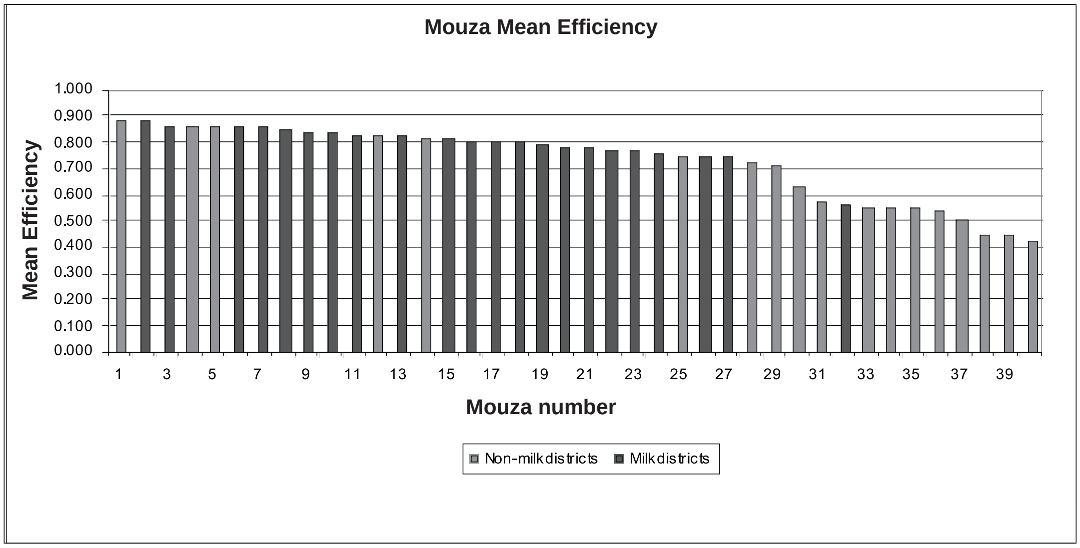


Figure 3. Mean technical efficiency levels by *mouza*

Table 4 and Figure 4 (panel A) shows that the largest herd-size category of 16 or more dairy animals is most efficient (90 percent efficiency) while the subsistence dairy producers or herd-size 1–2 are least efficient (68 percent). It should be noted that the largest efficiency gains occur while moving from herd-size 1–2 to herd-size 3–4. The mean technical efficiencies are estimated to be 76 percent for herd-size 3–4, 78 percent for herd-size 5–6, 82 percent for herd-size 7–10 and 80 percent for herd-size 11–15, suggesting an average efficiency differential of close to 2 percentage points between these four herd-size categories.

In order to compare efficiency of farms by herd-size, we also present in Figure 4 (panel B and panel C) the distributions of estimated efficiency for the milk district and non-milk district sub-samples. Stacked up against each other in terms of technical efficiency, what appears from Figure 4 is that mean technical efficiency in milk district for herd-size 1–2, 3–4 and 5–6 is in each case relatively much higher as compared with efficiency levels in non-milk district. Since most of the farms in our sample fall in these categories, it implies that dairy farms in non-milk district as a group are less efficient.

The mean and the median efficiency of dairy farms who do not adequately feed water to dairy animals also appears to be significantly lower than those who are more prudent in managing their herds. Although majority of the dairy farms feed water to their dairy animals only twice a day, our results show that large efficiency gains accrue to those dairy farmers who feed water to their animals four times a day; a practice that could easily be adopted without any additional cost. A further examination of the distribution of technical efficiency by feeding practices of the dairy farms indicates that, although only 2.5 percent of sample dairy farms report feeding of molasses to the dairy animals, the estimated mean and median technical efficiency of these farms is 15 percentage points and 8.5 percentage points higher, respectively than those who do not feed molasses.

That 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 depressive disorders (74 percent and 82 percent). These results suggest that farmers without major depressive disorders cluster much closer to the frontier production function than those with major depression.

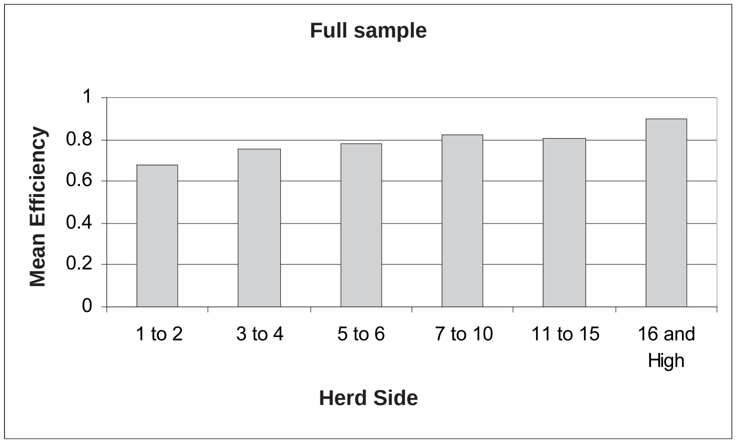
5. Conclusions

This paper provides some empirical evidence on how participation of local dairy producers in organized supply chain network affects smallholder efficiency in Pakistan. We exploit evidence from a natural experiment on building of milk supply chain network in rural Punjab to examine the relationship between supply chain and technical inefficiency on the basis of survey data of 800 smallholder dairy producers taken from milk and non-milk district. We use the frontier inefficiency effects model to examine differential impact on relative inefficiency of smallholder dairy producers.

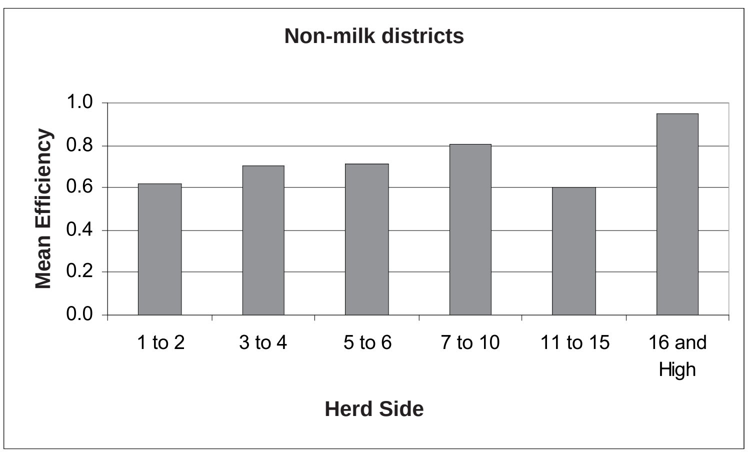
The findings of this paper are that while location of dairy households in our sample is exogenously determined, building of milk supply chain network indeed decreases technical inefficiency of smallholder dairy households. Evidence in the present case suggests that dairy farms located in milk district employ fewer resources relative to those located in non-milk district to produce given output levels.

In general, remoteness of rural communities remains a key feature in Pakistan where local population is often excluded from the basic facilities. Therefore, it makes intuitive sense when we find that farms located far from *pucca* road are technically more inefficient than those who are near. But the analysis reveals that building of milk supply chain tends to decrease technical inefficiency of dairy farms with their increasing distance from *pucca* road. Similarly, we find 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. Increase in the number of market players in the supply chain leads to decrease in technical inefficiency of dairy farms. In essence, technical inefficiency is highest where market structure resembles monopsony while lowest technical inefficiency is found where market structure resembles oligopsony.

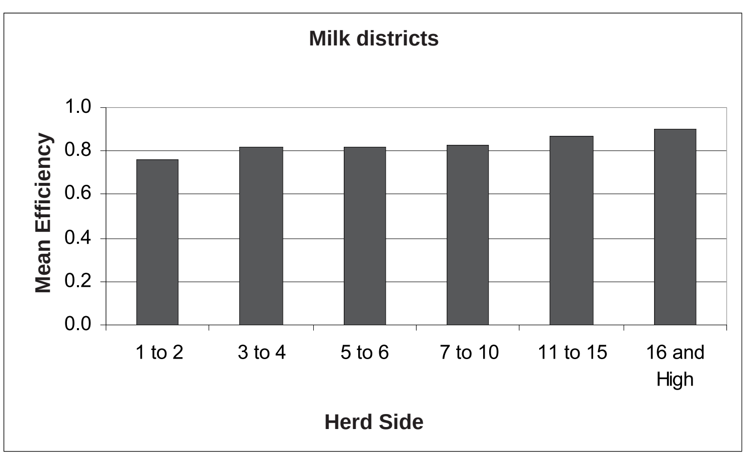
If policy makers are indeed interested in increasing productivity and growth of smallholder dairy producers then they should promote building of supply chains in rural areas. However, efficiency and productivity gains are far greater if the supply chains also bring into their fold medium and relatively large farmers based in remote rural areas. The results of this study 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. In the absence of government intervention, profit motive should supply the incentives for farms to move toward greater efficiency. Our results clearly indicate that experienced farmers, timely feeding of water to dairy stock and better feeding regimes can significantly enhance farm efficiency. Since depressive disorder is a common occurrence in our sample, it seems to interfere with cognitive and physical ability of dairy producers to work. In some cases the results in this paper may justify additional public spending for adequate depression treatment.



Panel A



Panel B



Panel C

Figure 4. Mean technical efficiency levels by herd-size

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Abstract

Many developing countries are re-orienting their production and marketing systems by linking local agri-producers with organized supply chain networks and supermarkets to meet increasing consumer demands. However, the existing literature is silent on the effects of such integration on relative inefficiency of smallholder producers. This paper analyzes the effects of such supply chains using data from a natural experiment in the dairy sector of Pakistan. We study the impact of rural milk supply chain, known as milk district, on smallholder efficiency of commercial dairy producers by employing stochastic production frontier and technical inefficiency effects model using survey data of 800 dairy households. While location of dairy households in our sample is exogenously determined, building of milk supply chain indeed decreases technical inefficiency. We detect stronger power of milk district in further reducing technical inefficiency if the farms are located in remote areas, or if their size is relatively large. The advice to policy makers from these results conforms to the standard economic view that market competition leads to decreased levels of technical inefficiency of smallholder producers.

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Keywords: Supply chain; Production frontiers; Dairy efficiency; Food policy

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