ECONSTOR
Make Your Publications Visible.

A Service of
ZBW
Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Burkitbayeva, Saule; Janssen, Emma; Swinnen, Johan F. M.

Working Paper

Technology adoption and value chains in developing countries: Panel evidence from dairy in Punjab

LICOS Discussion Paper, No. 410

Provided in Cooperation with:
LICOS Centre for Institutions and Economic Performance, KU Leuven

Suggested Citation: Burkitbayeva, Saule; Janssen, Emma; Swinnen, Johan F. M. (2019) : Technology adoption and value chains in developing countries: Panel evidence from dairy in Punjab, LICOS Discussion Paper, No. 410, Katholieke Universiteit Leuven, LICOS Centre for Institutions and Economic Performance, Leuven

This Version is available at:
https://hdl.handle.net/10419/200494

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

WWW.ECONSTOR.EU

Mitglied der Leibniz-Gemeinschaft

LICOS Centre for Institutions and Economic Performance

Centre of Excellence

LICOS Discussion Paper Series

Discussion Paper 410/2019

Technology Adoption and Value Chains in Developing Countries: Panel Evidence from Dairy in Punjab

Saule Burkitbayeva, Emma Janssen and Johan Swinnen

Faculty of Economics And Business
LICOS Centre for Institutions and Economic Performance
Waaistraat 6 – mailbox 3511
3000 Leuven
BELGIUM
TEL:+32-(0)16 32 65 98
FAX:+32-(0)16 32 65 99
http://www.econ.kuleuven.be/licos

Technology Adoption and Value Chains in Developing Countries:

Panel Evidence from Dairy in Punjab[1]

Saule Burkitbayeva, Emma Janssen and Johan Swinnen

LICOS Centre for Institutions and Economic Performance
& Department of Economics
KU Leuven

Version: January 2019

Abstract

The adoption of modern technologies in agriculture is crucial for improving the productivity and welfare of poor farmers in developing countries. Not much is known about how value chains do (not) affect technology transfer and/or adoption in domestic food chains in developing countries. Our paper analyzes farm-level technology adoption in the dairy chain in Punjab, India, combining quantitative panel data from representative surveys in 2008 and 2015 with data from targeted interviews with emerging modern dairy farms. Between 2008 and 2015 there were important increases in technology adoption in the form of better hygienic practices, better feed and improved livestock among traditional dairy farms. Especially those farms which lagged behind in 2008 improved their technology. However, the role of vertical coordination in value chains in stimulating technology adoption among these traditional dairy farmers seems to be minor. In contrast, we document the emergence of a group of dynamic modern dairy farms which are much larger, only use modern technology, and are fully integrated in vertically coordinated value chains which support these modern farms' management and investments.

[1] We would like to thank the Guru Angad Dev Veterinary and Animal Science University (GADVASU), and more specifically Dr. Inderpreet Kaur and Dr. Kushal Bhalla, for their assistance during data collection. This research was financially supported by the KU Leuven (Methusalem Program) and the Excellence of Science (EOS) Research project of FWO.

1. Introduction

The adoption of modern technologies in agriculture is essential for improving the productivity and welfare of poor farmers in developing countries and is a key ingredient for achieving poverty reduction and rural development. However, the adoption of modern technology has been disappointing, particularly in the poorest agricultural regions of the world (Evenson and Gollin, 2003; Sheahan and Barrett, 2014).[2]

The role of value chains in technology adoption has only recently begun to receive attention as an important source of technology transfer and adoption for small farmers (Kuijpers and Swinnen, 2016; Maertens and Vande Velde, 2017; Zilberman et al., 2017). Studies show that value chains can play a very important role in technology adoption, not just by processing companies, but also by farmers through vertical coordination and spillover effects (Dries et al., 2009; Swinnen and Kuijpers, 2017).

Investments made by modern processing and retailing companies typically include the modernization of procurement systems for sourcing high quality raw material in order to meet new consumer demands. An important aspect of this modernization process is the introduction of standards to enhance the quality of supplies and to overcome information asymmetry and reduce transaction costs. This often requires farmers to invest in new technologies, be it to improve productivity in order to achieve minimum output, to upgrade product quality, or to

[2] Explanations in the literature for the failure of technology adoption include imperfections in credit, information and labor markets: access to credit and information (Banerjee and Duflo, 2014; Bardhan and Udry, 1999; Feder et al., 1985; Feder and Umali, 1993), the importance of learning through social interactions or extension services (Cameron, 1999; Munshi, 2004; Bandiera and Rasul, 2006; Conley and Udry, 2010; Genius et al., 2013) and labor constraints (Moser and Barrett, 2006). Another reason for the farmer to not adopt the technology is when there is uncertainty about whether this investment will be rewarded. One possibility is buyer holdup at the time of delivery (Klein et al., 1978; Gow and Swinnen, 2001). Examples are late payments, renegotiation of prices at product delivery and the absence of transparent and reliable quality evaluation procedures (which could lead to inappropriately rejecting produce) (Barrett et al., 2012; Cungu et al., 2008; Saenger et al., 2014)

satisfy other types of private standards.[3] Many studies have pointed at the challenges small and poor farmers face in satisfying these new requirements, as they put them at risk of further marginalization (Reardon et al., 2003; 2009). However the same processes and forces that impose new challenges on these farmers may also be a force of innovation, technology transfer, and, thus productivity and income growth.

With imperfect (or non-existing) technology markets, various forms of institutional innovations in value chains (such as vertically coordinated supply systems and interlinked contracting[4]) have been introduced by up and downstream companies to overcome constraints and enhance their access to and adoption of new technologies. This process of quality and technology upgrading has been documented and analyzed in transition countries (e.g. Dries et al., 2009; Gow et al., 2000; Van Herck et al., 2012) and in high-value (often export) supply chains in developing countries (eg. Bellemare, 2012; Bolwig et al., 2009; Jones and Gibbon, 2011; Kumar et al., 2016; Maertens and Swinnen 2009; Minten et al., 2009).

However, much less is known about how value chains do (not) affect technology transfer and/or adoption in domestic food chains in developing countries. Some recent studies have found that this process of vertical coordination and technology transfer seems to have not (yet) emerged in staple foods in developing countries (e.g. Minten et al., 2016; Rearden et al., 2010).

[3] Most standards, codified or not, either directly or indirectly prohibit the use of less costly technology (Swinnen et al., 2015). In fact many of the most visible standards for consumers directly prohibit or require the use of certain inputs. Examples of commonly prohibited inputs are child labor, chemical inputs (in accordance with organic farming standards), or battery cages in the production of poultry. Examples of commonly required inputs are milk cooling equipment for dairy farmers and traceability systems for farmers supplying supermarket channels. Additionally, standards often require certain practices. For example GlobalGap certification requires Lychee farmers in Madagascar to use clean water for pre-harvest hand washing and to implement good picking and packaging practices for the transportation from the farm to the processing unit (Subervie and Vagneron 2013).

[4] Such interlinked contracts are well known in the traditional development literature for basic input provisions (Bardhan, 1989; Bell and Srinivasan, 1989)

In this paper we will contribute to our understanding of this by (a) analyzing farm-level technology adoption in the dairy chain in India and (b) by studying dynamic changes in a period of rapid demand growth using panel data from surveys in Punjab in 2008 and 2015 complemented with qualitative information from interviews. In an earlier study using data from 2008 from Punjab and Andhra Pradesh, Janssen and Swinnen (2017) found that very little transfer of technology occurred through value chains. Our paper uses new (2015) survey panel data to analyze whether continued growth in the Indian dairy markets has resulted in more technology transfer through value chains. In addition, we complement the survey data with information from a series of targeted interviews with a new class of larger and modern dairy farms which have recently emerged in Punjab.

The dairy chain in India is a highly relevant case for our study for several reasons. First, the Indian dairy sector is arguably the world's largest agri-food sector, employing more than 70 million households.

Second, dairy production is argued to contribute to inclusive growth, especially in India where there is a high dependency of the poor on agricultural employment. Agricultural production activities such as dairy, which are labor-intensive but do not overly rely on access to land or economies of scale, are generally expected to offer better prospects for income growth to the poorest rural households, often characterized by limited access to land but easy access to cheap family labor. In fact, the Indian government has massively promoted development in the dairy sector due to its potential for 'pro-poor' growth. For instance, the Operation Flood program, launched in 1970, had the objective of increasing milk production and income for small rural farmers; within 30 years it became one of the world's largest rural development programs.[5]

[5] India has also used these arguments in trade negotiations (both within the World Trade Organization (Jha, 2003) and in bilateral negotiations (Mondal et al., 2012)) to keep the dairy sector largely off the negotiation table (Goswami, 2007).

Third, value chain initiatives have had dramatic effects on farm-level technology upgrading in the dairy sector in other countries characterized by (a) imperfect (or missing) credit and technology markets, and (b) liberalization and growth in demand for (better quality) milk products. This was particularly the case in Eastern Europe in the 1990s, where significant investments made by dairy processing companies triggered dairy farms, both large and small, to invest in improved technology (Dries and Swinnen 2004, 2010; Dries et al. 2009; Van Herck and Swinnen 2015). Of course, there are differences between Eastern Europe in the 1990s and India today. A key difference is the level of income, which affects consumer demand. While incomes were much higher in Eastern Europe, incomes have been increasing rapidly in India over the past 25 years, creating a strong growth in demand for milk products (see Section 2). In addition, rapid urbanization and the spread of modern retail in India have contributed to a demand for high quality products and safety standards (Minten and Reardon 2008; Reardon and Timmer 2014). While demand growth over the past 25 years was initially mostly driving the need for higher quantities of milk supplies, more recently there has been increasing demand for better quality and safety of milk products (Squicciarini and Vandeplas 2013).

The answer to this question is not just important from the Indian perspective, but has more general implications as it will provide insights into the nature of changes in demand that lead to changes upstream in the value chain and, in particular, technological improvements at farm-level.

2. Dairy and Technology in India and Punjab

2.1 Dairy production and consumption

India is the largest milk producing country in the world. Dairy is a traditional activity in many regions of India. More than 70 million rural households produce milk (Sharma et al., 2002). They produced 155.5 million tonnes of milk in 2016 (National Dairy Development Board,

2017). The value of milk produced in India is 43 billion USD, making it India's largest agricultural commodity by value (FAOSTAT, 2018). Figure 1 illustrates the impressive growth of Indian dairy production. Strong income growth in India has led to higher levels of dairy consumption. Milk consumption has grown at an average rate of 6–8% per annum since 1990 and experts estimate that demand for milk and milk products will be growing even stronger at around 8–10% annually in the coming years (Rajeshwaran et al. 2014; VGBO 2009). In addition, with increasing urbanization, Indian households increasingly rely on markets to buy milk, rather than keeping their own cows or buffaloes.

Punjab, in the north of India, is one of India's leading agricultural states and is the fourth largest milk producing state with a total production of 10.7 million tonnes in 2015–2016. As Figure 1 illustrates, milk production in Punjab has been growing at an average of 2.4% per year since 2000. Moreover, Punjab has the highest per capita milk production within India (1032 grams/capita/day compared to a national average of 337 grams/capita/day (NDDB, 2017)). This is due to several factors: (1) favorable agro-climatic conditions (ensuring a high availability of green fodder), (2) well-developed transport infrastructure that supports dairy commercialization, (3) a relatively high standard of living, which pushes up local demand, and (4) extensive government support of the dairy sector (Chand, 1999; Staal et al., 2008). Dairy farm sizes are somewhat larger in Punjab than in the rest of India: the share of farmers with less than 2 ha of land in milk production was 39% in Punjab compared to 69% for India as a whole (Kumar et al., 2011).

2.2 Milk quality

Demand growth may provide incentives for adulteration. For example, excessive demand growth contributed to milk adulteration and major food safety problems (the "milk scandal")

in China in the late 2000s (Mo et al., 2012). A series of food scandals[6] in India in the early 2000s increased national awareness of safety concerns in the production, processing and marketing of food (Squicciarini and Vandeplas, 2010). This caused debates on the need to introduce safety and quality standards for milk, which led to the introduction of the Food Safety and Standards Act (FSSA) in 2006.[7] The Food Safety and Standards Authority of India (FSSAI) was established in 2011 to oversee the implementation of this Act. However a recent audit of the FSSA showed that the policy has been implemented poorly (CAG, 2017). Anticipation of proper implementation of the legislation – in conjunction with increasing pressure from consumers – may spur the emergence of private food standards in the Indian dairy industry. Squicciarini and Vandeplas (2010) report that Indian dairy processors decided to pursue different levels of Hazard Analysis and Critical Control Points (HACCP) and International Organization for Standardization (ISO) certification as a 'competitive' strategy, in an attempt to convince consumers that their milk is of high quality. However, it is unclear how far these changes have spread along the value chain and to what extent these efforts have affected the farm-level activities.

2.3 Technology adoption in dairy production

Increased demand and changes in consumer preferences following higher incomes could give the dairy sector incentives and means to invest in new technologies. Demand-driven

[6] It was revealed that bottled water, milk and soft drinks contained dramatically high pesticide residue levels (Umali-Deininger and Sur, 2007).

[7] In 2006, Indian policy makers, pressured by civil society protests, drafted the Food Safety and Standards Act (FSSA). The Act determines which actor in the supply chain bears responsibility when food safety regulations are not complied with (Article 27 of FSSA 2006). For milk traders this implies that they are liable for any adulterants (e.g., water, oil, skimmed milk powder, soda) added to the milk, even if the responsibility for adulteration lies with their suppliers – unless they can specifically identify the culprit (Squicciarini and Vandeplas, 2013). These regulations extend to informal traders including street hawkers and itinerant vendors. Opponents of the Act claim that poor street vendors will be unable to comply with the food standards that have been imposed. Despite the existence of the FSSA, a wide number of procedures, guidelines and mechanisms are yet to be framed by the Food Safety and Standards Authority of India (FSSAI).

institutional innovations (in particular, vertical coordination) have contributed to farm assistance programs led by dairy processors to help farms invest in new technologies and improve milk quality and safety in other countries (see e.g. Dries et al., 2009). In the Indian dairy context, improvements in technology and production practices relates to several elements (Janssen and Swinnen, 2017).

First, milk quality can be enhanced by improving basic hygienic and food safety practices. Hygienic milking is important and includes washing hands, utensils, and the udder and teats of dairy animals (DA) before and during milking (Kumar et al., 2011). At the same time, especially given India's climatic conditions, storage and preservation practices are essential to guarantee safe milk. Timely cooling of the milk is critical.

Second, an important area for increasing productivity is improving the quality of animal feed. Studies identify limited availability and affordability of quality feed as a major constraint to higher milk yields (Nagrale et al., 2015). The traditional diet of green and dry fodder should be enriched with concentrated feed to ensure the intake of sufficient protein, energy, minerals, and vitamins. Furthermore, these nutrients should be administered in amounts that match the physiological needs of the DA, which vary with status (pregnant, in milk, dry) and type (FAO, 2012).

Third, another important technology to increase yields are crossbred cows. The traditional DA in India are local (desi) cows with low milk yields. Crossbreeding has been the main method to increase animal productivity.[8] Crossbred cows are the result of inseminating local desi cows with foreign cow breeds (exotic) – usually the Holstein-Friesian (H.F.) and Jersey breeds. With proper feeding, they yield considerably more milk than local desi cows.

[8] Crossbreeding practices in India go back to as far as 1856 (Sinha, 1951) although the scaling up of this practice started only in 1963 with the introduction of the Intensive Cattle Development Project (ICDP) as part of the Special Development programme during the Third Five-Year Plan period (Rao et al., 1995). By 1982, 4.65% of the DA population consisted of crossbred animals, but their prevalence differed across states (Livestock Census, 1982, as cited in Rao et al., 1995).

Dairy company interviews suggest that various improved practices and technologies are increasingly promoted to farmers by dairy companies. However, an earlier study by Janssen and Swinnen (2017) found that by 2008, improved technology adoptions were not widespread in Punjab (and even less so in Andhra Pradesh, a poorer state in the south of India). In this paper we use new (panel) survey data from Punjab in 2015 to analyse whether these technological developments have advanced since 2008, and to study whether they are related to changes in the institutional organization of value chains.

3. Data

Our analysis uses two types of data. Our main analysis uses data collected in a random (two-round) sample of dairy farmers and households in rural Punjab. The baseline was collected in the summer of 2008 and the follow-up round seven years later in 2015 during the same period. This analysis is complemented with a data and qualitative information from a series of interviews with a group of recently emerged modern dairy farms.

For the survey in 2008 Punjab was divided into five regions: the north-west (Amritsar and Gurdaspur), the north-east (Hoshiarpur, Jalandhar, Kapurthala and Nawanshahar), the south-west (Bathinda, Faridkot, Ferozepur, Moga and Muktsar), the south-east (Mansa, Patiala and Sangrur), and the central region (Fatehgarh Sahib, Ludhiana and Ropar) (see Figure 2). In order to avoid oversampling of households in smaller districts, one district was selected at random in each region, with the probability of selection being proportional to the district's population share within that region. All villages in these districts were stratified according to the marketing channels operating in that area, based on their appearance in a list of procurement villages provided by Nestlé, respective milk unions if available, and otherwise on their proximity to cooperative sector cooling plants. We selected at random 15 'Nestlé villages', 15 'cooperative villages', five villages where both companies were expected to

operate, and 15 villages where none of them were expected to operate. These 50 villages were spread over the five selected districts, resulting in a final selection of six villages in the district of Amritsar, six in Hoshiarpur, 14 in Ludhiana, 18 in Ferozepur, and six in Mansa. In each village, 20 households were stratified and randomly sampled using a prior village census. Households were categorized based on the number of DA they owned (0 DA; 1–2 DA; 3–10 DA; >10 DA) and their marketing channel. This sampling strategy allowed for oversampling of Nestlé and cooperative suppliers and large- and medium-size dairy farmers (as the majority of milk suppliers in Punjab have fewer than 3 DA) and to extrapolate to the level of Punjab, using the appropriate weighing factors.

During the second survey round in 2015, we tried to resurvey all the households from the original sample. However, we were not able to locate 130 households, which corresponds to an attrition rate of 13%. While the reasons for their resettlement are unknown, statistical analysis showed that the relocated households were not statically different from those households that were retraced. The final sample is a balanced panel data set containing 870 households.

In both survey rounds, the same questionnaire was administered, containing questions on the households' general characteristics, their income generating activities and expenditures, their (productive) assets and living standards, and, in particular, on their dairy production practices, and use of input and output markets.

During the 2015 survey, we received information on the emergence of a group of new, larger and “modern" dairy farmers, which we suspected would not be (sufficiently) captured by the survey. Therefore, in addition to the household surveys, a series of unstructured interviews with these large farmers was conducted in the field. A non-exhaustive list of open questions was used to collect information about these new dairy farms and their integration in dairy value chains in Punjab. The information obtained from these interviews is not

necessarily representative, but yields important additional insights into the dynamics of the Punjab dairy sector. The analysis in sections 4.5 and 6 is based on the representative sample of dairy farms. In section 7 we provide additional insight from the interviews with the “new dairy farms".

4. The Dairy Value Chain Structure

Figure 3 illustrates the structure of the dairy supply chains in Punjab. There are several possible outlets for the milk produced by the dairy farms in our survey.

Part of the milk produced is used for home consumption. Another part is sold informally, either directly to neighbours or friends, or to informal milk traders (dudhiyas). These dudhiyas pick up the milk from the household’s doorstep and directly market it to other households within the (neighboring) village(s).

Traditionally, the main formal channel was the sale of surplus milk to cooperative dairies (Cunningham, 2010). In Punjab, the cooperative sector is mainly represented by the Punjab State Cooperative Milk Producers Federation Ltd., popularly known as Milkfed – or by its brand name “Verka”. Milk procurement by cooperatives in Punjab is organized through village-level collection centers. Dairy farmers can bring their milk to these centers. Since 1991, when de-licensing of dairy companies was introduced, private dairy companies have emerged as another formal dairy channel. In Punjab, private dairy companies buy milk from farmers either through private milk buyers or milk collection centers. An important private dairy company in the region is the multinational, Nestlé, which has a longstanding tradition of milk procurement in Punjab.

Finally, larger commercial dairy farmers often directly supply to processing plants (cooperatives, Nestlé or domestic private companies) and their milk is collected on the farm by the dairy companies.

4.1 (Changes in) the importance of different channels in the dairy value chain

Table 1 documents the importance of the various channels and how their importance has changed between 2008 and 2015.[9] The data reveal some important changes, and several of these changes are counterintuitive given the significant growth in dairy production and consumption.

In 2008, 25.5% of the dairy farmers did not sell any milk, and this share increased to 29.1% in 2015. The share of farms selling informally increased greatly: from 13.6% in 2008 (of which 2.3% directly to other households and 11.3% to informal milk traders) to 25.7% in 2015 (of which 10.2% to other households and 15.5% to informal milk traders). In contrast, the share of dairy farmers selling to formal dairy channels declined from 61.0% to 45.5%. These changes are somewhat surprising since one would have expected growth in dairy markets to be associated with a growing share of formal sales.

The share of all formal channels declined. The share of farms selling milk to cooperatives declined from 22.1% in 2008 to 18.5% in 2015. The most important cooperative (Verka) stopped buying milk in four of our sample villages, where 41.2% of the households that were selling milk in 2008 were supplying to Verka. At the same time, Verka started procuring in five new villages but only managed to capture 28.6% of the sample households that were selling milk in these villages. Furthermore, in two of our sample villages, there was a remarkable decline in households selling to Verka: from 83.3% in 2008 to 10.5% in 2015 (average for the two villages). No specific reasons for this were cited in the survey. At the same time, Mother Dairy, another cooperative, entered three of our sample villages and sourced from 23.7% of the households selling milk.

[9] Table 2 includes all dairy farmers in the sample. Table 1A in the appendix shows the same table including only those households that had DA in both 2008 and 2015.

The decline in sales was even sharper in the private sector, and especially for Nestlé. The share of households selling to private dairy companies fell from 38.9% in 2008 to 26.9% in 2015. The share selling to private domestic dairies declined from 14.2% to 12.6%. The decline was especially large for households selling to Nestlé: from 24.7% in 2008 to 14.4% in 2015. The significant decline in households selling to Nestlé can be partly explained by a restructuring of their sourcing across villages and reputational problems. Nestlé ceased procurement activities in five of our sample villages, where, on average, 67% of the households that were selling milk sold to Nestlé. They only opened new collection centers in two of our sample villages, where, on average, 58% of the households that were selling milk now sell to Nestlé. Furthermore, in one village, 50% of the households that used to sell to Nestlé in 2008 indicated that they stopped selling to them because they suspected the manager of Nestlé's collection center of cheating them on fat measurements.

4.2 Farm characteristics and value chain choices

Table 2 presents the distribution of households by marketing channels based on herd and land size. A first observation is that sales of milk have increased strongly in the 3-10 DA category: their share in the "no sales" category fell from 46% to 17%. In 2015, the households that did not sell milk are almost exclusively (83%) households with one or two DA. Another observation is that very small milk producers (1-2 DA) make up a larger share of the supply base for the informal sector (61% and 50% to other households and informal traders respectively) but also a significant share of suppliers to the formal sector (between 29% for cooperatives to 39% for Nestlé). This indicator suggests that there is no obvious "exclusion" of small dairy farmers from formal value chains. All farms with 10 DA or fewer make up more than 90% of the suppliers of formal channels. These farmers also represent around 60% of the amount of milk supplied to formal channels.

In summary, there have been significant changes in the importance of the various channels in the value chains. There has been a significant increase in the share of medium size farms (DA between 3 and 10) that sell milk. Small farms (with one or two DA) sell mostly to informal channels, but still represent a significant share of the suppliers of the formal private and cooperative dairy companies. In section 5 we analyze how technology adoption has evolved between 2008 and 2015 and how this is related to the supply channels.

4.3 Contracting

Interestingly, and importantly from the perspective of value chain developments, as discussed earlier, we did not find any evidence of contracts (not even oral agreements) between dairy farmers and milk buyers in Punjab for the farmers in our sample in either 2008 or 2015. This suggests the absence of vertical coordination in the Indian dairy value chains at the time of the surveys. These findings seem to contrast with the findings of Birthal et al. (2017) who report that in Punjab the multinational dairies and private local firms engage farmers owning larger herds (25 and more) in production on the basis of a written contract and provide them with cattle feed and equipment, such as milking machines, milk coolers, and veterinary and extension services as part of the contract. Our survey, which includes eight farms owning 25 or more DA (five farms in 2008 and three farms in 2015) did not reveal any presence of such schemes neither in written nor in informal form.

As we will document in section 7, these contracts seem to be only introduced for a new group of larger and more modern dairy farms which are not well captured by a representative survey.

5. Technology Adoption

5.1 Better hygienic practices

Table 3 summarizes hygienic practices in Punjab in both 2008 and 2015. The vast majority of the households washed their hands before milking and in between milking different animals. This decreases the likelihood of transmitting infections between DA. In 2015, 56.8% of the households reported using soap, detergent or disinfectant for hand washing compared to only 13.5% in 2008. In almost all cases, udder and teats were washed before milking (only with water), to remove mud, dust and dung. In addition, more households reported drying udders and teats in 2015 (23.4%) compared to 2008 (14.2%). Washing and drying the udder and teats decreases the probability of contamination of the milk and the exposure of the udder and/or teats to infections (mastitis). In 2015, almost all households (99.0%) washed their utensils at least once a day, and most importantly, more households (79.8%) used soap, detergents or disinfectant (more than just water) compared to 2008 (17.4%). The time between milking and cooling the milk to an appropriate temperature is crucial, since in this moment the microbial content of the milk grows exponentially. The methods of milk preservation before sales did not change much between 2008 and 2015, and around 60% of households do not treat (cool, boil) milk before sales: in fact the majority reported selling milk directly after milking.

The overall improvement in hygienic practices becomes even more apparent when looking at changes over time using an index of hygienic practices.[10] Figure 4 a and b show that the hygiene index increased on average from 0.53 in 2008 to 0.70 in 2015, an improvement of 31%. What is also interesting is that convergence seems to have taken place. Households that were in the lowest quartile in 2008 improved their hygiene score from 0.37 to 0.70 on average (Figure 4a), which is an impressive 91 percentage change from 2008 (Figure 4b). Growth is much lower for the other quartiles and even negative for the fourth quartile. The improvement in hygienic practices across all households is also confirmed by the rightward shift of the

[10] The index of hygienic practices is the average of the compliance levels for various sanitary practice indicators before and during milking which are demonstrated in Table 4.

distribution of the hygienic index from 2008 to 2015 (Figure 5).[11] Moreover, the adherence to hygienic practices has leveled up across marketing channels; there is less variability in the mean hygienic index across different marketing channels (Figure 6).[12]

However, dairy company incentives still seemed to be limited to minimizing time between milking and cooling by investing in collection centers close to the farmers. The organization of the value chain in Punjab allows for close contact between milk buyers and dairy farmers and this could serve as a vehicle for information distribution at a relatively low cost. However, while the number of households that received information on clean milk production increased significantly, by 2015, still only 2.5% received information from their milk buyer (informal or formal) (see Table 4 Panel A). At the same time, there is a remarkable increase in the number of households indicating that they received information on clean milk production practices from other farmers and the government (from 0.3% in 2008 to 15.7% in 2015). At the same time, in 2015, households reported fewer on-farm inspections by both milk buyers and government institutions.

In summary, from 2008 to 2015, the adherence to hygienic practices increased significantly across all households, except for the highest quartile, and convergence between different households was observed. However, for the vast majority of dairy farmers, value chain initiatives have focussed on investment in village milk collection centers but not in providing information on and incentives for the adoption of better hygienic practices, nor in organizing inspections at farm level.

5.2 Better feed

[11] Figure 5 includes all dairy farmers in the sample. Figure 1A in the appendix shows the same graph including only those households that had DA in both 2008 and 2015.

[12] Figure 6 includes all dairy farmers in the sample. Figure 2A in the appendix shows the same graph including only those households that had DA in both 2008 and 2015.

Figure 7 and Table 4 Panel B indicate that improved feeding practices[13] through the use of mixed concentrated feed were more common in 2015 (68.8%) than in 2008 (53.3%). The greatest increase in the use of mixed feed is among households that did not use mixed feed at all in 2008; 67% of them reported using mixed feed in 2015 (Figure 7). More so, Figure 8 shows that the share of households using mixed feed increased across all marketing channels from 2008 to 2015.[14]

Value chains could improve the accessibility of good quality mixed feed. Most dairy companies told us during our company interviews in Punjab that they offered mixed feed to their farmers at production costs and that some provided subsidized feed.

However, our farm-level data present a different picture. Most of the households in both 2008 (28.6%) and 2015 (48.8%) indicated the general store as the primary place for purchasing mixed feed. In 2015, only 2.1% and 2.5% of the farmers bought mixed feed from private companies and cooperatives respectively, which is even lower than in 2008.

Apart from enhancing the availability of mixed feed, companies can assist in increasing yields by informing households of the benefits of feed practices and training them in using proper quantities and ratios. Although there was a substantial increase in the number of households exposed to information on the importance of feed for milk quality, most received such information from other farms (14.9%), the government (3.9%) or veterinary doctors

[13] In our survey, we distinguished between four different types of concentrate feed: a) grains and grain bran, b) oilseeds and oilcakes, c) mixed concentrated feed, and finally d) other concentrates, which includes salts and mineral mixtures. While grains, oilseeds/oilcakes, and salts/mineral mixtures are all part of a balanced diet, the mixed concentrates usually contain all these elements and is therefore the best indicator of whether a household has adopted enhanced feeding practices. In Punjab, different types of mixed concentrated feed can be found. First, branded pre-mixed feed with different compositions that are combined in such way that fulfill the requirements of different types of animals (crossbred/desi) as well as match the status of the DA (pregnant, in milk, dry) can be purchased (if available). Second, there is unbranded pre-mixed feed with varying composition. The survey data does not allow to distinguish between these two types of concentrated feed so they are both classified as mixed feed. Finally, some dairy farmers also mix their own concentrates, although this is done by only a small minority in our sample.

[14] Figure 8 includes all dairy farmers in the sample. Figure 3A in the appendix shows the same graph including only those households that had DA in both 2008 and 2015.

(10.1%). Less than 1% of farmers received any advice or training related to animal feed from both private companies and cooperatives in both 2008 and 2015 (see Table 4 Panel B).[15]

Finally, in Punjab, some milk buyers, both informal and formal ones, provide advance payments on milk.[16] These advances can be used by the household for any purpose, including the purchase of improved feed. In 2008, 11.3% of the farmers received advances but only 2.7% used them to buy inputs (medicines, fodder, improved feed, AI, etc…).[17] In 2015, this increased to 17.7% of dairy farmers receiving advances and 4.8% of them using these advances to purchase inputs.

In summary, the use of mixed feed increased from 53.3% to almost 70% between 2008 and 2015. This is a substantial improvement, but still leaves room for increasing productivity through better feed. Dairy companies claimed that they were increasingly providing such feed to their farmers, often at subsidized prices. However, according to our survey, very few small farmers bought or used mixed feed from the companies. In addition, there was virtually no training or information offered by the dairy companies on the potential benefits of (better) mixed feed.

5.3 Better animals

Punjab is one of the most important crossbred cow breeding states in India. According to the latest official census in 2012, 27.6% of the total bovine population in Punjab were crossbred cows. Our survey data shows slightly higher numbers with 30.5% of total sample population consisting of crossbred cows in 2008 and 39.2% in 2015. Although the total number of DA in

[15] Again, we can not exclude the possibility that this remarkable increase in the exchange of information can be attributed to differences in the way the question was posed by the interviewers in the two survey rounds.

[16] Note that the provision of monetary funds in formal value chains is not provided by the processing firm themselves but rather by the managers of the collection centers who act like money lenders.

[17] Because of the way the question was posed, we cannot distinguish between these inputs.

our sample decreased from 2008 to 2015, crossbred cow numbers increased by almost 13% in this period (see Table 5).

In 2015, 49.6% of the households indicated owning crossbred cows, compared to 39.8% in 2008 (see Table 4 Panel C). Figure 9a shows the increase in the share of crossbred cows and convergences across households from 2008 to 2015. In 2015, households had on average 29% of crossbred cows in their total herd, which is a 45% change from 2008 (Figure 9b). This significant increase was largely driven by those households who had 0% to 50% of crossbred share in 2008. Figure 10 also shows that the increase in the mean share of crossbred cows took place across all marketing channels.[18]

Yet again, the role of value chains in stimulating the adoption of more productive animal breeds appears to be limited. While in 2015, 30.7% of the dairy farmers indicated receiving information on the benefits of choice of breed, almost none of them indicated their milk buyer as the source. Both in 2008 and in 2015, less than 1% of farmers received information on the choice of breed from Nestlé and cooperatives. Again, most farmers cited other farmers, the government and veterinary doctors as providers of such information. Investing into better animals with the help of value chain finance was absent in both 2008 and in 2015. Very few farmers used a loan to finance the purchase of a crossbred cow (0.9% in 2008, and 3.9% in 2015) and none of these loans were provided by value chains.

5.4 Summary

There are three key conclusions from our analysis so far. First, there is an important increase in technology adoption level between 2008 and 2015 by the farmers in our survey:

[18] Figure 10 includes all dairy farmers in the sample. Figure 4A in the appendix shows the same graph including only those households that had DA in both 2008 and 2015.

(a) Hygienic practices improved significantly in 2015 compared to 2008, with scores on the hygiene index increasing on average from 0.53 to 0.70, an improvement of 31%.

(b) The use of mixed feed increased from 53.3% in 2008 to 68.8% in 2015.

(c) The percentage of farmers owning crossbred DA increased from 39.8% in 2008 to 49.6% percent in 2015.

Second, the increase in the average technology is mostly due to improvements in technology adoption of the slow adopters in 2008, and much less due to further increase of farms that had already relatively high levels in 2008. In other words, there has been convergence amongst households in technology adoption between 2008 and 2015.

Third, during interviews in both rounds of the survey, dairy companies in Punjab claimed that they actively supported better technology adoption at the farms. However, our farm-level data show that this was (still is) not the case among traditional dairy farms, except for the largest farmers. For all technologies, vertical coordination in the value chains seem to have played a minor role in either promoting hygienic practices, fostering the use of mixed feed, or encouraging the purchase of higher yielding DA.

Similarly, although more farmers received information regarding the benefits of all three technologies in 2015 compared to 2008, farmers indicated that this information was mostly coming from other farmers, the government and veterinary doctors, not from dairy companies.

6. Profile and Value Chains of Technology Adopters: Econometric Analysis

To further explore the relationship between technology adoption and specific value chains, we turn to econometric analysis. Most of the literature on technology adoption relies on cross sectional data, which makes it methodologically challenging to establish a causal relation between specific value chains and technology adoption due to various self-selection and

endogeneity issues. Our panel data set allows us to address some of these caveats. As dependent variables we use three technology adoption indicators: (1) an index of good hygienic practices, (2) a dummy indicating the use of mixed feed, and (3) the share of crossbred cows in total herd size.

We estimate Fixed Effects[19] (FE) models for our two continuous adoption indicators (the index of good hygienic practices and the share of crossbred cows in total herd size) and a Limited Probability Model[20] with Fixed Effects (LPM FE) for our binary adoption indicator (use of mixed feed), and thereby eliminating bias stemming from time-invariant unobserved heterogeneity. It is important to note that the FE estimator can still suffer from endogeneity bias when unobservable time-variant factors are correlated with both technology adoption and buyer choice or when reversed causality is driving the relationship. The FE model is specified as follows:

$$y_{i,t} = \alpha_i + \beta C_{i,t} + \delta T_{i,t} + \gamma HS_{i,t} + \theta X_{i,t} + Y_t + \varepsilon_{i,t} \quad (1)$$

[19] To verify that the Fixed Effects model is appropriate, we conduct the following steps: First we perform a Haussman test to decide between a FE and a Random Effects (RE) model. Next, we check if the assumption of strict exogeneity of explanatory variables holds by comparing outcomes of FE and first difference estimators (FD). The two estimators yield similar results, which means that explanatory variables do not correlate with past, current and future error terms. In short, the results showed that the FE model is preferred for studying both the adoption of improved hygienic practices and of crossbred cows. The different models are presented in Tables A2 and A3 in the Appendix.

[20] There exists no consensus on the econometric technique that should be used to estimate a model with a binary dependent variable in a panel setting. We follow Angrist and Pischke (2009) in using a Limited Probability Model. The LPM offers econometric advantages over a logit model when running estimations on panel data as using a logit model in this setting will give rise to the incidental parameter problem and lead to inconsistent parameter estimation, especially when T is small. However, as a robustness check, we estimate i) a probit model with FE and ii) a correlated random effects probit model proposed by Mundlak (1978). This correlated random effects model relaxes the strong assumption of RE models that time-invariant unobserved heterogeneity is not correlated with the independent variables. Concretely, time averages of the time-varying explanatory variables are added for each household as a set of controls. As such, we are estimating the effect of changes in the time-varying explanatory variables while keeping the time average fixed (Wooldridge, 2004). The results for all three models are similar and can be found in the appendix table A4.

where $y_{i,t}$ is the technology adoption indicator for household i at time t, α_i is the individual household intercept, $C_{i,t}$ is a set of marketing channel dummies, $T_{i,t}$ is a vector of technology adoption indicators other than the one on the left hand of the equation, $HS_{i,t}$ is a vector of variables related to farm size and income, $X_{i,t}$ is a vector of other socioeconomic household characteristics, Y_t is a year dummy (taking the value of one for 2015) and finally $\varepsilon_{i,t}$ is the error term. The summary statistics of the variables used can be found in Table 6.

First, the vector with marketing channel dummies was added to assess the primary objective of this paper: the impact of specific value chains on technology adoption. More specifically, the dummies capture the effect of switching to a specific value chain on technology adoption. $HS_{i,t}$ also comprises of herd size as we expect farmers who expanded their herd sizes to be more likely to have adopted new technologies. Furthermore, it also includes physical capital in the form of land owned (in acres) and an index capturing non-land asset ownership. Both asset-types may reflect the capacity of households to invest in improved technologies. $HS_{i,t}$ also includes the share of dairy income in total income as households that have an increased dependency on dairy may be more inclined to invest in new technologies

Furthermore, we include a control vector with time-variant household variables $X_{i,t}$ that may influence technology adoption. We control for human capital by including age, gender and education of the household head as well as household size. Since anecdotal evidence from our fieldwork suggests that the task of taking care of the DA is often assigned to the women and elderly in the household, we also control for the number of household members over 55 as well as the number of female adults. Additionally, we include a dummy indicating whether the household head changed between 2008 and 2015 to pick up potential changes in management of dairy activities. Finally, we include the year dummy Y_t, to capture all temporal variation in Punjab between 2008 and 2015, such as weather shocks and price variations. To deal with

serial correlation and heteroscedasticity, we use robust standard errors and cluster them at the household level.

The results for all three technology adoption indicators are presented in Table 7. Most importantly, the econometric analysis confirms what our descriptive statistics suggested: we find no effect of switching value chains on technology adoption indicators. Despite continued growth in demand for milk products, value chains (still) do not appear to play a major role in stimulating technology adoption at the farm-level.

Interestingly, a unit increase in the total number of DA has a significant and positive impact on both the probability of the use of mixed feed and the share of crossbred cows, but not on the adoption of improved hygienic practices. One explanation is that the adoption of improved feed and crossbred cows requires additional investment compared to the adoption of improved hygienic practices and is therefore more strongly related with herd size expansion and commercialization.

7. Growing Modern Dairy Farms and Integration in Value Chains

As explained before, the analysis in sections 4 to 6 is based on a random panel sample of dairy farmers in rural Punjab. However, during the 2015 surveys, we received information on the emergence of a group of new and larger commercial dairy farmers. We suspected that these farms would not be (sufficiently) captured by our surveys due to several reasons.

First, the majority of the milk producers in Punjab is very small and owns only 1 or 2 DA (Vandeplas et al., 2013). Random sampling would thus lead to a sample with predominantly small farmers. We tried to overcome this by using a stratified random sampling strategy, allowing for the oversampling of large farmers (defined as owning more than 10 DA) (see section 3). However, the probability of capturing the very large farms in the survey remains low.

Second, an important share of these new large dairy farms is located in the vicinity of urban areas. Because our survey was designed to represent the rural population of Punjab, we do not (sufficiently) capture the farmers located in these areas close to the cities.

Third, our panel survey includes households/farms that were already living and operating in rural areas in Punjab in 2008. Many of these larger dairy farms were established fairly recently, often after 2008, led by young professionals (like engineers and computer scientists) who consider commercial dairy farming as an interesting business opportunity with demand growing.

Not only are these new farms quite different from the ones captured in the survey, ad hoc evidence suggests that they also represent an increasingly important share of Punjab dairy production. This is also consistent with a comparison of production indicators in the official statistics of the total Punjab dairy sector and in our sample. Total production in our sample declined slightly (-6%) over the 2008 - 2015 period, while according to official statistics, total milk production in Punjab increased by 11.5% (Figure 1). This gap is most likely at least partly due to the growing share of production in these new large farms.

To get a better insight in this emerging new part of the dairy chain, in addition to the household surveys, we conducted a series of unstructured interviews with 11 of these large commercial farmers. They represent a mixture of histories and location: 4 of the 11 farms were established since 2008; 5 were located close to urban areas; and 2 were existing rural dairy farms which grew strongly in size between 2008 and 2015. A non-exhaustive list of open questions was used pertaining to the main challenges and opportunities within the dairy sector and the working of milk value chains in Punjab. The information from these interviews is not necessarily representative, but is relevant since it provides important additional insights into the dynamics of the Punjab dairy sector.

Table 8 summarizes some important characteristics of these farms based on the interviews. In the discussion and the comparison below we refer to these farms as "*modern dairy farms*". To compare, Table 9 summarizes the same characteristics for the 24 largest farmers in our panel sample, i.e. the farms owning more than 10 DA in 2015.

Almost all modern dairy farms (10 out of 11) and large sampled farmers (20 out of 24) were selling their milk to formal buyers, and none on the basis of a procurement contract. However, in many other ways, these two groups were very different:

- The modern dairy farms were much larger and technology adoption was much more advanced.
- Herd sizes of modern dairy farms ranged from 70 DA to 165 DA, with an average of 114 DA, while herd sizes of large sampled farmers were smaller and ranged from 11 DA to 96 DA, with an average of 19 DA.
- Herds of modern dairy farms virtually only comprised of crossbred cows (on average 96%), while herds of large sampled farmers on average only comprised of 60% crossbred cows in 2015.
- Modern dairy farms had bigger land holdings, 41 acres on average, which is considerably more than the 12 acres owned on average by large sampled farmers.
- Almost all modern dairy farms (10 out of 11) had mechanised milking, while only six out of 24 of the large sampled farmers had milking machines.

The level of interaction with dairy processors was also very different. Dairy processors often approached modern dairy farms and offered certain services, of which almost none were offered to the large sampled farmers.

- One such service was the picking-up of milk directly from the farmer or even the instalment of a bulk milk cooler (BMC) on the farm. As is well known,

timely cooling of the milk is very important to ensure milk quality. All modern dairy farms indicated that their buyer picked up the milk from their farm, while only 10 out of 24 large sampled farmers reported that they received this services.

- The modern dairy farms also indicated that representatives of their milk buyer visited their farm regularly and provided information related to a broad range of topics, including issues related to veterinary care, government schemes, dairy technology, etc. However, only four (16.7%) large sampled farmers stated that their milk buyers provided them with information on different dairy related topics.
- The majority of the modern dairy farms indicated that they received interest-free loans from dairy companies to finance investments in dairy equipment like milking machines or feeding computers (which allow for better balancing of feed ratios). Specifically, dairy companies not only helped put modern dairy farms in contact with companies that were selling this equipment, in certain cases they also offered interest free loans as part of a contract. The loans were repaid in instalments which were deducted from the milk payments. In most cases, a contract was drafted, stipulating a timeline and the amount of the instalments. The modern dairy farms indicated that the order of repayment was mutually agreed upon. In contrast, none of the large sampled farmers received support for the purchase of dairy equipment.
- Dairy companies assisted modern dairy farms in their search for quality crossbred cows, and in some cases, facilitated bank loans for herd extensions. While companies told us during interviews that they facilitated bank loans for farmers with all herd sizes, we only find evidence of this practice for modern dairy farms.

In summary, this comparison based on interviews with modern dairy farms suggest that in addition to the rural farm sector captured by our sample, there is a different and more dynamic part of the Punjab milk production system. It consists of farms which are considerably larger, fully commercial, using only modern technology (crossbred cows and milk machines), and receiving extensive assistance in their management from the dairy companies (including loans for investments). They are part of much more integrated and vertically coordinated value chains than the value chains of the traditional dairy sector.

8. Conclusions

Adoption of modern technologies in agriculture can be crucial for improving the productivity and welfare of poor farmers in developing countries. Value chains can play a crucial role in fostering the adoption of new technology, by spreading information and supporting the modernization of procurement systems. While this process has been analyzed in emerging countries and in high-value supply chains in developing countries, little is known about how value chains do (not) affect technology transfer and/or adoption in domestic food chains in developing countries.

In this paper we analyzed the impact of value chains on farm-level technology adoption in the dairy chain in India. Dairy products are a major part of Indian diets and milk production is a major production activity for many poor Indian farmers. There has been strong growth in dairy production and consumption in India over the past two decades.

Our analysis relies on unique two-round household survey data from 2008 and 2015 in Punjab, one of the most rapidly expanding and dairy-developed regions in India. We combine information from a unique two-round household survey data from 2008 and 2015 and from interviews with an emerging group of new modern dairy farms.

First, we find that in the traditional dairy sector in Punjab there was an impressive increase in adoption of all three technology indicators between 2008 and 2015. Hygienic practices improved significantly by 2015, with scores on our hygienic index increasing on average by 31%: from 0.53 in 2008 to 0.70 in 2015. The use of mixed feed increased from 53.3% in 2008 to 68.8% in 2015. Finally, the percentage of farmers owning crossbred DA increased from 39.8% in 2008 to 49.6% in 2015, while the share of crossbred cows households had in their total herd increased to 29%, a 45% change from 2008.

Second, there has been convergence amongst households in technology adoption between 2008 and 2015. The increase in the average technology is mostly due to improvements in technology adoption of the slow adopters in 2008, and much less due to further increase of farms that had already relatively high levels in 2008.

Third, despite companies reporting providing information other support for technology adoption by small farmers, dairy companies (still) do not appear to play a major role in stimulating technology adoption for all farms in our sample. In both rounds of the survey, hardly any information on hygienic practices was provided by dairy companies: there were fewer farm-level inspections in 2015; fewer households sourced mixed feed from value chains in 2015 than in 2008; and no loans were provided by dairy companies for purchasing better breeds.

However, our study identified another, rapidly growing, more dynamic part of the Punjab dairy sector which is modern and much better integrated in vertically coordinated value chains. A group of modern and fully commercial dairy farms has emerged and grown over the past decade, often led by younger people and closer to urban areas. These modern farms use only modern technology (crossbred cows and milk machines) and receive extensive assistance in their management from the dairy companies (including loans for investments). They are part of a much more integrated and vertically coordinated part of the dairy value chain than the

traditional dairy sector. The information on this modern part of the value chain was based on non-representative interviews, so there is considerable room to improve insights on these dynamics by more representative methodologies.

In summary, our study identified two parts of the Punjab dairy system which are evolving quite differently. One part consists of the more traditional dairy farms. Our survey shows that there is considerable improvement in technology adoption in these traditional dairy farms and especially those who lagged in 2008 have improved their technology use. However, none of these improvements have resulted from vertical coordination in value chains and there is much room for further technology adoption. The second part is a dynamic development of modern dairy farms which are much larger, more commercial and using only modern technology. These farms are assisted by dairy companies in their management and investments and are fully integrated in vertically coordinated value chains.

References

Angrist, J. D., and J. S. Pischke. (2009). *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press.

Bandiera, O., and I. Rasul. (2006). Social Networks and Technology Adoption in Northern Mozambique. *The Economic Journal*, *116*(514), 869–902.

Banerjee, A. V., and E. Duflo. (2014). Do Firms Want to Borrow More? Testing Credit Constraints Using a Directed Lending Program. *The Review of Economic Studies, 81*(2), 572–607.

Bardhan, P. (1989). *The Economic Theory of Agrarian Institutions Clarendon*. Oxford University Press.

Bardhan, P., and C. Udry. (1991). *Development Microeconomics.* Oxford University Press.

Barrett, C. B., E. B. Maren, M. F. Bellemare, H. C. Michelson, S. Narayanan, and T. F. Walker. (2012). Smallholder Participation in Contract Farming: Comparative Evidence from Five Countries. *World Development, 40*(4), 715–30.

Bell, C., and T. N. Srinivasan. (1989). Interlinked Transactions in Rural Markets: An Empirical Study of Andhra Pradesh, Bihar and Punjab. *Oxford Bulletin of Economics and Statistics, 51*(1), 73–83.

Bellemare, M. F. (2012). As You Sow, So Shall You Reap: The Welfare Impacts of Contract Farming. *World Development, 40*(7), 1418–1434.

Birthal, P. S., Chand, R., Joshi, P., Saxena, R., Rajkhowa, P., Khan, M. T., . . . Chaudhary, K. R. (2017). Formal versus informal: Efficiency, inclusiveness and financing of dairy value chains in Indian Punjab. *Journal of Rural Studies, 54*, 288-303.

Bolwig, S., P. Gibbon, and S. Jones. (2009). The Economics of Smallholder Organic Contract Farming in Tropical Africa. *World Development, 37*(6), 1094–1104.

CAG. (2017). *Performance Audit on Implementation of Food Safety and Standards Act*. Report No.37 of 2017, Union Government.

Cameron, L. A. (1999). The Importance of Learning in the Adoption of High-yielding Variety Seeds. *American Journal of Agricultural Economics, 81*(1), 83-94.

Chand, R. (1999). Emerging crisis in Punjab agriculture: Severity and Options for future. *Economic and Political Weekly, 34*(13), A2-A10.

Conley, T. G., and C. R. Udry. (2010). Learning About a New Technology: Pineapple in Ghana." *The American Economic Review, 100*(1), 35-69.

Cungu, A., H. Gow, J. F. M. Swinnen, and L. Vranken. (2008). Investment with Weak Contract Enforcement: Evidence from Hungary during Transition. *European Review of Agricultural Economic, 35*(1), 75–91.

Cunningham, K. (2010). *Rural and Urban Linkages: Operation Flood's Role in India's Dairy Development*. IFPRI discussion paper 00924.

Dries, L., E. Germenji, N. Noev, and J. F. M. Swinnen. (2009). Farmers, Vertical Coordination, and The Restructuring of Dairy Supply Chains in Central and Eastern Europe. *World Development*, *37*(11), 1742-1758.

Dries, L., and J. F. M. Swinnen. (2004). Foreign Direct Investment, Vertical Integration, and Local Suppliers: Evidence from the Polish Dairy Sector. *World Development*, *32*(9), 1525–1544.

Dries, L., and J. F. M. Swinnen. (2010). The Impact of Interfirm Relationships on Investment: Evidence from the Polish Dairy Sector. *Food Policy*, *35*(2), 121-129.

Evenson, R. E., and D. Gollin. (2003). Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, *300*(5620), 758–62.

FAO. 2012. *Balanced Feeding for Improving Livestock Productivity – Increase in Milk Production and Nutrient Use Efficiency and Decrease in Methane Emission, by M.R. Garg*. FAO Animal Production and Health Paper No. 173. Rome, Italy.

FAOSTAT (2018). Available at: http://faostat.fao.org.

Feder, G., R. E. Just, and D. Zilberman. (1985). Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic development and cultural change*, *33*(2), 255-298.

Feder, G., and D. Umali. (1993). The Adoption of Agricultural Innovations: A Review. *Technological Forecasting and Social Change*, *43*(3-4), 215-239.

Genius, M., P. Koundouri, C. Nauges, and V. Tzouvelekas. (2013). Information Transmission in Irrigation Technology Adoption and Diffusion: Social Learning, Extension Services and Spatial Effects. *American Journal of Agricultural Economics*, *96*(1), 328–344.

Goswami, B. (2007). Can Indian Dairy Cooperatives Survive in the New Economic Order? *Paper presented at the WTO Public Forum "How Can the WTO Help Harness Globalization"*, Geneva, Switzerland.

Gow, H. R., D. H. Streeter, and J. F. M. Swinnen. (2000). How Private Contract Enforcement Mechanisms Can Succeed Where Public Institutions Fail: The Case Of Juhocukor A.S. *Agricultural Economics*, *23*(3), 253-265.

Gow, H. R., and J. F. M. Swinnen. (2001). Private Enforcement Capital and Contract Enforcement in Transition Economies. *American Journal of Agricultural Economics*, *83*(3), 686–90.

Janssen, E., and J. F. M. Swinnen. (2017). Technology Adoption and Value Chains in Developing Countries: Evidence from Dairy in India. *Food Policy. (in press)*..

Jha, B. (2003). India's Dairy Sector in the Emerging Trade Order. *IEG Working Paper E/243/2004*.

Jones, S., and P. Gibbon. (2011). Developing Agricultural Markets in Sub-Saharan Africa: Organic Cocoa in Rural Uganda. *Journal of Development Studies*, 47(10), 1595–1618.

Klein, B., G. C. Robert, and A. A. Alchian. (1978). Vertical Integration, Appropriable Rents, and the Competitive Contracting Process. *The Journal of Law and Economics*, *21*(2), 297–326.

Kuijpers, R., and J. F. M. Swinnen. (2016). Value Chains and Technology Transfer to Agriculture in Developing and Emerging Economies. *American Journal of Agricultural Economics, 98,*1403–1418.

Kumar, A., D. Roy, P. K. Joshi, G. Tripathi, and R. P. Adhikari. (2016). Impact of Contract Farming on Profits and Yield of Smallholder Farms in Nepal: An Evidence from Lentil Cultivation. *Annual Meeting, July 31-August 2, 2016, Boston, Massachusetts. Agricultural and Applied Economics Association*.

Kumar, A., I. A. Wright, and D. K. Singh. (2011). Adoption of Food Safety Practices in Milk Production: Implications for Dairy Farmers in India. *Journal of International Food & Agribusiness Marketing, 23*(4), 330-344.

Kumar, A., S. J. Staal, and D. K. Singh. (2011). Smallholder Dairy Farmers' Access to Modern Milk Marketing Chains in India. *Agricultural Economics Research Review, 24*, 243-253.

Maertens, M., and K. Vande Velde. (2017). Contract-Farming in Staple Food Chains: The Case of Rice in Benin. *World Development, 95*, 73-87.

Maertens, M., and J. F. M. Swinnen. (2009). Trade, Standards, and Poverty: Evidence from Senegal. *World Development, 37*(1), 161-178.

Minten, B., and T. Reardon. (2008). Food Prices, Quality, and Quality's Pricing in Supermarkets vs Traditional Markets in Developing Countries. *Review of Agricultural Economics, 30*(3), 480-490.

Minten, B., T. Reardon, and A. Vandeplas. (2009). Linking Urban Consumers and Rural Farmers in India: A Comparison of Traditional and Modern Food Supply Chains. *IFPRI discussion papers 883, International Food Policy Research Institute (IFPRI)*.

Minten, B., S. Tamru, E. Engida, and T. Kuma. (2016). Transforming Staple Food Value Chains in Africa: The Case of Teff in Ethiopia. *The Journal of Development Studies, 52*(5), 627-645.

Mo, D., J. Huang, X. Jia, H. Luan, S. Rozelle, and J. F. M. Swinnen. (2012). Checking into China's Cow Hotels: Have Policies Following the Milk Scandal Changed the Structure of the Dairy Sector? *Journal of Dairy Science, 95*(5), 2282-2298.

Mondal, B., S. Sirohi, and V. Thorat. (2012). Impact of ASEAN-India Free Trade Agreement on Indian Dairy Trade: A Quantitative Approach. *MPRA working paper 40790*.

Moser, C. M., and C. B. Barrett. (2006). The Complex Dynamics of Smallholder Technology Adoption: The Case of SRI in Madagascar. *Agricultural Economics, 35*(3), 373–388.

Mundlak, Y. (1978). On the Pooling of Time Series and Cross Section Data. *Econometrica, 46*, 69-85.

Munshi, K. (2004). Social Learning in a Heterogeneous Population: Technology Diffusion in the Indian Green Revolution. *Journal of Development Economics, 73*(1), 185–213.

Nagrale, B. G., K. K. Datta, and A. K. Chauhan. (2015). An Analysis of Constraints Faced by Dairy Farmers in Vidarbha Region of Maharashtra. *Indian Journal of Dairy Science, 68*(4), 390-394.

National Dairy Development Board. 2017. Statistics available at http://www.nddb.org/information/stats/milkprodindia. Accessed on 03/04/2017.

Rao, S. V. N., V. Venkatasubramanian, and J. De Wit. (1995). Consequences of Crossbreeding Programme in India. *Economic and Political Weekly*, *30*(39), A112–16.

Reardon, T., Timmer, C. P., Barrett, C. B., & Berdegue, J. (2003). The rise of supermarkets in Africa, Asia, and Latin America. *American Journal of Agricultural Economics*, *85*(5), 1140–1146.

Reardon, T., C. B. Barrett, J. A. Berdegue, and J. F. M. Swinnen. (2009). Agrifood Industry Transformation and Small Farmers in Developing Countries. *World Development*, *37*(11), 1717-1727.

Reardon, T., and C. P. Timmer. (2014). Five Inter-Linked Transformations in the Asian Agrifood Economy: Food Security Implications. *Global Food Security*, *3*(2), 108-117.

Saenger, C., T. Maximo, and M. Qaim. (2014). Impact of Third-Party Contract Enforcement in Agricultural Markets—A Field Experiment in Vietnam. *American Journal of Agricultural Economics*, *96*(4), 1220-1238.

Sharma, V. P., R. V. Singh, S. Staal, and C. L. Delgado. (2002). Annex I: Critical issues for poor people in the Indian dairy sector on the threshold of a new era. In C. L. Delgado and C. A. Narrod (eds.), *Impact of Changing Market Forces on Structural Change in the Livestock Industries of Selected Fast-Growing Developing Countries. Final Research Report of Phase I – Project on Livestock Industrialization, Trade and Social-Health-Environment Impact in Developing Countries*. FAO, Rome: Agriculture and Consumer Protection Department.

Sheahan, M., and C. B. Barrett. (2014). *Understanding the Agricultural Input Landscape in Sub-Saharan Africa: Recent Plot, Household, and Community-Level Evidence*. The World Bank.

Sinha, B. N. (1951). Taylor Cows of Patna. *Indian Veterinary Journal*, *27*, 272-276.

Squicciarini, M., and A. Vandeplas. (2010). *The Dairy Sector of Andhra Pradesh: Findings from a Company Survey*. No. TAPSIM deliverable D5.3, LICOS, KU Leuven, Belgium.

Squicciarini, M., and A. Vandeplas. (2013). Food Safety Standards for Domestic and International Markets: The Case of Dairy. In Brouwer, F., Joshi, P.K. (eds.) *International trade and poverty; the future of Indian agriculture*. Oxfordshire: CABI Publications.

Staal, S. J., A. Nin Pratt, M. Jabbar. (2008). *Dairy Development for the Resource Poor*. Part 3: Pakistan and India Dairy Development Case Studies. PPLPI Working paper No.44-3, International Livestock Research Institute and Food and Agriculture Organization of the United Nations.

Subervie, J., and I. Vagneron. (2013). A Drop of Water in the Indian Ocean? The Impact of GlobalGap Certification on Lychee Farmers in Madagascar. *World Development*, *50*, 57-73.

Swinnen, J. F. M., K. Deconinck, T. Vandemoortele and A. Vandeplas. (2015). *Quality Standards, Value Chains and International Development.* Cambridge University Press. New York, USA.

Swinnen, J. F. M. and R. Kuijpers. (2017). Value Chain Innovations for Technology Transfer in Developing and Emerging Economies: Conceptual Issues, Typology, and Policy Implications. *Food Policy. (in press).*

Umali-Deininger, D., and Sur, M. (2007). Food safety in a globalizing world: opportunities and challenges for India. *Agricultural Economics, 37*(s1), 135-147.

Vandeplas, A., B. Minten, and J. F. M. Swinnen. (2013). Multinationals vs. Cooperatives: The Income and Efficiency Effects of Supply Chain Governance in India. *Journal of Agricultural Economics, 64*(1), 217–244.

Van Herck, K., and J. F. M. Swinnen. (2015). Small farmers, Value Chains, and Structural Change: Panel Evidence from Bulgaria. *British Food Journal, 117*(10), 2435-2464.

Van Herck, K., J. F. M. Swinnen, and K. Deconinck. (2012). How the East Was Won: Supply Chain Restructuring in the Eastern European Beer Market. *Journal of International Agricultural Trade and Development, 61*.

Wooldridge, J. M. (2004). *Econometric Analysis of Cross Section and Panel Data*. The MIT Press. London, England.

Zilberman, D., L. Lu, and T. Reardon. (2017). Innovation-Induced Food Supply Chain Design. *Food Policy (In press).*

Table 1. Main channels of milk sales in Punjab for all dairy farmer in sample

	In 2008 % of dairy farmers in sample (N=710)	**In 2015** % of dairy farmers in sample (N=676)
A. Cooperative	22.1%	18.5%
B. Private companies	38.9%	26.9%
Including: domestic companies	14.2%	12.6%
foreign (Nestlé)	24.7%	14.4%
C. Informal channels	13.5%	25.7%
Including: households	2.3%	10.2%
informal milk traders	11.3%	15.5%
D. No Sales	25.5%	29.1%

Source: Survey data

Table 2. Distribution of dairy farmers associated with different value chains (%)

	In 2008 (N=710)						**In 2015** (N=676)					
	No Sales	Informally to households	Informal milk traders	Domestic private company	Cooperatives	Nestlé	No Sales	Informally to households	Informal milk traders	Domestic private company	Cooperatives	Nestlé
Land size												
Landless	24%	25%	18%	10%	13%	17%	26%	12%	9%	11%	6%	7%
< 4 acres	23%	19%	26%	24%	34%	19%	30%	33%	25%	21%	19%	30%
4 -10 acres	34%	50%	34%	45%	29%	39%	25%	26%	40%	27%	31%	38%
> 10 acres	18%	6%	23%	22%	24%	25%	19%	29%	27%	41%	44%	25%
All	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Herd size												
1-2 DA	53%	44%	23%	20%	29%	27%	82%	61%	50%	34%	29%	39%
3-10 DA	46%	56%	71%	73%	66%	63%	17%	36%	49%	60%	63%	57%
>10 DA	1%	0%	6%	7%	5%	10%	1%	3%	2%	6%	8%	4%
All	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Note: Table includes only HH that had DA.
Source: Survey data

Table 3. Hygienic and food safety practices in Punjab (% of dairy farmers in sample)

	In 2008 (N=710)	**In 2015** (N=671)
Hygienic practices		
Cleaning hands		
Are the hands washed?		
Never	2.8%	0.5%
Only before milking	38.5%	36.9%
In between	58.7%	62.1%
Mode of washing hands		
No hand washing	2.8%	0.5%
Water only	83.6%	42.7%
Use soap/detergent/disinfectant	13.5%	56.8%
Hands dried with paper/cloth before milking?		
Yes	25.5%	66.4%
Cleaning of udder and teats		
Washed before milking?		
No washing	11.8%	4.6%
Water only	83.9%	90.2%
Cold water+ soap/detergent/disinfectant	3.4%	5.4%
Dried with paper /cloth before milking?		
Yes	14.2%	23.4%
Cleaning of milk utensils		
How are milk utensils washed?		
Water only	80.4%	14.1%
Water +soap/detergent/disinfectant	17.4%	79.8%
Water +sand+ ash	0%	6.3%
How often are the utensils washed?		
Less than once daily	3.1%	0.14%
Once daily	20.4%	1.6%
More than once daily	75.7%	98.3%
Before milking each new cow/buffalo	0.14%	0.14%
Food safety practices		
How long does the milk stay on the farm before sales?	19 min	19.2 min
Method of milk preservation before sales		
Not treated	64.2%	61.9%
Boiling	1.5%	0.9%
Refrigerating/chilling	5.1%	7.9%
Other	8.3%	0.14%

Source: Survey data

Table 4. Value chains, technology adoption and information in Punjab

	In 2008		In 2015	
	Number of dairy farmers in sample	% of dairy farmers in sample (N=710)	Number of dairy farmers in sample	% of dairy farmers in sample (N=671)
A. Hygienic practices				
Received information on clean milk production	6	0.9%	125	18.6%
Sources:				
Other farmers	0	0%	89	13.3%
Government	2	0.3%	16	2.4%
Nestlé	3	0.4%	7	1.0%
Cooperative	1	0.2%	6	0.9%
Veterinary doctor	0	0%	1	0.2%
Informal Milk trader	0	0%	3	0.4%
Other	0	0%	3	0.4%
Received inspection on farm	105	14.8%	35	5.2%
By:				
Milk buyer	40	5.6%	1	0.1%
Government	44	6.2%	13	1.9%
Other	21	3.0%	7	1.0%
B. Mixed feed				
Received information on improving milk quality through feeding	7	1.0%	211	31.4%
Sources:				
Other farms	0	0.0%	100	14.9%
Government	2	0.3%	26	3.9%
Nestlé	3	0.4%	3	0.4%
Veterinary doctor	0	0.0%	68	10.1%
Cooperative	2	0.3%	6	0.9%
other	0	0.0%	8	1.2%
Use mixed feed	375	53.3%	457	68.8%
Bought mixed feed	344	48.5%	448	67.0%
Sources:				
Nestlé	47	6.6%	14	2.1%
Cooperative	27	3.8%	17	2.5%
General store	203	28.6%	327	48.8%
Feed company	46	6.5%	49	7.3%
Other	21	3.0%	41	6.1%
Received advances from milk buyer	80	11.3%	119	17.7%
Used advances for buying inputs	19	2.4%	32	4.8%

Table 4 continued on next page

C. Crossbred cows				
Owns crossbred DA	283	39.8	333	49.6%
Received information on improving milk quality through choice of breed	7	1.0%	206	30.7%
Sources:				
Other farms	0	0.0%	96	14.3%
Government	2	0.3%	23	3.4%
Nestlé	2	0.3%	2	0.3%
Veterinary doctor	0	0.0%	72	10.9%
Cooperative	2	0.3%	4	0.5%
other	1	0.2%	9	1.3%
Took a loan to finance purchase of crossbred cow	6	0.9%	26	3.9%

Source: Survey data

Table 5. Dairy animals in the sample and Punjab

In our sample					
Number of female adult DA	**In 2008**		**In 2015**		**% change from 2008**
Crossbred cows	853	30.5%	895	39.2%	+12.9%
Indigenous cows	47	1.7%	14	0.6%	-70.0%
Buffalos	1894	67.8%	1377	60.2%	-27.3%
Total	2794	100.0%	2286	100.0%	-18.2%

Source: Survey data

Table 6. Summary statistics of variables used in econometric analysis by sample year

		2008 sample		2015 sample	
Technologies					
Hygiene	Index	0.5	(0.1)	0.7	(0.2)
Use of mixed feed	%	53.4	(49.9)	68.8	(46.4)
Share of crossbred	share	0.2	(0.3)	0.3	(0.3)
Farm size and income					
Total no. of DA	Nr	4.1	(4.3)	3.5	(4.9)
Land	Acres	8.2	(10.4)	9.8	(13.9)
Asset index	Index	0.3	(1.0)	0.3	(1.0)
HH characteristics					
Age HH head	Years	50.5	(12.0)	54.4	(14.1)
HH head is female	%	3.0	(17.1)	6.3	(24.3)
HH head education	Years	5.4	(4.6)	7.5	(5.0)
HH size	Nr	6.2	(5.6)	6.0	(2.5)
HH members over 55	Nr	0.7	(0.8)	1.0	(1.0)
No. of female adults in HH	Nr	2.2	(1.1)	2.2	(1.1)

Note: Standard deviation in parenthesis. The table is based on all households that had DA in both 2008 and 2015.

Table 7. Technology adoption and value chain in Punjab.

	Hygiene index (FE)	Share of crossbred (FE)	Use of mixed feed (LPM FE)
Supply chain: HH switched to			
Nestlé	-0.0008	0.0108	0.0239
	(0.0491)	(0.0480)	(0.1060)
Cooperative	-0.0317	0.0412	0.0900
	(0.0267)	(0.0444)	(0.0850)
Private domestic firm	-0.0319	0.0555	0.0818
	(0.0286)	(0.0444)	(0.0936)
Informal milk traders	-0.0086	-0.0285	0.0622
	(0.0225)	(0.0382)	(0.0748)
Informally to households	-0.0233	-0.0525	0.1400
	(0.0243)	(0.0446)	(0.0870)
Farm size and income			
Total No. of DA	0.0292	0.0924***	0.2930***
	(0.0202)	(0.0300)	(0.0413)
Land	0.0223*	-0.0078	0.0382
	(0.0126)	(0.0198)	(0.0417)
Asset index	-0.0394***	0.0073	-0.0436
	(0.0099)	(0.0163)	(0.0326)
HH characteristics			
Age HH head	-0.0001	0.0013	-0.0020
	(0.0009)	(0.0015)	(0.0024)
HH head is female	0.0507	-0.1130*	-0.0327
	(0.0357)	(0.0602)	(0.0978)
HH head education	-0.0005	0.0010	-0.0023
	(0.0012)	(0.0021)	(0.0036)
HH size	-0.0034	-0.00429	0.0036
	(0.0042)	(0.0069)	(0.0126)
HH members over 55	-0.0087	-0.0031	0.0037
	(0.0067)	(0.0105)	(0.0195)
No. of female adults in HH	0.0084	-0.0146	0.0083
	(0.0073)	(0.0116)	(0.0215)
Year 2015	0.1850***	0.0857***	0.1350***
	(0.0128)	(0.0207)	(0.0314)
Change HHH	-0.0282	0.0828	-0.0375
	(0.0323)	(0.0528)	(0.0976)
Observations	1,359	1,373	1,718
R^2	0.457	0.110	0.640

Note: Fixed effects models (FE) was chosen for hygiene index and crossbred adoption, and linear probability model with fixed effects (LMP FE) was used for adoption of mixed feed. Robust standard errors (clustered at individual level) in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 8. Characteristics of large dairy farmers interviewed

	Location	Herd size	% crossbred cows	Milk buyer	Procurement contract	Milking machines	Land size
Farmer 1	Outskirts of Amritsar	165	100%	Verka	no	yes	15 acres
Farmer 2	Outskirts of Amritsar	122	100%	Verka	no	yes	60 acres
Farmer 3	Rural area in Amritsar	90	100%	private dairy	no	yes	45 acres
Farmer 4	Outskirts of Ludhiana	150	98.7%	Verka	no	yes	10 acres
Farmer 5	Outskirts of Ludhiana	160	100%	PDFA	no	yes	70 acres
Farmer 6	Outskirts of Moga	130	100%	Nestlé	no	yes	60 acres
Farmer 7	Rural area in Ludhiana	105	98%	private dairy	no	yes	50 acres
Farmer 8	Rural area in Mansa	70	100%	households	no	yes	/
Farmer 9	Rural area in Mansa	93	96.8	Nestlé	no	yes	/
Farmer 10	Rural area in Hoshiarpur	70	92.9%	private dairy	no	no	30 acres
Farmer 11	Rural area in Firozpur	103	98.1%	Nestlé	no	yes	30 acres

Source: Interviews large farmers

Table 9. Characteristics of large sample farmers

	Herd size	% crossbred cows	Milk buyer	Procurement contract	Milking machines	Land size
Farmer 1	11	0.5	cooperative	no	no	1
Farmer 2	11	0.7	cooperative	no	no	4
Farmer 3	12	0.2	households	no	no	0
Farmer 4	12	1	Nestlé	no	no	12
Farmer 5	12	0.8	cooperative	no	no	13
Farmer 6	12	0.7	cooperative	no	yes	4
Farmer 7	13	0.5	informal milk traders	no	no	5
Farmer 8	13	0.2	informal milk traders	no	no	22
Farmer 9	13	0.8	Nestlé	no	no	2
Farmer 10	13	0	no sales	no	no	40
Farmer 11	13	0.2	Nestlé	no	no	24
Farmer 12	13	0.3	cooperative	no	no	7
Farmer 13	14	0.4	cooperative	no	no	7
Farmer 14	15	0.2	cooperative	no	no	17
Farmer 15	15	1	private domestic firm	no	no	7
Farmer 16	15	0.7	cooperative	no	no	5
Farmer 17	18	0.4	cooperative	no	/	15
Farmer 18	18	0.9	cooperative	no	yes	10
Farmer 19	19	1	PDFA	no	yes	11
Farmer 20	20	0.5	households	no	no	15
Farmer 21	20	1	PDFA	no	yes	12
Farmer 22	31	1	PDFA	no	yes	7
Farmer 23	32	0.4	Nestlé	no	no	23
Farmer 24	96	0.9	PDFA	no	yes	22
Average	19	0.6				12

Source: Survey data

FIGURES

Figure 1. Growth of Milk production in Punjab (% growth since 2002)

Source: National Dairy Development Board (2017)

Figure 2. Location of selected districts in Punjab, India

Selected districts

Source: Vandeplas et al (2013)

Figure 3. Milk procurement structure in Punjab

Source: Janssen and Swinnen (2017)

Figure 4. Hygiene index (level and growth) by adoption rate in 2008

Source: Survey data

Figure 5. Distribution of hygiene index in 2008 and 2015 in Punjab

Source: Survey data

Figure 6. Hygiene index and milk marketing channels

Source: Survey data

Figure 7. Improvement in mixed feed use

Source: Survey data

Figure 8. Mixed feed use and milk marketing channels

Source: Survey data

Figure 9. Share of crossbred DA (% and change) by adoption rate in 2008

Source: Survey data

Figure 10. Share of crossbred cows across marketing channels (means)

Source: Survey data