Socioeconomic impacts of innovative dairy supply chain practices – The case of the Laiterie du Berger in the Senegalese Sahel

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Abstract

This study analyzes the Laiterie Du Berger (LDB)'s milk supply chain and its contribution to strengthening the food security and socioeconomic resources of Senegalese Sahelian pastoral households. Porter's value chain model is used to characterize the innovations introduced by the LDB dairy in its milk inbound logistics and supplier relationships. A socioeconomic food security index and qualitative data are used to assess the dairy's supply chain's contribution to strengthen smallholder households' livelihoods. Data for this research were obtained through individual surveys, focus groups and in-depth interviews of LDB managers and milk suppliers. Results show that milk income contributes significantly to household food security. Suppliers who stabilize their dairy income between rainy and dry seasons, diversify income sources and have larger herds are more likely to remain food secure. The LDB innovations contribute by helping herders access biophysical and economic resources, leading to better livestock feed and household food security.

Keywords

Innovation; Dairying; Food security; Pastoralism; Value chains

1- Introduction

The livestock system in Senegal is mainly dominated by traditional activities. These cannot be measured solely in quantitative or monetary terms because they also have significant non-market drivers, which may be as or more important than market drivers (Wane et al. 2014). Livestock keeping occupies 30% of the population. Overall, 90% of rural households own livestock while 52% of urban households also own animals. Of the three main livestock sub-systems in Senegal, the pastoral system in Northern Senegal (a region called "Ferlo") is considered the most traditional in this Sahelian environment. It occupies close to one-third of the national territory. Livestock densities in this extensive itinerant system are low: between 2 and 10.6 TLU[1] per km² (de Haan 2016).

Like the dairy sectors of other West African countries, Senegal is confronting many changes in terms of milk production and imports. Several mini-dairies have emerged in the past 25 years; these are primarily located in rural areas and supported by NGOs. Farming practices are changing: use of crop by-products as feed; breeding of crossbred animals and forage crops; settling of animals; new suburban intensive dairy farms. These changes have increased milk productivity and sales. However, this emerging local dairy development cannot compensate for Senegal's increasing imports of milk powder. In 2010 nearly 60% of the country's total demand for milk of 421 million litres was covered by imports, which represented a value of USD166.2 million (Duteurtre and Corniaux 2013). The country has become structurally dependent on foreign markets for milk. Although milk powder imports allow urban populations to access cheap dairy products and the dairy processing sector to grow, they also compete with local milk production. Although local milk is more expensive to source because of diseconomies of scale, dairies are showing a growing interest in supplying local milk because it allows them to produce dairy products more closely aligned to local consumers' tastes, and thus achieve higher added value (Duteurtre and Corniaux 2013).

It is in this context that the Laiterie du Berger (LDB) was created in 2006 as a modern dairy plant collecting milk in pastoral areas of Northern Senegal. Its largest challenge has been to address the seasonality of rains, and thus fodder, the determining factor for milk production in the Ferlo. The business increased quickly from 200 farmer suppliers at the beginning to more than 800 suppliers in 2010; the volume of milk collected has more than quadrupled (Parisse 2012). The development of modern retailing and agro-industries in developing countries has had an important impact on the livelihoods of the smallholder farmers who supply large-scale enterprises like the LDB (Reardon et al. 2003). Setting up agri-food value chains that are inclusive of smallholder farmers requires changes in business models from the buyer but also major transformations of the farm management models and livelihoods by suppliers (Vorley et al. 2009). Can the LDB be considered as a socially motivated enterprise? The LDB website brands the company as an agribusiness firm that is developing strong corporate social responsibility by helping its pastoralist suppliers while continuing to respect sound financial standards in a competitive dairy market[2].

Consequently, this article aims to assess the contribution of the LDB and its modern supply chain management to strengthening the food security and socioeconomic resources of pastoral dairy households in the Ferlo.

[1] TLU (Tropical Livestock Unit) aggregates different livestock species, based on 250 kg live weight: 1 TLU is equivalent to 1 camel, 0.7 TLU is 1 cattle, 0.1 TLU equals 1 sheep or goat, and 0.01 TLU represents 1 chicken.

[2] https://lalaiterieduberger.wordpress.com/ [accessed January 12, 2017]

Although there are already many theoretical and empirical contributions on the topic of value chains inclusive of smallholder farmers in developing countries, their study scope is relatively wide (crops, forestry, fair trade, governance and food safety) and none have specifically covered the livestock sub-sector and more particularly, Sub-Saharan pastoral systems. The main contribution of this article to the agribusiness literature is to highlight the consequences of modern dairy supply practices introduced by LDB on the livelihood choices, food security and market orientation of pastoral milk suppliers. ***Section 2*** of this paper describes the local context and organization of the LDB dairy plant's supply chain. ***Section 3*** discusses the conceptual framework, data and method to analyze the impacts of the LDB's supply chain on its suppliers. ***Section 4*** presents the main findings from this research and ***Section 5*** concludes by considering the research gaps, proposing future research directions, and suggesting recommendations for agribusiness development.

2- Context of the Laiterie du Berger's dairy business

Pastoralism in the African Sahel is a production system and a livelihood strategy confronted with risks, uncertainties and opportunities. This situation is also valid in the Senegalese Ferlo. Pastoralists and agro-pastoralists combine market and non-market inputs to produce livestock products. These individuals also diversify their livelihoods by producing crops. The household productions are consumed within the household, sold or stocked. This economic activity occurs in a context of various changes, which impact actors in isolation or simultaneously, sequentially or occasionally. The major shock element comes from extreme weather changes with high variability of annual rainfall and temperatures. The herders attempt to address these spatiotemporal variations through mobility, leading their herds to areas where there is still grass. This itinerant livelihood remains the main strategy in their uncertain environment. In addition, herders are increasingly subjected to other shocks: price volatility of food and animal feed at national and international levels (Wane et al. 2009, 2014); diseases due to vaccination programs barely achieving the 80% coverage recommended by the World Organization for Animal Health and Animal Diseases (Kaboret 2010); uncontrolled human and animal demography (Touré et al. 2013); and social transformations. All of these shocks make pastoral economic activities and livelihoods more vulnerable and jeopardize the ability of these marginalized populations to be resilient.

As the main source of food in the Sahel, livestock contributed an average of 38% to agricultural GDP in the 2000s (Ly et al. 2010). The increasing demand for meat and milk in West Africa is seen as an opportunity if various stakeholders can collectively develop the resilience of this system (Ickowicz et al. 2012). However, efforts to achieve food security are strongly constrained by socioeconomic factors such as poverty, low productivity, unfair marketing relationships, human and animal demographics, lack of institutions and infrastructure. Negative biophysical trends such as climate variability or pressure on natural resources are further constraints to the sustainability of the system's food security.

The LDB began operating a private dairy plant in Richard Toll City, in northern Senegal (Figure 1), to collect and add value to milk from local herders and help meet the increasing demand for milk products in the country. In the context of Sahelian pastoral systems, setting up a supply chain for a modern dairy plant is far from impact-neutral. This impact is materialized by changes towards more efficient dairy production and sourcing. In particular, the procurement process has to be thought out carefully because milk production by traditional pastoral herders is not market-driven.

The LDB collects milk from pastoralist campsites located in the arid wilderness around the city. To limit the transportation time of fresh milk on dirt roads, the dairy has encouraged milk producers to become partially sedentary. The main non-written contractual link between the LDB and its pastoralist milk suppliers is developed around a package of transactions on milk production with collaterals provided by the LDB to secure its milk supply. In this context of market and environmental uncertainties (Wane *et al.* 2014), the main innovations generated by the LDB consist of ***i)*** settling dairy farmers within a 50 km radius of the dairy; ***ii)*** organizing six daily milk collection routes; ***iii)*** providing animal feed through a check-off recovered on future milk sales; ***iv)*** providing technical support through development partners to farmers on milking hygiene, dairy herd nutrition, veterinary advice, protected areas for grazing and water wells.

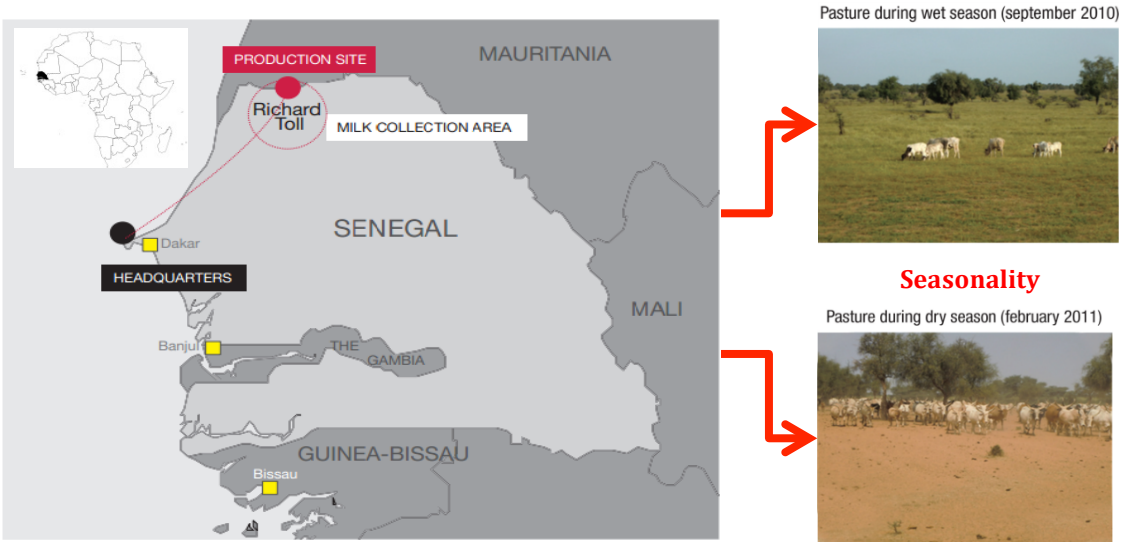

Figure 1. Location of the Laiterie du Berger in Senegal in a context of inter-annual climate variability (Parisse 2012)

3- Conceptual frameworks, data and quantitative research methodology

3.1. Conceptual frameworks

3.1.1. The generic value chain model helps characterize the LDB's supply chain innovations

From the perspective of the LDB, the challenges posed by the creation of a dedicated supply chain to source local milk from pastoral herders can be envisaged through the model of a firm's generic value chain (Porter 1985: 37). A company applying this generic value chain model to improve its inbound logistics needs to reinforce the support activities that will allow its staff to deal with supply challenges and help its suppliers deliver the raw materials the firm needs in sufficient quantity, and to an appropriate quality standard. These support activities encompass procurement (finding suppliers and organizing the supply chains), technology development (innovating in production, information and management processes to remain competitive), human resources management (training company staff and suppliers to put innovations into practice to reach the supply objective), and firm infrastructure (the company's support systems that allow it to run and pay its staff and suppliers). The results section reviews the LDB's

innovations in dairy supply chain management along the lines of this generic value chain model for the primary activity of inbound logistics.

3.1.2. A more holistic model is needed to understand the contribution of the LDB's activities to the sustainability of the wider pastoral system

However, this study of the LDB's contribution to restructure complex traditional pastoral systems also needs to address whether the dairy's innovations are impacting on individual supplier households and the sustainability of the traditional pastoral system within which they live. Therefore, a complementary conceptual framework would consist in analyzing the sustainability of the dairy's business and supply chain models. For the very particular context of Sahelian pastoral systems, Lambert et al. (2014) have merged various sustainability assessment approaches and, in accordance with findings by Rey-Valette et al. (2008) and Gerber et al. (2009), used the three classical pillars of sustainable development (economic, social and environmental) to integrate these within three fields of analysis of a pastoral system within its territory (Figure 2).

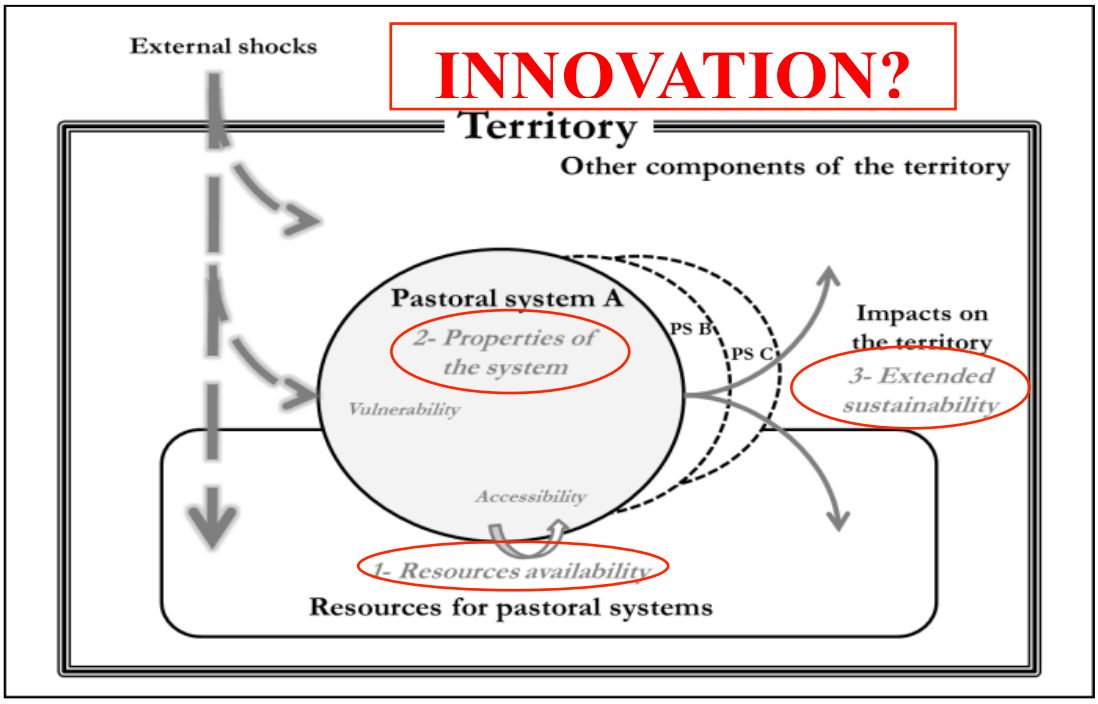

Figure 2. Pastoral system in its territory (Lambert et al. 2014)

The first field of analysis concerns the "availability of resources" in the territory and considers that the sustainability of a farming system depends on the dynamics of available resources, which enable the functionality of the production activity and enable households to survive. The second field of analysis concerns the "properties of the system" and includes factors that allow access to resources as well as the potential reactions of a system to external shocks. Finally, the third field concerns "extended sustainability", which considers the positive or negative impacts of pastoral systems on the components of the territory. In this study's context of the LDB's dairy supply chain, the processor has started a contractual relationship with supplier

households. It is thus relevant to take the herder household as the unit of study to reveal the linkages between availability of resources and properties of the system. Elaborating further along the framework by Lambert et al. (2014) of pastoral systems, studying the socioeconomic sustainability of households translates into understanding how households' socioeconomic resources match their livelihood choices in terms of food security: allocation of dairy products between household consumption and market sales, purchase of food from outside using dairy income (Figure 3).

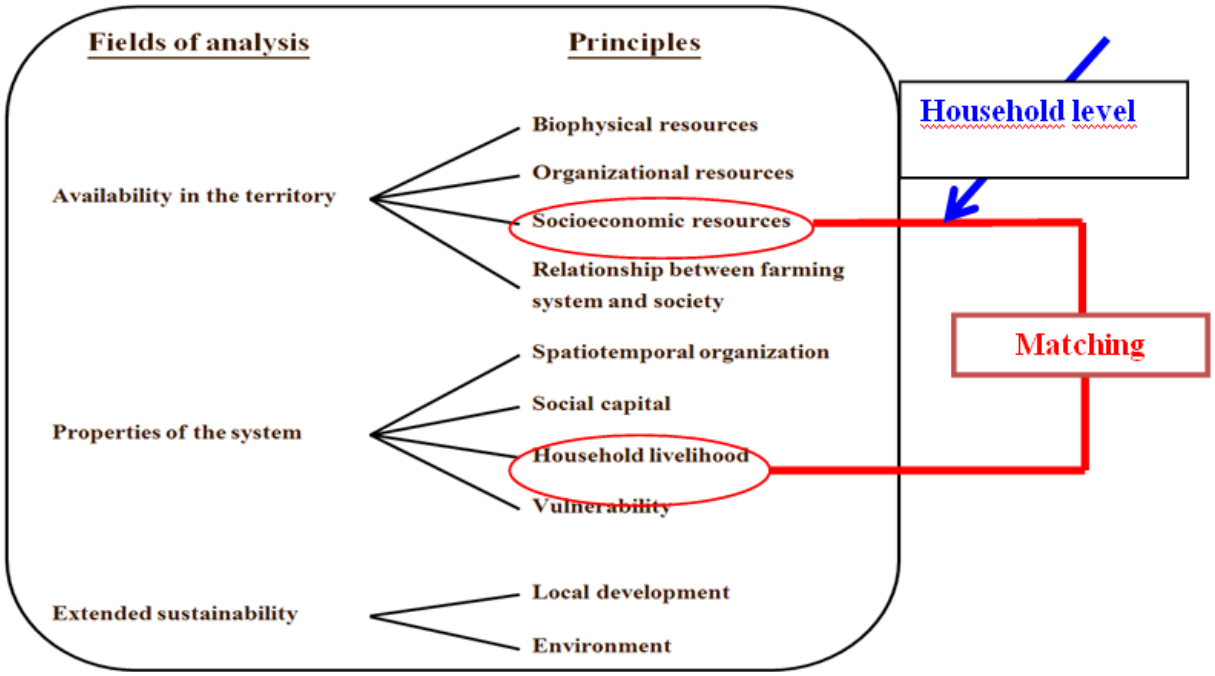

Figure 3. Fields and principles of pastoral systems' sustainability at household level (Lambert et al. 2014)

3.1.3. Gender roles in African pastoral households

Boogaard et al. (2015) have reviewed the literature on gender roles within livestock keeping households in Africa. A household consists of diverse members with different characteristics, perspectives and influence, and who make different decisions; all these components determine the allocation of resources among household members (Haddad et al. 1997). Thus, household decisions – such as when to use livestock for home consumption, when to sell livestock and how to use the money – strongly influence the way livelihood assets are put to use within livelihood strategies. Assets are often owned by individual household members instead of being pooled, as defined by intra-household allocation rules (Haddad et al. 1997). As such, men and women within the household can own or have access rights to different assets, and assets may be unequally distributed within a household (Doss 2013, Huss-Ashmore 1996, Meinzen-Dick et al. 2011). For these reasons, women's ownership or access rights to livestock, livestock products and their resulting income, should not be considered as given. Women's access rights to livestock also vary with the social status of the individual: Buhl and Homewood (2000) showed how power in decision making within the household changed over time for

women according to their age and status in Fulani herder families. Younger women, second and third wives or daughters had less freedom in decision making over assets than older women, first wives and mothers in law.

3.1.4. Research questions to be answered and overall research methodology

In light of this article's objective to assess the contribution of the LDB's milk supply chain to strengthening the livelihood and socioeconomic resources of pastoral smallholders in the Senegalese Sahel, one can use both Porter's (1985) generic value chain model to understand how the LDB's milk supply chain organization contributes to adding value for the firm while reviewing the same supply chain arrangements through the lens of the conceptual framework for pastoral systems by Lambert et al. (2014) to identify changes to supplier households' livelihoods and socioeconomic resources. This article therefore attempts to answer the following research questions:

- Q1: Do the LDB's innovative milk supply chains add value to the company's products?
- Q2: Do the LDB's innovative milk supply chains contribute to improve the livelihoods of pastoral herder households?
- Q3: Do the LDB's innovative milk supply chains help build up the socioeconomic resources needed by the herder households to sustain their pastoral system?

In a Sub-Saharan African context, the implementation of modern processing plants in the agricultural sector has generally been viewed as an innovation similar to technology introduction and has been empirically studied in terms of adoption in accordance with Griliches' (1957) seminal economic perspective. Subsequently, more rigorous approaches based on innovative statistical tools have used regression models following a logistic law (LOGIT model) or a Gaussian law (probit model), which provide similar results in experiments involving with-and-without group comparisons (Negatu and Parikh 1999). However, these models are criticized for their lack of discernment of the adoption failures due to technology or innovation availability or access problems, particularly in countries facing gaps in technology and innovation dissemination (Mulubrhan et al. 2012).

In this paper, we use these classical impact assessment methodologies in a very broad sustainability framework to reflect the complexity of Sahelian pastoral systems characterized by the strong interaction between production, social and cultural aspects. Thus, the model proposed by Lambert et al. (2014) (Figure 3) is used as a starting point to define the successive steps of analysis for the contribution of the LDB's supply chain practices on strengthening the sustainability of the Ferlo's pastoral system measured at the level of herder households. To implement this framework, we analyze the changes undertaken by the dairy's pastoralist suppliers on their milk production practices, the milk production destination and the diversification of income sources between dry and rainy season in order to supply raw milk to the LDB.

3.2. Data sources

To answer the research questions stated above, both qualitative and quantitative data were used.

The viewpoints of the LDB were collected through in-depth interviews of its CEO and of the general manager of the Richard Toll processing plant, who was in charge of the raw milk supply chain at the time of field research. These two in-depth interviews were conducted in May 2014. They were meant to gather information on the business strategy of the LDB, the managers'

viewpoints on the organization of its raw milk supply chain, and their assessments on their supply chain's and overall business performance.

Additional primary data on the social aspects of sustainability were collected through individual qualitative surveys of 70 milk suppliers to LDB from January 2013 to January 2014. The supplier surveys were conducted on the Rosso and the Mouda milk delivery routes established by the LDB; both these routes were among the first to be part of the LDB's raw milk supply chain. The sample was divided equally: 35 suppliers interviewed on the Rosso route and 35 on the Mouda route. Suppliers to be interviewed were chosen by simple random selection among the list of suppliers along both routes. Suppliers comprised both herder households and cooperatives supplying raw milk to the LDB. Respondents were interviewed in the Fulani language, which is spoken by two of the authors. The qualitative surveys were meant to gather information on the suppliers' pastoral practices, their relationship with the LDB (in particular, access to LDB services and technical assistance), and their perception of their level of income (for households).

Two focus group discussions were also organized with women from pastoral households involved in this supply chain in May 2014. One focus group was held with ten women producing milk in a fixed settlement called Niassanté of the Dièri region. The second focus group was held with seven women and two men producing milk in Ngoudompe village in the Walo region, which is located in an irrigated perimeter closer to Richard Toll City. Both focus groups comprised individuals supplying milk to the LDB and others who had never supplied or who had stopped supplying milk to the dairy. Because all the researchers conducting the interviews were men, the two focus group discussions were organized through the head of the villages who gathered participants according to the researchers' sample requirements (mainly women, all types of social status, suppliers and non-suppliers to the dairy). In both cases, the focus groups were held in the presence of men related to the women being interviewed. The discussions nonetheless allowed all participants to engage by prompting the shier women in the groups after the men and the older women had expressed themselves. These group discussions were held in the local language, which is spoken by one of the authors. The focus group discussions encouraged participants to discuss their cattle herding practices, decisions concerning milk allocation for household consumption or for sale, milk marketing conditions, the relationship with LDB milk collectors and technical staff, and the household decisions on the use of the money from milk sales.

The quantitative data gathered for this research came from existing databases collected from 445 households of LDB milk suppliers by a research consortium grouping IFPRI, CIRAD and GRET (Bernard et al. 2015). The households surveyed were self-selected as the volunteer participants to a supply contract research experiment linking regular supply of 0.5L of raw milk per cow per day to the LDB over five days of the week in exchange for free access at milk collection points to an iron-fortified milk product targeted to the supplier's children aged 2-to-5. The consortium undertook two visits of the same volunteer supplier households in January 2013 and January 2014 to capture the evolution of variables over the calendar year. Out of the 445 households surveyed in 2013, 437 repeated the survey the following year. The questionnaire collected information on the household's wealth, demographics and milk production. Mothers in the households were interviewed on their child feeding practices, living conditions and their individual milk production enterprise. Additional information linked to these households was gained through milk container level data from the LDB supply chain: level of relationship

between herders and LDB, milk quantities sold, resulting milk income and whether herders belonged to milk cooperatives (Table 1).

Table 1. Descriptive statistics for the households included in the IFPRI-CIRAD-GRET nutrition database

	N	All
Container level data		
Female container head	381	0.24
Number of children on contract	385	4.05
Number of cows listed in contract	385	3.77
Collective container	385	0.13
Milk production from December 9, 2012 (pre-study)		
Total weekly-milk delivered to LDB (liters)	385	22.59
Container delivered at least once in the past week (%)	385	0.96
# of days delivered milk in the past week	385	6.29
Household level data		
Female household head	437	0.19
Age of household head	436	49
Household head has any schooling	437	0.04
Household size	437	8.73
Number of children 0-5 years	437	1.99
Owns or manages land	436	0.51
=1 if HH member is responsible for milk container	437	0.83
=1 if HH member fills other milk containers	437	0.16
Total number of milk containers HH is responsible for or fills	437	1.05
Number of lactating cows	436	6.53
Number of cows that were milked yesterday	435	6.38
Liters of milk collected yesterday	431	5.96
Liters of milk collected in a typical day (dry)	435	4.17
Liters of milk collected in a typical day (rainy)	435	12.69
Percent of income from - Milk (dry)	433	25.43
Percent of income from - Milk (rainy)	433	55.91
Percent of milk sold to LDB (dry)	407	55.72
Percent of milk sold to LDB (rainy)	434	64.03
Percent of milk sold to local market (dry)	407	3.55
Percent of milk sold to local market (rainy)	434	3.8
Number of years affiliated with LDB	437	4.75

Source: Bernard and al. (2015)

3.3. Quantitative research methodology

3.3.1. Food security index

Access to food through dairy income generation constitutes a central parameter of our analysis. A food security index was tabulated as one indicator of the livelihood of producer households according to Lambert et al. (2014)'s sustainability conceptual framework adapted to Sahelian pastoral systems. Our food security index (FSI) is based on the Household Food Insecurity Assessment Scale (HFIAS) defined by USAID from recommendations by FAO. IFPRI has also adopted this approach in its ongoing research on nutrition aspects in the Ferlo (Coates et al. 2007). The food security index was developed using a Multiple Correspondence Analysis (MCA**)** from 18 questions related to food security including, for example, eliminating certain types of food from the household diet, a reduction in the number of meals and a reduction of the quantities consumed. Household groups were characterized according to their degree of food insecurity through an Ascending Hierarchical Classification (AHC).

If we consider Q qualitative variables chosen for the index, let us define:

1) $$X_i(j,q) = \begin{cases} 1 \; if \; the \; household \; has \; the \; level \; j \; of \; the \; variable \; q \\ 0 \; if \; not \end{cases}$$
and $W(j,q)$ *is the weight of level* j *for variable* q

The food security index (FSI) is defined, for a household i, as follows:

2) $$FSI_i = \frac{1}{Q}\sum_{q=1}^{n}\sum_{j \in J_q} W(j,q)X_i(j,q)$$

Where J_q is the number of levels for variable q

We computed a standardized index to facilitate interpretation:

3) $$FSI_i^* = \frac{FSI_i - \min(FSI_i)}{\max(FSI_i) - \min(FSI_i)}$$

Knowing that a suitable index must respect a hierarchy, we ensured that the First Axis Ordinal Consistency was well reflected. This result helped us define the weight of each component of the index. To do so, let $G_1(j,q)$ be the coordinates of level j for variable q on the first axis and λ_1 the eigenvalue. The weight of the index is then defined as follows:

4) $$W(j,q) = \frac{G_1(j,q)}{\sqrt{\lambda_1}}$$

Introducing this term into equation 2), the FSI becomes:

5)

$$FSI_i = \frac{1}{Q}\sum_{q=1}^{n}\sum_{j \in J_q}\frac{G_1(j,q)}{\sqrt{\lambda_1}}X_i(j,q)$$

To evaluate the index, we acted in accordance with Ki (2005)'s approach, which consists in defining classes for the index and comparing the distribution of the variables throughout those classes. For instance, if we consider a privative variable, its degree should be reduced if we move from one quartile of the index to another. In our case, this resulted in four household groups of food security, which were labeled as follows: *Group 1:"insecure"* because households of this group suffered food insecurity, *Group 2:"poorly secure"* because they occasionally suffered food insecurity, *Group 3:"secure"* because they rarely suffered food insecurity and *Group 4:"highly secure"* because they never suffered food insecurity. The distribution of households interviewed across the food security index can then be calculated (Table 2).

Table 2. Statistical information on the food security index

Groups	Class size	Proportion (%)	Mean	Standard deviation	Minimum	Maximum
Group 1: "insecure"	121	27	0.16	0.08	0.00	0.27
Group 2: "poorly secure"	138	31	0.38	0.05	0.27	0.49
Group 3: "secure"	108	24	0.61	0.07	0.50	0.76
Group 4: "highly secure"	78	18	0.92	0.08	0.77	1.00
Total	445	100	0.47	0.27	0.00	1.00

Source: Own calculations on data from IFPRI-CIRAD-GRET data base on nutrition of 445 LDB suppliers.

3.3.1. Calculating the probability of changing food security status

The analysis of milk income was performed using a First-order Markov Chain; this was supported by income mobility indices to highlight the links between dairy income stability and food security. A Markov Chain is a finite states process. A Markov Chain is also a stochastic process with a limited memory; its state at time t depends on its state at time $t-1$. This property can be translated into the following equation:

6)
$$P(X_{t+1} = j | X_t = i_t, X_{t-1} = i_{t-1}, \dots, X_0 = i_0) = P(X_{t+1} = j | X_t = i_t) = p_{ij}(t)$$

Where $p_{ij}(t)$ is the transition probability from state i to state j at time t. The transition probabilities define the transition matrix, which has the following properties:

7)
$$p_{ij}(t) \geq 0 \quad for\ all\ \ (i,j)$$
$$\sum_j p_{ij}(t) = 1 \quad for\ all\ \ i$$

In this study, we consider a homogenous Markov Chain, i.e.:

8)

$$P(t) = P \ \ for\ all\ t$$

We are interested in knowing the transition situation of households between the wet season and dry season. In this case, we consider the total income of households divided in four classes or states. The income mobility indices were calculated using the transition matrix or Markov chain from the variable "dairy income", which was divided into four quartiles that represented the four groups of households previously defined. Then, we determined the transition probabilities from one income group to another between the rainy season and the dry season. We calculated a Shorrock index (μ_{1nor}) to indicate whether the households are mobile in terms of income. Therefore, a certain hierarchy is considered between the states. Our approach is based upon the fact that moving from class 1 to class 2 between the seasons is a relative improvement in terms of income, whereas moving from class 2 to class 1 is a relative degradation. The movements in the matrix are synthesized by mobility indices. The Shorrock index μ_1 calculates the overall mobility in the Chain:

9)

$$\mu_1 = \frac{1}{n-1}\sum_{j}(1 - p_{jj})$$

The standardized Shorrock index is given by the formula:

10)

$$\mu_{1nor} = 1 - \frac{tr(P)}{n}$$

Where tr(P) represents the trace of the transition matrix P. We then estimated the households' income improvement or degradation through adequate indicators (μ_{imp} and μ_{deg}, respectively) and analyzed the direction of change of the income mobility indices.

The improvement index is given by:

11)

$$\mu_{imp} = \frac{1}{n-1}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} p_{ij}$$

The degradation index is defined by the formula:

12)

$$\mu_{deg} = \frac{1}{n-1}\sum_{j=1}^{n-1}\sum_{i=j+1}^{n} p_{ij}$$

3.3.1. Regression model for the determinants of food security

The determinants of food security were identified using an ordered probit multinomial regression model. The idea behind this approach is to know how the income mobility movements

(transition matrix) and other household characteristics impact on the food security of the households between seasons.

The Ordered Multinomial approach is developed on usual regression techniques to explain a variable of interest by other variables. In this case, the variable to be explained is the food security index: a qualitative variable with more than two levels and a natural order between them. Assume that Y is a qualitative variable with $m + 1$ levels. The model is defined by:

13) $$Y_i = \begin{cases} 0 \ if & Y_i^* \leq c_1 \\ 1 \ if & c_1 \leq Y_i^* \leq c_2 \\ & \dots \dots \dots \\ m \ if & Y_i^* \geq c_m \end{cases}$$

With $c_{j+1} \geq c_j$ and:

14) $$Y_i^* = X_i\beta + \varepsilon_i$$
$$\varepsilon_i \sim (iid)\,(0, \sigma_\varepsilon^2)$$
$$i = 1, \dots, N$$

ε_i could follow the logistic law (logit model) or the Gaussian law (probit model). In this study, Y represents the food security index with its four levels. We are interested in estimating the probability that an individual belongs to a definite level of the food security index:

15) $$P(Y_i = j) = F\left(\frac{c_{j+1}}{\sigma_\varepsilon} - \frac{X_i\beta}{\sigma_\varepsilon}\right) - F\left(\frac{c_j}{\sigma_\varepsilon} - \frac{X_i\beta}{\sigma_\varepsilon}\right)$$
$$j = 1, \dots, m$$
$$c_0 = -\infty \quad and \quad c_{m+1} = \infty$$

Where *F* is the distribution function of the logistic or the Gaussian law. In this case, the probit and logit models provide similar results. In this study, we chose a probit model with the Gaussian law, which is more commonly used in social science (Powers and Xie 2000: 215).

The explanatory variables (Table 3) of the probit model were chosen based on the combination between primary data collected during our fieldwork with milk suppliers, semi-structured in-depth interviews with managers of the LDB and the IFPRI-CIRAD-GRET databases. Multicollinearity tests showed no correlation between variables used in the model.

Table 3. Descriptive statistics for the independent variables used to explain herder households' probability of being in a given class of the food security index

Independent variables		Percentage of total sample
Income mobility	Deterioration	69
	Stability	30
	Improvement	1
Sources of income	1 or 2	72
	More than 2	28
Number of years supplying milk	[1-4[	3
	[4-5[	14
	[5-6[	19
	[6-8]	64
Number of livestock heads	[1-24[	24
	[24-45[	25
	[45-80[	25
	[80 and more [	26

Source: Own calculations on data from IFPRI-CIRAD-GRET database on nutrition of 445 LDB suppliers.

The Markov Chain convergence test also showed that our model satisfies all required hypotheses. The interpretations are based on the marginal effects of an ordered probit and probability calculations. The main quantitative changes that we can highlight *a priori* from the implementation of the LDB's milk supply chain management are intra-annual because we based our observations on a one-year database.

4- Interactions between LDB's raw milk supply chain and supplier households' food security and socioeconomic resources

4.1. The LDB's innovative supply chains secure good quality raw milk supplies to the dairy

4.1.1. The LDB's raw milk supply chain was purpose-built for the Senegalese Ferlo

The interviews with the LDB managers revealed that, having decided that the LDB would purposefully supply raw milk from pastoralist herders of the Ferlo, the company had no choice but to develop the supply chains that would allow this goal to materialize. The LDB collects milk from pastoralist campsites located in the arid wilderness around Richard Toll City. To limit the transportation time of raw milk on dirt roads to below two hours, the dairy has encouraged milk producers to become partially sedentary. The permanent settlements harboring the herders' dairy cows are located along six milk collection routes radiating up to 50 km away from the dairy plant.

The dairy has coopted some young men from the herder settlements and has helped them invest in motorbikes allowing them to become private milk collectors who operate the six collection routes on a daily basis. The collectors ride their motorbikes trailing a cart with plastic buckets belonging to the dairy, which contain the milk. Each bucket contains the milk of one

individual herder, a household or cooperative, allowing traceability of the milk back to each individual supplier.

With the dairy striving to source more local milk for its processing plant, the LDB is actively encouraging other agro-entrepreneurs to start semi-intensive dairy farms closer to the city. This would allow the LDB to enlarge its supplier base of local producers while making sourcing easier as these peri-urban producers can deliver milk to the processing plant by themselves.

4.1.2. The LDB has introduced technological and process innovations in its relationship with its suppliers

The main non-written contractual link between the LDB and its pastoralist milk suppliers is developed around a package of transactions on milk production in exchange of financial, technological and training collaterals provided by the LDB to secure its milk supply.

As part of its supply stabilization strategy, the LDB has developed and implemented various services to increase the milk production of pastoralists. The most innovative service was the provision of animal feed through a check-off recovered on future milk sales. Because they wanted to stabilize their dairy incomes, suppliers were motivated to change many of their production practices. Thus, 58% of LDB's suppliers interviewed report and characterize changes in their milk production system (Figure 4).

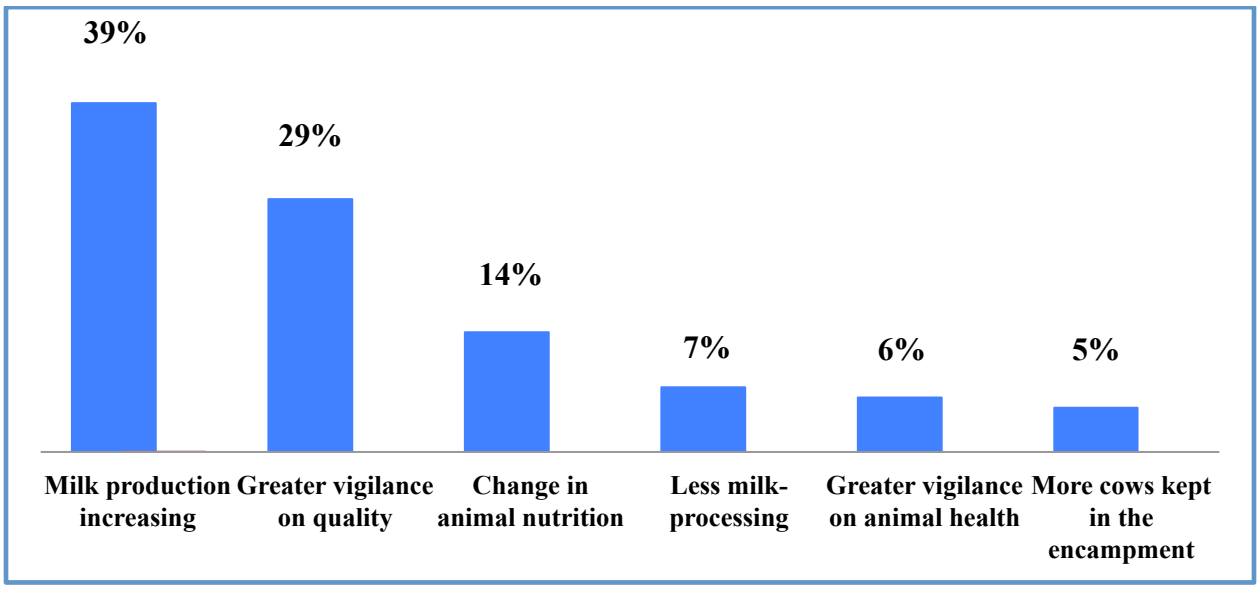

Figure 4. Changes in production practices by LDB milk suppliers (number of respondents implementing the non-exclusive changes and % of total sample)

Source: Own calculations on IFPRI-CIRAD-GRET database on nutrition of 445 LDB suppliers

In particular, 39% of the milk suppliers declare having increased their milk production. Moreover, 29% of suppliers put a greater focus on the quality of the milk produced than before, and 14% confirm changes in animal nutrition through the use of feed supplement. Individual qualitative interviews with herders and the focus groups have uncovered that the changes in milk productivity are predominantly related to the technical support of LDB and the income incentive

from increasing milk sales to the dairy. Producers who did not supply the dairy were less likely to implement the technical innovations.

4.1.3. Human resources management and capacity development by the LDB

The LDB has also invested in developing the capacities of its own staff, collectors and suppliers to put the innovations into practice. Thanks to partnerships with local and international NGOs specialized in agricultural development, the LDB's suppliers have benefited from training on milking hygiene and dairy herd nutrition. They have also received veterinary advice and learned how to protect areas for grazing and water wells from itinerant livestock to sustain their forage and water resources.

To reach the women who are the traditional dairy livestock keepers in these highly patriarchal pastoralist communities, the LDB managers indicated that the trainings were first delivered to the men, who would then allow the trainers' access to the communities' women to replicate the training in favor of those who would likely make most use of it.

4.1.4. Modifying company systems and infrastructure to adjust to local sociocultural practices

The LDB has had to modify its accountancy and milk supply chain to accommodate the practices and customs of its local pastoralist suppliers. The check-off system for the animal feed has led the LDB's supply manager and accountants to monitor both feed purchase and milk sales from each individual supplier in order to calculate their monthly negative or positive balance. The close relationships developed by the LDB's supply manager and individual suppliers have led him to consent credit to some suppliers whose overall monthly check-off balance was negative, but who had to be seen bringing some milk income back to the household, thus allowing the male heads of households to save face back in the village.

The interview with LDB managers revealed that the dairy had even made its supply chain less efficient in order to keep good relationships with its suppliers. Indeed, the polygamous nature of households among traditional pastoralist herders resulted in several wives producing milk under the same household supplier contract. However, it transpired that each individual wife had access and control to their own animals and did not want to pool the milk from their cows with the milk from the other wives' cows. So the male heads of households who had signed the supply contract with the dairy were asking for individual buckets for each one of their wives. To accommodate these special requests from its suppliers, the LDB was issuing many individual buckets with a capacity of 10 liters to individual women producers within the same household, thus increasing its own transaction costs to process all these containers and making the collectors travel with buckets containing only a few liters of milk. These inefficiencies were nonetheless judged a prerequisite to develop their suppliers' trust in the LDB and encourage sales of milk.

Overall, according to the LDB managers, the supply chain arrangements, technological innovations, human resources management, and infrastructure changes implemented by the LDB seem to have contributed to increase the quantity and quality of milk supplied, thus adding to the value creation by the dairy.

4.2. The LDB's innovative milk supply chains have positive and negative effects on supplier households' livelihoods depending on their income status

In this study, the main indicators used to measure household livelihood are food security and income stabilization between seasons.

4.2.1. Suppliers face complex choices in terms of food security practices

In the traditional pastoral cattle production system of the Ferlo, only 0.5% of milk produced was sold due to a lack of viable market opportunities (Wane et al. 2009). Thus, a large portion of the milk available was intended for feeding calves, while another was used for own-consumption by pastoral households in the form of fresh and processed milk (butter and curdled milk). The appearance of the LDB has changed the milk use habits for 75% of its suppliers. Own-consumption has been reduced for 51% of suppliers during the entire year and for 33% of households in the dry season to increase the share of milk that is marketed (Figure 5).

In comparison, our qualitative interviews show that own-consumption remains very widespread among non-suppliers, who continue to drink or process for their own use 74% of the milk they produce. Before the arrival of the LDB, herders offered their dairy products for sale on the main road (informal market). This random marketing process has declined with the appearance of the LDB, particularly for its suppliers: the LDB has become the sole outlet of the milk produced for 75% of the dairy's suppliers. This explains why 15% of LDB suppliers report a fall in market sales: these producers have chosen to sell most of their milk to the dairy directly.

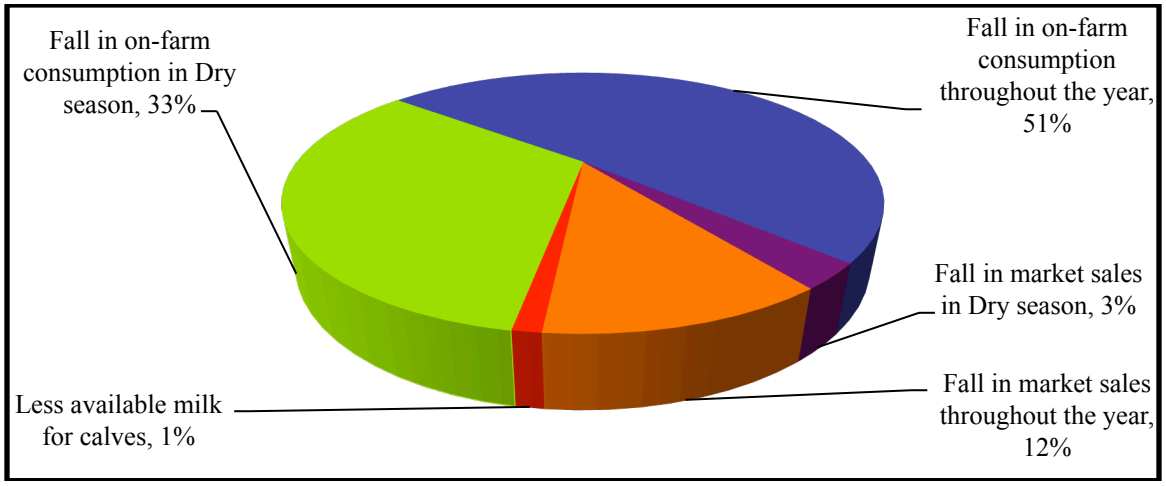

Figure 5. Changes in milk outlet of LDB suppliers
Data: IFPRI-CIRAD-GRET database on nutrition of 445 LDB suppliers

With the monthly payment of milk sales from the LDB, and the additional check-off system that can lead some suppliers actually owing money to the dairy for feed, LDB suppliers can be seen as actually more cash-strapped than they used to be when they marketed some milk surplus on the informal market. Due to this lack of monetary resources, 77% of the LDB suppliers deprive themselves of the staple foods they usually consume. Although 33% report that this situation rarely occurs, more than half (55%) experience this occasionally and 12% often (Figure 6).

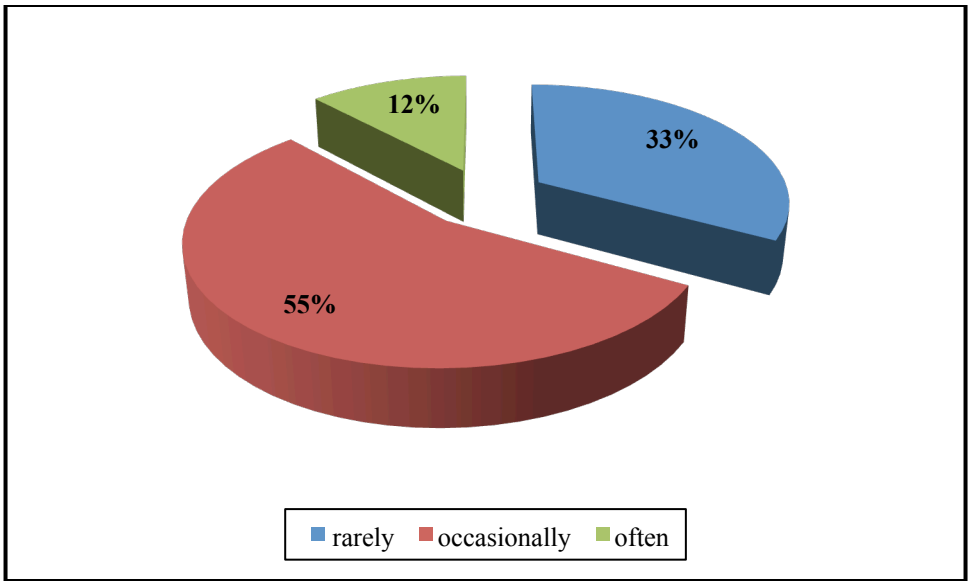

Figure 6. Share of LDB suppliers who have to deprive themselves of staple food. Data: IFPRI-CIRAD-GRET database on nutrition of 445 LDB suppliers

Another strategy to cope with the lack of money to buy food is to forego a meal. Nearly half (49%) of LDB suppliers interviewed have had to reduce the number of meals per day during the four weeks prior to the surveys. Among these, 9% had encountered this situation often, whereas half have encountered it occasionally and 41% rarely.

To address food security issues, it is useful to consider the quantities of food consumed per person. The IFPRI-CIRAD-GRET questionnaire lists household members who have been forced to reduce the quantity of food they previously ate. The results show that the majority (64%) of the LDB's milk suppliers needed to reduce the quantity of food consumed. Of these, 13% encountered this situation often, whereas 57% did so occasionally and 30% rarely.

4.2.2. The income status of LDB suppliers is largely dependent on their ability to keep delivering milk during the dry season

The second indicator of supplier household livelihoods used in this study is income stabilization. Crossing the income mobility indices with the food security status typology of pastoral households highlights the importance of income stabilization between the seasons in explaining the households' food security status. Overall, the value of the Shorrock index calculated for the entire sample ($\mu_{1nor} = 0.62$) indicates that households are relatively mobile within food security groups: their food security status tends to change between dry and wet seasons in a given year for the better or for the worse (Table 4).

Table 4. Income mobility indices and food security groups of LDB milk suppliers

	Income mobility groups		
Food security groups	**Shorrock index (μ_{1nor})**	**Improvement (μ_{imp})**	**Degradation (μ_{deg})**
Group 1 - "insecure"	0.58	0.25	0.53
Group 2 - "poorly secure"	0.59	0.32	0.47
Group 3 - "secure"	0.70	0.61	0.32
Group 4 - "highly secure"	0.63	0.55	0.29
Total	**0.62**	**0.41**	**0.42**

Source: Own calculations on data from IFPRI-CIRAD-GRET database on nutrition of 445 LDB suppliers

Groups 1 and 2 are more likely to observe degradation than improvement of their relative income ($\mu_{imp} \leq \mu_{deg}$). Thus, it is difficult for these groups to maintain their relative level of income between seasons. In groups 3 and 4, there is more income improvement than degradation ($\mu_{imp} > \mu_{deg}$). These households appear to find a means to stabilize their incomes between dry and wet seasons. In fact, despite the significant decrease in dairy revenues in the dry season, groups 3 and 4 likely manage to stabilize their overall revenue by selling a portion of their herds.

If we consider *Group 1: "insecure"*, income mobility and herd size are key factors that explain the food insecurity of these households (Table 5). The probability of being in the food insecure group decreases significantly by 0.21 when income mobility moves from deterioration to improvement. Thus, the stability of dairy income between the dry and rainy season brought by being a regular supplier of the LDB plays an important function in the food security strategies of pastoral households.

Table 5. Ordered probit results on marginal effects of various variables on household food security

Food security groups		**Insecure**	**Poorly secure**	**Secure**	**Highly Secure**
Income mobility	Deterioration	*Reference*	*Reference*	*Reference*	*Reference*
	Stability	-0.07	-0.08	0.07	0.08
	Improvement	-0.21***	-0.16***	0.24***	0.13***
Sources of income	1 or 2	*Reference*	*Reference*	*Reference*	*Reference*
	More than 2	-0.04	-0.14**	0.16**	0.02
Number of years supplying milk	[1-4[	*Reference*	*Reference*	*Reference*	*Reference*
	[4-5[	-0.02	-0.16**	0.04	0.13**
	[5-6[	0.04	0.02	0.04	-0.1 **
	[6-8]	-0.05	-0.11	0.18***	-0.02
Number of livestock heads	[1-24[	*Reference*	*Reference*	*Reference*	*Reference*
	[24-45[	-0.08	0.03	-0.04	0.09
	[45-80[	-0.02	-0.11	0.07	0.05
	[80 and more [	-0.14**	-0.07	-0.03	0.24***

Levels of statistical significance: *** 1%; ** 5%; *10%

Source: Own calculations on data from IFPRI-CIRAD-GRET database on nutrition of 445 LDB suppliers

In *Group 2: "poorly secure"* households, income mobility, number of years supplying milk and number of income sources appear to be the most important factors. The odds of being in this poorly food secure group also decreased very significantly by 0.16 when household income went from degradation to improvement. The seniority in milk supply is also a determining factor; in fact, adding one additional year of supplying milk from the reference group of "less than four years supplying milk" decreases the probability of being "*poorly secure*" by 0.16. This result is all the more relevant as focus group discussions uncovered that women with the most experience of supplying milk to markets continue to supply milk in the dry season and therefore, benefit from dairy income despite the more difficult production conditions.

In *Group 3:"secure"*, income stability, number of income sources and number of years supplying milk are also the main determining factors. Moving from the reference income degradation to income improvement increases the probability of being food secure by 0.24 at the 1% statistically significant level. Seniority in supplying milk is a key factor of food security; from less than four to at least six years of supplying milk, the probability of being "*secure"* increases by 0.18. Thus, the oldest suppliers of LDB have a significant chance of not experiencing food deprivation.

Being in *Group 4:"very secure"* in food depends significantly on income mobility, seniority in milk supplying and herd size. Moving from income degradation to improvement increases by 0.13 the probability of being *"very secure"*. It is worth noting that seniority in milk supplying reveals a double trend. When moving from less than four years of supplying milk to more years, the probability of being in this food security group increases by 0.13. However, a move from the reference of less than four years of milk supply to 5-to-6 years decreases the chances of belonging to this *"very secure"* food security group by 0.1. The mixed effect of milk supply seniority can be explained by the fact that most of the relatively new suppliers to the LDB are also in this *"very secure"* group: already relatively food-secure pastoralist households have spotted this new income opportunity of supplying milk to the LDB. By choosing to channel more of their milk production to the dairy, these households can increase their household income and thus purchase increasingly more varied foods, thus improving their food security status when they move from the new supplier status to 4-to-5 years of supplying dairy. However, this overall increase in income also leads households to choose to spend it on non-food items such as clothing or improving their living conditions, to the detriment of food security. The focus group discussions with women who supply the dairy also showed that mothers were selling the majority of the milk they produced rather than retaining a portion of this nutritious foodstuff for their children, as they previously did when pastoralists had no market outlet for their milk. These livelihood decisions could contribute to a decrease in the household's food security status in the longer term; thus, this explains the negative sign of the coefficients when *"very secure"* farmers become established suppliers of the LDB.

4.3. Supplying milk to the LDB seems to improve herders' socioeconomic resources

4.3.1. LDB suppliers have a greater diversification of income sources

In the Ferlo, 98% of herders' incomes are related to the marketing of ruminants (Wane et al. 2009). But in the LDB's milk supply area, there are different sources of income for pastoral households (Table 6). Despite livestock sales during the dry season remaining the most important source of income (61%), there is an emerging trend of milk sales constituting an increasing share of household income. In the rainy season milk income constitutes more than half (56%) of

overall household income. Milk is increasingly becoming a new opportunity for income generation, whereas in the past, pastoralists were forced to recapitalize by selling a portion of their herd to obtain cash. This finding also links being a milk supplier to the LDB with the potential to keep increasing one's herd size rather than having to sell animals in times of financial need. The results of the ordered probit model (Table 5) showed that increasing the number of income sources and the number of cattle heads had a significant positive impact on improving the food security status of the already more food secure households.

Table 6. Components (%) of LDB suppliers' overall household income in the dry and rainy seasons

	Dry season	**Rainy season**
Livestock sales	61	34
Milk sales	25	56
Crop production	6	4
Other sources of income/Self-employment	4	3
Wage labor	2	1
Others (rent, transfers, donations)	2	1
	100%	**100%**

Data: IFPRI-CIRAD-GRET database on nutrition of LDB 445 suppliers

4.3.2. The LDB has become a facilitator for linking family farmers to competitive markets

The qualitative interviews reveal that the LDB has increased the market orientation of pastoral cattle herders. The milk suppliers to the LDB are price-takers who adapt to the conditions set by the dairy plant. The price system arising from the relationship between the LDB and milk suppliers does not always correspond to the relative scarcity of milk and the optimal resource allocation by herder households. Pastoral households now respond to milk market opportunities by allocating more of their milk produced to sales. These opportunities are reflected in particular by the existence of market outlets for milk produced beyond what is needed to feed calves and the household members, mainly in the wet season.

The LDB's role in facilitating farmers' access to markets is also reflected by its supply of animal feed and loan grants when pastoral investment strategies were previously based on self-financing (Wane 2005). Credit advances for animal feed have always been the cornerstone and the strength of the LDB. However, the qualitative data gathered from milk suppliers indicate that they generally consider the quantities of feed received as insufficient. Despite the apparently advantageous conditions, these suppliers also deplore the high cost of these feed supplements.

Similarly, the dairy plant has removed obstacles previously faced by pastoralists to access the complex and competitive markets of livestock products. The facilitation of the marketing of pastoral products contributes to the herder households' evolution from a primarily subsistence production logic to an increasing use of markets, which leads to a change of productive strategies (Barrett 2008). However, the pastoralists remain subject to uncertainty in their productive activities, to the combined effects of prices and taxes on their decisions and to the conditions of access to other market players (Wane 2005, Duteurtre 2009). To remove these market access constraints, different institutional initiatives could be used based around collective action (Markelova et al. 2009) particularly through producer organizations, market standards or partnerships.

744 *4.3.3. The LDB is a catalyst in the partial restructuring of pastoral mobility*

745 Because monetary incentives are not the most important ones for pastoral herders, it is
746 equally essential to analyze the possible impacts of the LDB milk supply chain on the pastoral
747 practices of its suppliers, as noted by Cesaro (2009).

748 The majority of milk suppliers continue to use geographical mobility as a strategy for
749 cattle herd management. However, this traditional itinerant lifestyle is partially modified in its
750 general organization for milk suppliers of the LDB. The most radical change for herders stems
751 from the desire to continue to supply milk in the dry season by maintaining many of the dairy
752 cows in a sedentary encampment.

753 This change translates into the splitting of the herd and to a change in the social
754 organization of mobility. Our qualitative individual interviews and the focus group discussion
755 held in the pastoral settlement concur in identifying that women and children now remain on the
756 sedentary encampment with the dairy cows, whereas the men move to other locations with the
757 remainder of the herd in search of pastureland. Similarly, the pace and magnitude of
758 transhumance have been modified by the herders' strategy to remain within the dairy's milk
759 collection area. Nonetheless, pastoral mobility remains the principal coping strategy of
760 pastoralists who live in an uncertain biophysical context.

761

762 ## 5- Conclusion

763 Using the generic value chain model (Porter 1985), this study has shown that the
764 innovative raw milk supply chain developed by the Laiterie du Berger in Northern Senegal has
765 allowed the dairy to increase its number of pastoralist suppliers, and the quantity and quality of
766 the milk they sold to the processing plant. We have also studied the changes brought by this new
767 supply chain from the viewpoint of the pastoralist households using a conceptual framework on
768 the sustainability of pastoral systems (Lambert et al. 2014). Our findings suggest that by
769 contributing to stabilizing suppliers' dairy incomes in the dry season, diversifying income
770 sources and enabling households to keep capitalizing into substantial livestock herds, the LDB's
771 milk supply chains could have played an important role in securing some of its supplier
772 households' food security. Supplier households in the Ferlo that had focused on the regularity of
773 their milk supply within a calendar year and over several years seemed to have witnessed an
774 improvement in their food security and overall access to socioeconomic resources. Households
775 placing milk sales to the dairy as their preferred source of stable income had likewise seemed to
776 improve their livelihoods.

777 However, the quantitative findings from this research are limited by the cross-sectional
778 data featuring only one calendar year of observations. In a context of great environmental and
779 market variability, as highlighted in the introduction, this limited data set does not allow to
780 conclude on the LDB's new supply chain as a cause of its suppliers' evolution in sustainability.
781 Further investigations on this topic should use longitudinal data covering several years of
782 observations from the herders. This could contribute to describing better the complex tendencies
783 that accompany innovation or technology introduction.

784 Nevertheless, the combined use of cross-sectional quantitative and qualitative data
785 suggests that the LDB's innovative raw milk supply chain does contribute to strengthening the
786 food security and socioeconomic resources of its supplier households. The new dairy marketing
787 outlet that appeared with the LDB has helped provoke profound changes in the local dairy
788 production system, with women and children now remaining in semi-permanent encampments
789 with the producing dairy cows, where they receive animal feed from the dairy to sustain their

cows' milk production, whereas the men of the community continue their pastoral practices, moving their herds of bulls and non-lactating cows to new areas as needed in search of water and forage.

The findings from this research have implications for other agro-processors interested in developing local milk supply chains in traditional pastoralist drylands environments so as to tap this large and still mobile potential milk reservoir. The LDB's example shows how innovations in supply chain management and business relationships tailored to smallholder herders have allowed the LDB to secure a good quality supply of milk across the year despite the natural trough in milk production during the dry season when forage becomes scarce. However, to ensure that this new access to milk markets and the income opportunities it brings do not destabilize the livelihoods of traditional pastoralist communities, additional training targeting women milk suppliers through development partners should also cover the strategies that will help protect the food security and welfare of the more vulnerable pastoralist household members, who have no say in how the new dairy income is used.

References

Ayantunde, A.A., J. de Leeuw, M. D. Turner, and M. Said. 2011. Challenges of assessing the sustainability of (agro)-pastoral systems. *Livestock Science* 139: 30–43.

Barrett, C. 2008. Smallholder market participation: concepts and evidence from Eastern and Southern Africa. *Food Policy* 33: 299–317.

Bernard, T., M. Hidrobo, A. Le Port and R. Rawat. 2015. Health benefits in contract farming and their impacts on production: evidence from the dairy sector in Senegal. Dakar, Senegal: IFPRI. http://a4nh.cgiar.org/2015/07/06/got-milk-the-role-of-gender-incentives-and-nutrition-in-dairy-contract-farming-in-northern-senegal/ [accessed January 12, 2017]

Boogaard, B. K., E. Waithanji, E. J. Poole and J.-J. Cadilhon. 2015. Smallholder goat production and marketing: a gendered baseline study from Inhassoro District Mozambique. NJAS –Wageningen Journal of Life Sciences 74–75(December): 51–63.

Buhl, S. and Homewood, K. 2000. Milk selling among Fulani women in Northern Burkina Faso. In Hodgson, D. L. (Ed.) *Rethinking Pastoralism in Africa*. Athens, OH: Ohio University Press.

Cesaro, J. D. 2009. *Mobilité pastorale et accès aux marchés : le cas des éleveurs du forage de Niassanté*, MSc Thesis, Paris, France: Université Paris 1 and Montpellier, France: Cirad.

Coates J., A. Swindale and P. Bilinsky. 2007. Household Food Insecurity Access Scale (HFIAS) for Measurement of Food Access: Indicator Guide (V.3). Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

de Haan, C. 2016. Prospects for Livestock-Based Livelihoods in Africa's Drylands. World Bank Studies. Washington, DC: World Bank.

Doss, C. 2013. Data Needs for Gender Analysis in Agriculture. IFPRI Discussion Paper 01261. Washington, DC: IFPRI.

Duteurtre, G. 2009. Accès aux marchés et développement des élevages en Afrique : la construction sociale du rapport marchand. *Actes de la Conférence Internationale sur la commercialisation du bétail sur pieds et l'accès au marché*, Bamako, Mali, 23–25 November 2009.

Duteurtre, G. and C. Corniaux. 2013. Etude relative à la formulation du programme d'actions détaillé de développement de la filière lait en zone UEMOA. Rapport définitif. Ouagadougou, Burkina Faso: UEMOA, and Dakar, Sénégal: CIRAD.

836 Gerber, M., L. Astigarraga, C. Bockstaller, J. L. Fiorelli, N. Hostiou, S. Ingrand, M. Marie, W.
837 Sadok, P. Veysset, R. Ambroise, J. Peigné, S. Plantureux and X. Coquil. 2009. Le modèle Dexi-
838 SH pour une évaluation multicritère de la durabilité agro-écologique des systèmes d'élevage
839 bovins laitiers herbagers. *Innovations Agronomiques* 4: 249–252.
840 Griliches, Z. 1957. Hybrid corn: An exploration in the economics of technological change.
841 *Econometrica* 25(4): 501–522.
842 Haddad, L., J. Hoddinott and H. Alderman. 1997. *Intrahousehold Resource Allocation in*
843 *Developing Countries: Models, Methods and Policy*. Baltimore, MA: Johns Hopkins University
844 Press.
845 Huss-Ashmore, R. 1996. Livestock, nutrition, and intrahousehold resource control in Uasin
846 Gishu District, Kenya. *Human Ecology* 24(2): 191–213.
847 Ickowicz, A., V. Ancey, C. Corniaux, G. Duteurtre, R. Poccard-Chappuis, I. Touré, E. Vall
848 and A. Wane. 2012. Crop–livestock production systems in the Sahel – increasing resilience for
849 adaptation to climate change and preserving food security. In *Proceeding of the FAO–OECD*
850 *Workshop on Building Resilience for Adaptation to Climate Change in the Agriculture sector*.
851 Rome, Italy: FAO–OECD.
852 Kaboret. 2010. Appuis institutionnels à la mise en œuvre de la stratégie régionale de
853 renforcement des services vétérinaires et préparation à l'accès des viandes sahéliennes aux
854 marchés des pays d'Afrique du Nord. Phase d'étude de faisabilité et de programmation des
855 activités du futur projet. Rapport final. Niamey, Niger: CILSS.
856 Ki, J. B., S. Faye and B. Faye. 2005. Pauvreté multidimensionnelle au Sénégal : une approche
857 non monétaire par les besoins de base. PMMA Working Paper N° 2005-05
858 http://ssrn.com/abstract=985928 [accessed January 12, 2017]
859 Lambert-Derkimba, A., A. Ickowicz, C. Aubron, I. Touré and C. H. Moulin. 2014.
860 Sustainability assessment of pastoral systems and their contribution to the one of territories.
861 International Rangeland Congress, Liflod Network's Workshop, Rosario, Argentine.
862 Ly, C., U. Pica-Ciamarra and J. Otte. 2010. *A Dual-track Approach to Livestock Development:*
863 *Economic Rationales and Institutional Bottlenecks in West Africa.* Accra, Ghana: FAO Regional
864 Office for Africa, and Rome, Italy: FAO Animal Production and Health Division.
865 Markelova, H., R. Meinzen-Dick, J. Hellin and S. Dohrn. 2009. Collective action for
866 smallholder market access. *Food Policy* 34: 1–7.
867 Meinzen-Dick, R., N. Johnson, A. Quisumbing, J. Njuki, J. Behrman, D. Rubin, A. Peterman
868 and E. Waithanji. 2011. Gender, Assets, and Agricultural Development Programs: A Conceptual
869 Framework. CAPRi Working Paper No. 99. Washington, DC: IFPRI
870 Mulubrhan, A., A. Solomon and S. Bekele. 2012. Welfare impacts of maize–pigeon pea
871 intensification in Tanzania. *Agricultural Economics* 43(1): 27–43.
872 Negatu, W. and A. Parikh. 1999. The impact of perception and other factors on the adoption of
873 agricultural technology in the Morert and Jiru *Woreda* (district) of Ethiopia, *Agricultural*
874 *Economics* 21: 205–216.
875 Parisse, P. 2012. Developing local dairy production: the Laiterie du Berger, Senegal, *FACTS*
876 *Reports* 6(November 2012) http://factsreports.revues.org/2271 [accessed January 12, 2017]
877 Porter, M. E. 1985 *The Competitive Advantage: Creating and Sustaining Superior*
878 *Performance*. New York, NY: Free Press.
879 Powers, D. A. and Y. Xie. 2000. *Statistical Methods for Categorical Data Analysis.* San
880 Diego, CA: Academic Press.

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

Rey-Valette, H., O. Clément, J. Aubin, S. Mathé, E. Chia, M. Legendre, D. Caruso, O. Milolasek, J. P. Blancheton, J. Slembrouck, A. Baruthio, F. René, P. Levang, P. Morissens, and J. Lazard. 2008. *Guide to the co-construction of sustainable development indicators in aquaculture.* Montpellier, France: CIRAD.

Touré, I., A. Ickowicz, A. Wane, I. Garba and P. Gerber (Eds). 2013. Atlas of trends in pastoral systems in the Sahel 1970–2012. SIPSA. Rome, Italy: FAO, and Dakar, Senegal: CIRAD http://umr-selmet.cirad.fr/publications-et-ressources/documents-techniques [accessed January 12, 2017]

Vorley, B., M. Lundy and J. MacGregor. 2009. Business models that are inclusive of small farmers. In da Silva, C. A., D. Baker, A. W. Shepherd, C. Jenane and S. Miranda-da-Cruz (Eds) *Agro-Industries for Development*. Rome, Italy: FAO, Vienna, Austria: UNIDO and Cambridge, MA: CABI, 186–222.

Wane, A. 2005. Marchés de bétail du Ferlo (Sahel sénégalais) et comportements des ménages pastoraux. *Colloque SFER*, 7–9 November 2005, Montpellier, France.

Wane, A., I. Touré and A. Ickowicz. 2014. Changing environment and market behaviours of Sahelian herders. 6th All Africa Conference on Animal Agriculture (AACAA), 27–30 October 2014, Nairobi, Kenya.

Wane, A., I. Touré and V. Ancey. 2009. Pastoralisme et recours aux marchés - Cas du Sahel sénégalais (Ferlo). *Cahiers Agricultures* 19(1): 1–7.

Acknowledgements

We would like to express our special gratitude and thanks to the Consortium of the International Food Policy Research Institute (IFPRI), The French Centre for Agricultural Research and International Cooperation (CIRAD) and GRET, an international development NGO governed by French law, for allowing us to use their databases from the study area. We also express thanks to partners from the Laiterie du Berger (LDB) and pastoralists for their time in in-depth discussions that helped us better understand various and complex dynamics. This work was undertaken as part of the CGIAR Research Program on Policies, Institutions, and Markets (PIM) led by IFPRI. Funding support for this study was provided by CIRAD, the Small Grants Program of the CGIAR Standing Panel on Impact Assessment and the CGIAR Research Program on Policies, Institutions, and Markets. The opinions expressed here belong to the authors, and do not necessarily reflect those of LDB, PIM, IFPRI, or CGIAR.