Key factors for increasing farmer participation in markets: evidence from the Malian dairy sector

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Summary

Substantial growth in Malian milk supply is necessary to meet rising demand for dairy products while also improving the livelihoods of milk producers and strengthening the competitiveness of the Malian dairy sector against imports. We applied a Cragg two-tiered model to a nationally representative dataset of dairy farming households to examine factors influencing market participation decisions. Four key findings and corresponding policy implications emerged. Firstly, dairy herd size was positively associated with market entry and milk sales. Improving the dissemination of higher-yielding improved breeds, to which less than 10% of households had access, should result in an increase in milk supply. Secondly, herd access to water, feed, and veterinary care also had the positive effect of increased milk supply, highlighting the importance of increased investment in animal health and nutrition. Thirdly, female-headed households were more likely to enter milk markets and they sold greater volumes than male-headed households. Because women typically face inequitable access to productive resources, gender-responsive policies and programs in the dairy sector should help to stimulate milk supply. Fourthly, an increase in milk price was associated with an increase in milk sales. This provides evidence that Malian milk producers are responsive to price incentives, while underlining the importance of incorporating dairy products into existing market information systems.

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■ INTRODUCTION

Consumer demand for dairy products in Mali and in the broader West African region has been climbing steadily with income growth and urbanization (Zhou and Staatz, 2016). Additionally, there is evidence that consumers and retailers have a strong preference for local fresh milk over imports (Vroegindewey et al., 2021; Lefevre, 2014). Since the late 1990s, this growing demand has led to the emergence of milk collection centers that have sought to link the region's production basins with urban areas (Corniaux et al., 2014). More recently, the Malian government's dairy development program (2008–2015) has joined other international development projects to construct or rehabilitate such collection centers, in addition to providing some support for producer training and artificial insemination (Government of Mali, 2016c).

However, despite such efforts, milk supply in Mali and the region has not been keeping pace with growing demand. Zhou and Staatz (2016) estimated, even under conservative assumptions of future income growth, that by 2040 dairy supply in West Africa will fall short of demand by a magnitude of five. Unless production growth increases, this deficit will have to be made up by a commensurate increase in imports in order to avoid real price increases. Figure 1 provides a picture of this pattern for the case of Mali. It presents linear trends of the per capita supplies of domestic cow milk and imported cow milk, based on the past decade of milk output and population growth. Government statistics likely underestimate domestic milk supply, as they are calculated based on limited sampling and multiple assumptions

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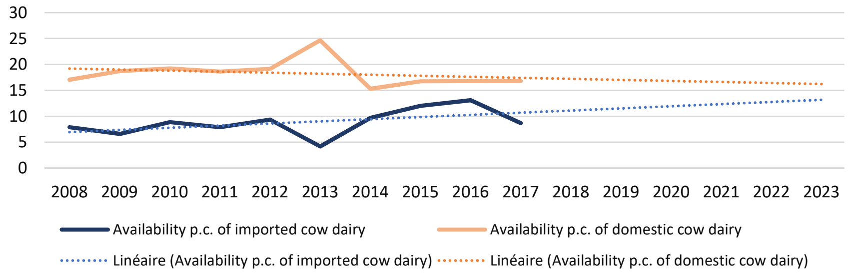

Figure 1: Supply of domestic milk and dairy imports (L/capita) in Mali. Sources: Authors' calculations from Government of Mali (2007–2017) for household availability; FAOSTAT (2019) for imports /// *Offre nationale de lait et importations de produits laitiers (L/habitant) au Mali. Sources : Calculs des auteurs à partir de Gouvernement du Mali (2007–2017) pour la disponibilité chez les ménages ; FAOSTAT (2019) pour les importations*

that do not fully take into account factors such as the increasing adoption of higher-yielding milk herds. FAOSTAT statistics likely also underestimate total dairy imports in Mali, as its classification of dairy products excludes (or significantly undercounts) volumes of imported fat-filled milk powder. Since the early 2010s, annual fat-filled milk powder imports have surpassed total annual imports of whole and skim powdered milk and account for the majority share of milk powder consumption in Mali. Over time, domestic supply has been decreasing while imports have been rising to meet the deficit. The large surge in domestic supply followed by a drop during the 2011-13 period might be explained by very good rain and pasture conditions in 2012 and, in contrast, poor agricultural and security conditions in 2013 (Government of Mali, 2012; 2013). The opposite inflection of imported milk supply during this period suggests the substitutionary relationship that domestic and imported dairy supply have with one another.

Multiple factors can help to explain the historically weak performance of Malian milk supply, including i) underinvestment in quality, productivity, and infrastructure, ii) limited policy support for the Malian dairy sector and poor coordination between government and market actors, and iii) the preference of urban milk processors for less expensive powdered milk imports (Vroegindewey et al., 2021; Mas Aparisi et al., 2012; Duteurtre, 2007). At a microeconomic level, the outcome of these underlying causes is summarized by a single trend: the weak participation of milk producers in markets. Although about 20% of Malian households produce milk, only 3% market any volume of milk during the year (authors' calculations from World Bank, 2015). The objective of this study was to investigate the underlying causes of this weak market participation. Specifically, we investigated the barriers that constrain Malian milk producers from entering and supplying milk markets, and identified policy measures that can boost such market participation.

The question of smallholder farm commercialization in Africa is an issue that has increasingly occupied the attention of policymakers, especially in recent years as liberalization of markets, globalization, and transformations in retailing and consumption are magnifying challenges and opportunities (Reardon and Timmer, 2012). As Barrett (2008, p. 300) summarizes, the theoretical benefits of market-oriented production and trade, relative to subsistence production for own consumption, are important, and include not only "the one-off, static welfare effects of trade according to comparative advantage" but also more rapid total factor productivity growth due to opportunities for larger-scale production and the increased interflow of ideas. Additionally, in the Malian context, an increase and stabilization in the market supply of milk should have broad economic benefits, by strengthening the competitiveness of local dairy value chains and contributing to greater accessibility of diverse foods, especially in urban areas (Vroegindewey et al., 2021; Theriault et al., 2018).

However, a body of evidence has shown that transaction costs are a significant impediment to the participation of African farmers in various agricultural markets (Barrett, 2008). Transaction costs include both the *ex ante* costs that a farmer faces in searching for a market and negotiating a transaction and the *ex post* costs of monitoring and enforcing the terms of the transaction (North, 1990; Williamson, 1985; Coase, 1937). Numerous market participation studies have focused on milk, because its perishability and other technical characteristics generate many transaction costs in its production, processing, and marketing (Jaffee, 1995). Most of these econometric studies are from either Kenya (Burke et al., 2015; Kavoi et al., 2013; Olwande et al., 2015) or Ethiopia (Holloway et al., 2005; 2004; 2000). Their salient finding, consistent with findings from other African markets, is that household-specific variables (e.g. herd and household size) and location-specific variables (e.g. distances to markets) strongly influence the probability and volume of sales among milk producers, reflecting the pervasive impacts of transaction costs in milk markets (Barrett, 2008). These studies also show the importance of productivity-enhancing technologies (e.g. crossbred dairy cows) and favorable agroecological conditions.

The present study focused on Mali because the quantitative economic literature addressing milk market participation has largely overlooked West Africa and especially the Sahel region, which differs distinctively from the East African context in terms of policy history, market structure, and agroecology. For example, the Kenyan dairy sector benefits from more favorable climatic conditions and, since 2002, has also enjoyed the protection of import tariffs of up to 60% (Orasmaa et al., 2016). In contrast, the West African Economic and Monetary Union (UEMOA) has established a Common External Tariff (CET) schedule that taxes imported powdered milk—the primary substitute for local fresh milk—at only 5% (Corniaux et al., 2014). The dairy sectors of these two regions also vary significantly in terms of their performance. For example, dairy farm intensification has taken hold more successfully in East Africa, to the point that regional milk production has grown significantly since the 1960s and currently accounts for about 97% of total milk supply (Duteurtre, 2007). In contrast, farm intensification has had a much slower pace in West Africa, where regional milk production only accounts for about 63% of total milk supply (Duteurtre, 2007).

To our knowledge, this is the first econometric analysis of milk market participation in a Sahelian country. Only two other quantitative papers previously examined milk market participation in the broader West Africa region. First, Somda et al. (2005) utilized a Tobit model and a limited sample to study market participation by milk producers in the Gambia. Second, Balagtas et al. (2007) employed a Heckman selection model to study a limited sample of households in Côte d'Ivoire. In this latter paper, the authors defined milk market entry as household ownership of any cattle (versus household ownership of dairy cattle specifically or the production of milk) and they used a small nonrandom sample. Here, we contributed to the relatively sparse literature by adopting a clearer definition of milk market participation, and by exploiting a randomly sampled and nationally representative household dataset, which allowed us to control for a rich set of variables. Additionally, Mali has the third-largest cattle population in West Africa (after Nigeria and Niger) and a similar ranking in terms of annual milk production (FAOSTAT, 2019). Three-quarters of Malian households own livestock of some kind, and in 2011 the livestock sector contributed to about 8% of the national gross domestic product (Salla, 2017). Thus, Mali provides a superior case study for understanding commercial behaviors in the region high-potential milk-supply basins.

In the next section, we present the conceptual framework for understanding an agricultural household's participation in milk markets when transaction costs are present. Following that, we describe the data and empirical approach for applying this framework to the Malian context. Lastly, we discuss the results and then conclude by highlighting key findings and their policy implications for increasing milk supply in the Malian market.

■ MATERIALS AND METHODS

Conceptual framework

Because our focus was to understand the supply behavior of milk producer households, the theoretical framework was the agricultural household model (Singh et al., 1986). If we could reasonably assume that Malian producers had perfect access to markets for milk and all necessary inputs, then household milk supply boils down to a profit-maximization problem in which decision-making is guided only by exogenously determined prices and conditioned on the given production technology. However, because Malian milk producers face significant transaction costs in these markets, we had to extend the model to account for market imperfections. Specifically, below we drew mainly from Barrett's (2008) articulation of the non-separable agricultural household model. Olwande et al. (2015) similarly drew from Barrett's (2008) model in their analysis of farmer participation in milk (and other) commodity markets in Kenya.

Assume that a household maximizes its utility over a bundle of commodities, subject to a budget constraint involving farm production, sales, and non-farm income, a production technology constraint, and a vector of unobservable "decision prices" (Key et al., 2000). The decision prices for selling (or purchasing) a given commodity equals its observable local market price (P) minus (plus) the transaction costs that a household faces to participate in that market. The transaction costs themselves depend on location- and household-specific variables that, together, influence the search, information, transportation, and negotiation costs associated with carrying out a transaction. Location-specific variables are comprised of the physical and institutional infrastructure (G) that is available for a commodity in a given geography (Barrett, 2008). For example, weak extension services, limited cell phone service, and poor roads would each drive up transaction costs for all households in a given location, by constraining their access to farming best practices, price information, and markets. Household-specific variables are comprised of household productive assets (A), liquidity from non-farm income (W), net sales (NS), and other household characteristics (Z) (Barrett, 2008). For example, within a given location, households with less education and without access to cell phones might face larger transaction costs than other households, because they are less able to access and effectively use market information.[1] Consequently, in a given milk market, we expected differentiated market participation in markets across households.

For milk-producing household i, the market participation decision has two parts. The first part is the decision to participate (or not) as a seller, denoted by M which equals one for market entry and zero otherwise. Second is the decision of sale volumes, denoted by the continuous variable Q, which is positive if and only if M equals one. We could express the reduced-form equation as:

$$Q_i = Q_i(M,P,Z,A,G,W,NS). \quad (1)$$

Data sources

We applied the household market participation model to the Malian context by using data from the 2014 Mali Living Standards Measurement Study (LSMS) / Integrated Survey on Agriculture, a cross-sectional survey of 4,009 household that was implemented by the Planning and Statistics Unit of the Malian Ministry of Rural Development (CPS/SDR) and the World Bank (World Bank, 2015). The LSMS survey had national coverage, with the exception of the northern region of Kidal which surveyors could not access due to insecurity at the time of data collection. Government of Mali (2016b) provides detailed information on the stratified random sampling approach of the LSMS survey.

Our analysis was based on 717 households that reported owning at least one female cow. Of these milk producers, 126 households participated in milk markets as sellers. Data from the livestock modules of the LSMS were collected in a single round from December 2014 to February 2015 (Government of Mali, 2016b). Other modules covered household- and location-, i.e. enumeration area, level characteristics, which were collected between July 2014 and February 2015.

Econometric model and estimation

Our econometric model must account for the two-staged nature of market participation, as depicted in Eq. (1), as well as for the large share of nonparticipants in the dataset (i.e. households that produce but do not sell milk). Nonparticipation in markets results in a corner solution response, in which the outcome variable (in this case milk sales) is zero for a nontrivial number of observations but is continuous otherwise. Applying an ordinary least squares estimator on such a truncated dataset would result in biased and inconsistent estimates (Wooldridge, 2015).

The Tobit model (Tobin, 1958) represents one solution for addressing the corner solution problem (see Holloway et al. [2004; 2000] for different applications of the Tobit approach in the Ethiopian milk market). However, this model relies on the restrictive assumption that the processes driving these two stages be the same, i.e. that the set of significant explanatory variables and the directions of their effects be the same for participation and sale volumes (Burke, 2009). Other studies have shown that this is an unreasonable assumption in the context of milk marketing (e.g. Burke et al., 2015).

Two other models have been previously used. The Heckman sample selection model, which treats nonparticipants as unobserved data resulting from nonrandom sample selection (see Balagtas et al. [2007] for an application in the Ivoirian milk market). However, in our data the dependent variable was observable for the entire random sample and zeroes were not imputed values to missing data. Therefore, the Heckman model was not appropriate for the analysis.

1. Net sales affect transaction costs when there is a fixed cost component wherein the per-unit amount of total transaction costs drops as volumes increase and, consequently, there exists a threshold quantity below which market participation is infeasible (Barrett, 2008; Holloway et al., 2004). Net sales can also capture purchase arrangements in which buyers pay differentiated prices based on volumes in a given sales lot.

The other approach is the Cragg (1971) two-tiered (or double-hurdle) model, which treats zeroes as observed outcomes and allows for two different decision-making processes for the probability of market participation and sale volumes (see Olwande et al. [2015] and Burke et al. [2015] for applications in the Kenyan milk market; Holloway et al. [2005] for an application in Ethiopia). Because these features were better suited to the theoretical model and dataset, we adopted the Cragg model for the analysis.

Specifically, we estimated regressions of the following form:

Stage 1, $P(M_i = 1) = P(Q_i > 0) = X_i\alpha + \varepsilon_i$ and (2)

Stage 2, $Q_i = Z_i\beta + \mu_i$. (3)

Eq. (2) defines the milk market entry decision for household i, where M_i takes on unity if the household makes any milk sales and zero otherwise. Eq. (3) defines the household's decision regarding its level of market participation, in terms of the quantity of milk sales. X_i and Z_i are the two vectors of explanatory variables according to the theoretical model depicted in Eq. (1), and α and β are the marginal effects of these vectors of explanatory variables, for the first and second stages, respectively. We estimated Eq. (2) using maximum likelihood estimation and a probit model. We could estimate Eq. (3) by fitting the data to either a truncated normal distribution or a lognormal distribution (Cragg, 1971). We assumed that the errors in both equations were normally and independently distributed.

Variable definitions

Table I defines the dependent and explanatory variables that we selected for the model. In addition to the theoretical model, the choice of variables was guided by a review of the other empirical studies investigating household participation in milk markets and data availability from the LSMS survey. The first stage dependent variable was binary, taking on unity when a household reported any milk sales made in the previous year, and zero otherwise. The second stage dependent variable represented the number of liters of milk that each household sold in the previous year, which we calculated based on the number of months in the year that households reported milk offtake and the average milk quantities that they reported selling in each of these months.

Household-specific explanatory variables

Household-level productive assets and production technology represented by A in Eq. (1), raise farm output and productivity, thereby increasing net sales (NS) and reducing per-unit production and transaction costs. Thus, we expected that household access to such resources would positively influence market participation. The number of female cows raised by the household was clearly a critical asset for milk production and we distinguished between local-breed cows and crossbred (and foreign) cows to also capture the yield-enhancing benefits of the latter type. We expected that farm households with larger herd size, especially of improved breeds, were more likely to participate actively in the market.

To capture household management of dairy herd health and nutrition, we included variables measuring (separately) the shares of the total cattle herd in the past year that were vaccinated, treated for internal parasites, and treated for ticks and other external parasites. As a measure of herd access to water throughout the year, we included a dummy variable indicating whether a natural water source (e.g. pond or stream) was one of the primary water sources during the dry season. Two other dummies indicated access to resources that were associated with intensive milk production: use of an oilseed cake as a primary type of feed, and household ownership of feeding (or drinking) troughs. We also included household ownership of other assets that improved access to information and markets. Cell phones and radios could be a means for accessing information on markets, prices, and production practices. Ownership of a means of transportation should reduce the time to market. Finally, we included the number of household adults, who might account for an important source of labor, and the number of farm hectares cultivated by the household, which might serve as an important source of animal feed. In a context of imperfect credit markets, we also included estimates of the total nonfarm income earned during two periods: the past twelve months (i.e. concurrent to the milk production period examined), and the past twelve to twenty-four months (i.e. preceding the milk production period examined).

Other household-level characteristics (Z) can influence market participation by influencing productivity, and/or by generating or attenuating transaction costs. Household characteristics are also determinants of milk consumption which, in the non-separable agricultural model, enter the market participation decision by constraining net sales (NS). We attempted to capture gender effects by including a dummy variable for male or female household headship and by disaggregating the total household adults variable by male and female. In the sample, 61% of households reported that female cows were primarily managed by the household head. Another 27% reported collective management by multiple household members, which presumably included partial management by the household head. Thus, focusing on the gender of this individual was appropriate.

However, there was some ambiguity around the expected net effects of gender and household size. Firstly, although women typically have more limited access to inputs and greater time and mobility constraints than men, in traditional West African agricultural households they tend to be more involved with dairy herd maintenance, milking, intrahousehold milk distribution, and milk marketing (Salla, 2017). Secondly, although an increase in the number of household adults increases access to labor (as mentioned above), it may also increase household consumption of milk, thereby reducing net surplus, all other factors held constant. Increases in the number of household children, which increases milk demand without improving labor, should have a less ambiguous negative effect on market participation.

Another household-level variable indicated whether the household head was Fulani, which is a large pastoral ethnic group in West Africa with a tradition of livestock management and, as such, may be able to maintain more productive dairy cattle. Additionally, in Mali the Fulani are also popularly reputed for selling high-quality milk (Vroegindewey et al., 2021), which may also increase the benefits (e.g. price) and/or reduce the transaction costs of participating in markets. We also included a continuous variable indicating the years of formal schooling completed by the household head, as a measure of his or her human capital, with the expectation that greater human capital has a positive effect on market participation.

Location-specific explanatory variables

Local market prices (P) are important determinants in a household vector of decision prices. Price differences across markets, furthermore, reflect a second layer of location-specific transaction costs that are determined by market integration and concentration. We obtained prices from the LSMS community-level dataset, in which survey enumerators recorded three price observations (for each of a selected number of consumer commodities) from the local market of each enumeration area and in both survey rounds. Due to insecurity and other reasons, LSMS survey teams were unable to obtain data from about 15% of the sample of milk producers. We addressed the missing data (i.e. prices and infrastructure) by imputing median values from the next-largest geographic units. Consumer prices should be a sufficient indicator of households' market incentives because milk supply chains in Mali are relatively short and many households sell their milk directly to consumers. To approximate the local output

Table I: Definitions of variables on Malian dairy farming households used in model /// *Définitions des variables relatives aux* ménages d'éleveurs laitiers maliens utilisées dans le modèle

Variable	Definition
Dependent variables	
Participation	HH made any volume of milk sales (level of participation > 0) during 12-month survey period
Level of participation	Volume of milk (L/year) sold by HH during 12-month survey period
Household-specific explanatory variables	
Num. local dairy cows	Num. female cows (local breed) raised by HH
Num. crossbred dairy cows	Num. female cows (mixed/exotic breed) raised by HH
% vaccinated	Share of HH cattle herd vaccinated in past 12 months
% treated for parasites	Share of HH cattle herd treated for internal parasites
% treated for ticks	Share of HH cattle herd treated for external parasites
Water source	Pond or stream was a primary or secondary herd water source during dry season (dummy)
Oilseed cake	Oilseed cake was a primary or secondary source of herd nutrition in past 12 months (dummy)
Trough	HH owns a feed/drinking trough (dummy)
Num. cell phones	Num. functioning cell phones owned by HH
Num. radios	Num. functioning radios owned by HH
Transport	HH owns at least one means of transportation: bicycle, motorcycle or car (dummy)
Ha Land	Total hectares of land that are cultivable by HH
Log (nonfarm income, lagged)	Total annual HH non-farm income (1000 CFAF/year) during 12 months prior to survey period
Log (nonfarm income)	Total annual HH non-farm income (1000 CFAF/year) during 12 months during survey period
Num. adult males	Num. HH members who are adult males
Num. adult females	Num. HH members who are male and over the age of 18
Num. children	Num. HH members who are under the age of 18
HH head gender	HH head is male (dummy)
HH head Fulani	HH head reported Fulani ethnicity (dummy)
HH head yrs of education	Num. years of formal schooling completed by HH head
Location-specific explanatory variables	
Log (milk price)	Ave. (of two survey rounds) of local median price (CFAF/L) of packaged fluid milk
Urban	Community is located in an urban area (dummy)
Num. collection centers	Num. collection centers inventoried at the *cercle* level
% electricity access	Share of HH sampled in communities that have access to electrical grid
Dist. weekly market	Distance (km) to nearest periodic market
Dist. daily market	Distance (km) to permanent nearest market
Dist. training center	Distance (km) to nearest agricultural training center
Dist. financial institution	Distance (minutes) to nearest microfinance institute
Dist. motorable road	Distance (km) to nearest clay or paved road
Average temperature	Average annual temperature (×10°C) during 1960–90 period
Annual rainfall	Total annual precipitation (mm) during 1960–90 period
Semiarid	Community is in a semiarid (vs arid or subhumid) agroecological zone (dummy)
Arid	Community is in an arid (vs semiarid or subhumid) agroecological zone (dummy)

Sample = 718; Market participants = 127; HH: Household ; CFAF: CFA francs /// *Echantillon = 718 ; Participation dans les marchés = 127 ; HH : Ménage ; CFAF : francs CFA*

milk price faced by producer households, we took the median consumer prices of packaged fluid milk for each enumeration area, then averaged these medians from both survey rounds. Because households produced and marketed milk on a daily basis throughout the year, taking the average from two periods was appropriate. Also, for these reasons, estimating expected prices (instead of realized prices) was less a concern for milk, compared to agricultural products associated with delayed production cycles. However, in an effort to capture longer-term expectations regarding milk demand and prices we included a dummy for whether the household was located in an urban area, i.e. the area has at least 5,000 inhabitants (Government of Mali, 2012b), versus a rural area. Because urban areas contain large and growing consumer markets, this variable should encourage market participation. However, higher population densities also place pressure on land that otherwise might be used for forage or livestock grazing; therefore, we could not predict the net effect of this variable.

Access to various physical and institutional infrastructure (G) can facilitate the adoption of productivity-enhancing technology and directly reduce the transaction costs to market participation. For example, milk collection centers, collection points, and dairies provide a market outlet for local producers and often facilitate access to other services and inputs such as veterinary care, vaccinations, and feed. We included a variable indicating the total number of centers at the *cercle*-level, which we expected to affect positively market participation (*cercle* and *commune* are the second and third administrative units in Mali, respectively). This data comes from a *commune*-level government inventory that distinguishes between (but does not define) collection points, collection centers, and dairies. For simplicity, we refer to all of these, collectively, as "collection centers." Access to electricity could enable such centers to operate lights, cooling tanks, and refrigerators, while relying less on gas generators. Electricity also enables retailers to store milk in refrigerators, which could increase milk demand from these intermediary buyers. Thus, we estimated the share of households in each community that reported having access to electricity and included this variable in the regressions.

To capture access to other various public goods, we included variables representing community distance to the associated infrastructure. We expected that access to a weekly market, and especially to a permanent (i.e. daily) one, would positively affect market participation, by reducing the transaction costs that households incurred to transport milk, search for buyers, and negotiate prices. Access to agricultural training centers should also positively affect market participation insofar as these improve access to extension agents and, thereby, encourage the adoption of productivity-enhancing technologies. Access to a financial institution was also expected to affect positively market participation by allowing producers to invest in lumpy assets (e.g. additional dairy cows). Household access to credit is likely to smooth income during stressed periods, thereby stabilizing demand for milk while helping producers to avoid destocking as a negative coping mechanism. Access to a motorable road (defined here as a clay or paved road) should reduce transportation costs and overall access to markets and services. Finally, we controled for agroecological conditions by including several variables that georeferenced rainfall and temperature.

■ RESULTS AND DISCUSSION

Descriptive statistics

Table II summarizes the milk sales for each quintile of the weighted sample. The top 20% of household milk sellers accounted for 85% of all sales, whereas the bottom 20% accounted for only 1%. This distribution of sales was quite concentrated. In contrast, Olwande et al. (2015) calculated that the top quintile of milk sellers in Kenya accounted for 59% of sales in 2010.

Table III reports summary statistics of the explanatory variables for the LSMS sample and also disaggregates these statistics between milk market participants and nonparticipants. The average size of the local breed herd was less than nine cows for the entire sample, but the average was 22 cows among market participants. For both the full sample and subsample, ownership of crossbred dairy cows was very low. There are reports that producer adoption of improved breeds is increasing in periurban Bamako through artificial insemination programs, direct breeding of local herds with crossbred bulls, and direct importation of breed stocks (Government of Mali, 2017). However, this adoption does not appear to be widespread in Mali as a whole.

Table II: Distribution of Malian households' milk sales across quintiles, weighted /// *Répartition des ventes de lait des ménages maliens entre les quintiles, pondérée*

	Quintiles, based on annual household milk sales				
	1st	2nd	3rd	4th	5th
Mean household sales (L/year)	144	256	437	1,147	12,926
Share of total sales (%)	1	1	3	9	85

Adoption of other productivity-enhancing technologies was also quite low. However, the average household landholding was almost 13 hectares. Average nonfarm household income was about 24,000 CFA francs (CFAF) during the year covered by the survey and 7,000 CFAF in the preceding year. The average household size was almost 14 people, with about half of that number made up of children under the age of sixteen. Household heads were almost always male, and on average had less than one year of formal education. Approximately 20% of producer households had a Fulani household head, but this share jumped to 44% among market participants.

Turning to location-specific characteristics, only 3% of producer households lived in areas classified as urban, and about the same share had access to electricity. On the other hand, 80% of producers lived in the semiarid zone. On average, producer households lived about 12 km from a weekly market, 38 km from a daily market, 30 km from a training center, 50 km from a financial institution, and 21 km from a motorable road. Over two-thirds of households reported owning some mechanical or motor-driven means of transportation for accessing these infrastructures and institutions, whereas the remainder presumably walked, or used public, borrowed, or animal-powered transport. On average, households lived in a *cercle* with 1.76 milk collection centers; however, because of the nature of this data it was not possible to estimate distances to a collection center.

Econometric results

Table IV presents results from the Cragg model. In order to facilitate interpretation of the maximum likelihood estimation (MLE) results of the probit regression, which is nonlinear, we computed the average partial effects (APE) of each explanatory variable on the probability of market entry. (We estimated standard errors and derived significance for the APE statistics from the probit model, and CAPE statistics from the lognormal model, via the delta method and then boostrapped them.) We first fitted the second stage with a truncated normal distribution; however, it was not sufficiently smooth to obtain MLE convergence. In the final model, in order to smooth out the distribution of the second stage dependent variable, we fitted the data with a lognormal distribution. The results of the second stage regression were already interpretable as conditional average partial effects (CAPE), representing the APE of each explanatory variables on the quantity of milk sold, conditioned on market entry. Further, because the dependent variable in the second stage was in logarithmic form, the estimated coefficients represented elasticities for explanatory variables that were also in logarithmic form (i.e. income and price) and semi-elasticities for all others.

Lastly, we estimated the unconditional APE (UAPE) in order to understand the net effect of each explanatory variable. The UAPE is dependent on both stages of the estimation and thus, represents an overall effect across the entire population of milk producers. For these reasons, it is a helpful summary statistic and is especially useful for policy analysis. (To obtain UAPE standard errors, we followed Burke [2009]'s bootstrapping method using 100 replications. However, to use this method we had to fit the data with a truncated lognormal distribution in the 2nd stage. A comparison of the 2nd stage coefficient estimates using lognormal and truncated lognormal showed that they were the same in significance and in value up to at least two decimal places.)

To test for robustness, we also fitted the data with two alternative models (Supplementary Material). The first was a Tobit model with the same explanatory variables as the original model. The second was a Cragg model that included regional dummies as explanatory variables. The results showed that the sign and significance of the parameters estimated in the original model were overall robust to these alternative specifications.

The overall pattern of results supported the hypothesis that each stage of market participation was driven by a different process: the signs and significance of almost all explanatory variables varied across the two equations. Thus, the data justified the use of a two-stage model as opposed to a one-stage Tobit. We also conducted a formal specification test of the Tobit model against the Cragg model, using a post-estimation likelihood ratio test (Lin and Schmidt, 1984), which confirmed that the Cragg model had the best fit.

The number of female cows of local breed was positive and statistically significant in both stages. Across both stages and for the entire population of milk producers, the UAPE estimate indicated that the acquisition of one additional local breed cow increased milk sales by an average of 4%. However, the number of crossbred cows was not a significant variable in either stage. This is surprising, given that every other market participation study that includes a similar variable finds the estimated coefficient to be significant and larger than the effect of local breed cows (Olwande et al., 2015; Balagtas et al., 2007; Holloway et al. 2005; 2000). The result may be due to the overall low level of adoption of crossbred cows in Mali. In the sample, only 8% of households owned such a cow, and only half of these owned more than one.

Herd vaccination rates, use of oilseed cakes in feed rations, and access to a trough, land, and year-round natural water source, each had a positive and significant effect on the probability of market participation. However, none of these variables positively influenced milk sales once households entered the market; further, oilseed cakes and vaccination had a negative effect on volumes sold. The herd share

Table III: Summary statistics of Malian dairy farming household's sample set /// *Statistiques synthétisées de l'échantillon de ménages de producteurs laitiers maliens*

Variable	Sample (n = 717)				Non-partpt (n = 591)	Participants (n = 126)
	Mean	SD	Min	Max	Mean	Mean
Household specific explanatory variables						
Num. local dairy cows	8.73	15.57	0.00	208.00	5.93	21.89
Num. foreign dairy cows	0.27	1.46	0.00	22.00	0.24	0.40
% herd vaccinated	0.54	0.43	0.00	1.00	0.51	0.68
% herd treated for parasites	0.38	0.44	0.00	1.00	0.37	0.41
% herd treated for ticks	0.24	0.39	0.00	1.00	0.23	0.30
Water source dummy	0.41	0.49	0.00	1.00	0.38	0.56
Oilseed cake dummy	0.14	0.35	0.00	1.00	0.12	0.22
Trough dummy	0.15	0.35	0.00	1.00	0.12	0.26
Num. cell phones	2.16	2.34	0.00	15.00	2.14	2.26
Num. radios	1.21	1.27	0.00	8.00	1.24	1.08
Transport dummy	0.67	0.47	0.00	1.00	0.68	0.61
Ha land	12.88	26.77	0.00	239.45	12.30	15.60
Nonfarm income, lagged (CFAF)	7,038.26	8,479.96	0.00	84,888.00	7,333.85	5,651.84
Nonfarm income (CFAF)	24,335.98	167,358.40	0.00	3,116,750.00	25,483.99	18,951.23
Num. adult males	2.91	2.00	0.00	15.00	2.95	2.75
Num. adult females	3.25	2.35	0.00	22.00	3.32	2.90
Num. children	7.64	5.77	0.00	47.00	7.81	6.83
HH head male dummy	0.98	0.14	0.00	1.00	0.98	0.96
HH head Fulani dummy	0.20	0.40	0.00	1.00	0.15	0.44
HH head yrs of education	0.72	2.42	0.00	16.00	0.73	0.67
Location-specific explanatory variables						
Milk price (CFAF/L)	440.81	126.15	133.29	1,225.00	435.89	463.93
Urban dummy	0.03	0.16	0.00	1.00	0.03	0.02
Num. collection centers	1.76	2.30	0.00	12.00	1.72	1.96
% electricity access	0.03	0.14	0.00	1.00	0.03	0.05
Dist. weekly market (km)	11.83	11.83	0.00	130.00	11.87	11.69
Dist. daily market (km)	38.13	33.00	0.00	200.00	36.86	44.06
Dist. training center (km)	30.48	31.92	0.00	240.00	29.73	33.96
Dist. financial institution (km)	50.43	53.65	0.00	600.00	48.34	60.21
Dist. motorable road (km)	21.15	22.77	0.00	185.00	20.89	22.39
Average temperature (°C×10)	275.97	7.34	261.00	300.00	276.19	274.93
Annual rainfall (mm)	715.95	293.23	78.00	1,299.00	708.81	749.45
Semiarid dummy	0.80	0.40	0.00	1.00	0.79	0.85
Arid dummy	0.15	0.35	0.00	1.00	0.15	0.10

Partpt: participants; HH: Household; SD: Standard deviation; CFAF: CFA francs /// *Particip: participants; HH : ménage; SD : déviation standard; CFAF : francs CFA* that was treated for ticks and the share that was treated for internal parasites each had a positive and significant effect on volumes sold. Of these productivity-enhancing resources and technologies, three had a net-positive effect (i.e. significant and positive UAPE) across the entire sample of milk producers. A 1% increase in the herd share that was treated for ticks, dry season access to a natural water source, and ownership of a trough were each associated with increases in milk sales of 4%, 42%, and 44%, respectively.

Surprisingly, the number of radios and nonfarm income had a negative effect on volumes sold for households that had entered the milk market. It could be that milk sales were a less-preferred means of income generation than other livelihoods (including nonfarm activities) that

Table IV: Determinants of Malian dairy farming household's market entry and sales: Cragg model results and average partial effects /// *Déterminants de l'entrée sur les marchés et des ventes des ménages producteurs de lait maliens :* résultats du modèle de Cragg et effets partiels moyens

	Probit (1st stage)						Lognormal (2nd stage)			Net effects		
	Regression results			APE			Regression results / Conditional APE			Unconditional APE		
	Coef.	Robust SE		Coef.	SE		Coef.	Robust SE		Coef.	SE	
Household specific explanatory variables												
Num. local dairy cows	0.032	0.009	***	0.006	0.001	***	0.020	0.005	***	0.040	0.013	***
Num. foreign dairy cows	0.039	0.032		0.007	0.006		-0.010	0.060		0.043	0.081	
% herd vaccinated	0.370	0.161	**	0.068	0.029	**	-1.173	0.390	***	0.223	0.204	
% herd treated for parasites	-0.140	0.173		-0.026	0.032		0.724	0.353	**	-0.035	0.237	
% herd treated for ticks	0.230	0.171		0.042	0.032		1.005	0.497	**	0.440	0.258	*
Water source dummy	0.352	0.132	**	0.065	0.024	**	0.073	0.253		0.421	0.168	***
Oilseed cake dummy	0.325	0.167	*	0.060	0.031	*	-0.763	0.327	**	0.243	0.194	
Trough dummy	0.366	0.152	**	0.067	0.028	**	0.099	0.328		0.439	0.215	**
Num. cell phones	0.042	0.033		0.008	0.006		-0.019	0.078		0.046	0.049	
Num. radios	-0.091	0.074		-0.017	0.014		-0.206	0.112	*	-0.142	0.095	
Transport dummy	-0.222	0.161		-0.041	0.030		0.395	0.290		-0.190	0.217	
Ha Land	0.004	0.002	*	0.001	0.000	*	-0.002	0.003		0.004	0.003	
Log (nonfarm income, lagged)	-0.045	0.039		-0.008	0.007		-0.037	0.072		-0.058	0.059	
Log (nonfarm income)	-0.021	0.035		-0.004	0.006		-0.180	0.090	**	-0.056	0.051	
Num. adult males	-0.013	0.050		-0.002	0.009		0.162	0.138		0.014	0.079	
Num. adult females	-0.002	0.048		0.000	0.009		-0.079	0.133		-0.017	0.074	
Num. children	-0.019	0.021		-0.004	0.004		0.051	0.045		-0.013	0.030	
HH head male dummy	-0.765	0.418	*	-0.141	0.077	*	-1.215	0.556	**	-1.099	0.546	**
HH head Fulani dummy	0.697	0.146	***	0.128	0.028	***	0.097	0.290		0.821	0.197	***
HH head yrs of education	-0.013	0.031		-0.002	0.006		0.031	0.057		-0.010	0.046	
Location-specific explanatory variables												
Log milk price (CFAF/L)	0.603	0.231	***	0.111	0.042	***	0.207	0.522		0.737	0.287	***
Urban dummy	-0.179	0.465		-0.033	0.085		2.201	1.630		0.171	0.838	
Num. collection centers	0.008	0.032		0.002	0.006		0.012	0.052		0.016	0.032	
% electricity access	0.462	0.542		0.085	0.098		1.633	1.299		0.819	0.594	
Dist. weekly market (km)	-0.004	0.007		-0.001	0.001		0.003	0.011		-0.005	0.010	
Dist. daily market (km)	0.005	0.002	*	0.001	0.000	*	0.002	0.004		0.006	0.003	**
Dist. training center (km)	0.001	0.002		0.000	0.000		-0.001	0.004		0.000	0.003	
Dist. financial institution (km)	0.001	0.001		0.000	0.000		0.001	0.001		0.001	0.002	
Dist. motorable road (km)	0.000	0.003		0.000	0.001		0.009	0.007		0.002	0.004	
Average temperature (°C×10)	-0.018	0.013		-0.003	0.002		-0.031	0.029		-0.026	0.018	
Annual rainfall (mm)	0.001	0.000		0.000	0.000		-0.002	0.001	**	0.000	0.001	
Semiarid dummy	1.086	0.525	**	0.200	0.098	**	-0.213	0.639		1.210	0.984	
Arid dummy	0.986	0.634		0.182	0.117		-1.073	1.018		0.940	1.072	
Constant	-0.783	4.192					17.472	8.724				
Pseudo R-squared	0.286						0.4694					
Observations	717						126					

APE: Average partial effects; SE: Standard error; HH: Household; Dependent variable of the probit model is 1 if household sold milk and 0 otherwise; Dependent variable of truncated normal model is 'liters of milk sold'; CFAF: CFA francs. *** p<0.01; ** p<0.05; * p<0.1 /// *APE : effets partiels moyens ; SE : Ecart-type ; HH : Ménage ; La variable dépendante du modèle probit est 1 si le ménage a vendu du lait et 0 dans le cas contraire ; La variable dépendante du modèle normal tronqué est « litres de lait vendus »* ; CFAF : francs CFA. *** *p<0,01 ; ** p<0,05 ; * p<0,1* were more accessible to wealthier households and that the number of radios partially captured this wealth effect. The usefulness of a radio or cell phone in facilitating access to market or production information depends on the availability of such information, which may in fact be limited in Mali. For example, the Malian government, in its market information system, does not currently monitor or publish the market prices of milk, as it does for other agricultural commodities.

Other household characteristics that influenced market participation were the gender and ethnicity of the household head. In addition to the number of local breed cows, the gender of the household head was the only other variable to have a significant positive effect on both stages of market participation. Female-headed households (15 in the sample of 717 producer households) were 14% more likely to participate in milk markets than male-headed households and were associated with a 122% increase in milk sales. Overall, the UAPE estimate indicated that such households were associated with a 110% increase in milk sales. Household heads that were of Fulani ethnicity were also 13% more likely to participate in milk markets than others. This was in line with Balagtas et al. (2007), who in Côte d'Ivoire found a positive association between Fulani ethnic group households and milk market participation. Additionally, the UAPE estimate indicated that Fulani households were associated with an 82% increase in milk sales.

Increases in the number of males, females or children in households did not significantly influence market participation. We expected some ambiguity with respect to the net effect of the number of household adults, since more adults potentially meant more household demand for milk (thereby reducing net surplus) as well as more labor (thereby potentially increasing milk output). However, the insignificance of the coefficient for children was surprising, assuming that these individuals only factored into the consumption aspect of household decision-making.

A 1% increase in the price of packaged milk was associated with an 11% increase in the probability of market participation. Although price did not have a significant effect in the second stage, its net effect on all producers (UAPE) was a 0.7% increase in sales for every 1% increase in price, all things being equal. Although being located in an urban zone and community electrification shares had only been statistically significant in the second stage at the 18% and 21% levels of confidence, respectively, their estimated effects were quite large.

Surprisingly, none of the variables capturing access to market institutions or infrastructure were significant, with the exception of distance to a daily market. However, its estimated coefficient on the probability of market participation was positive. The UAPE estimate was also positive and significant, suggesting that, as the distance of a household to a daily market increased by each additional kilometer, its milk sales also increased by an average of 0.6%, other factors held constant. It could be that a primary motivation for producing milk was to meet household milk demand, in which case it was the unconsumed surplus that was marketed. Access to daily markets could allow such households to outsource their milk supply, obviating the need to produce themselves. If milk marketing is a lesser preferred means of earning income than other activities that become more feasible in the presence of daily markets, it would strengthen this line of reasoning.

The lack of significance of the total number of collection centers at the *cercle*-level could potentially be explained by imperfections in the government inventory from which data on this variable was sourced. For example, it is possible that the inventory was incomplete or that many of the inventoried centers were non-functioning. The muted effects of access to a training center or financial institution might be explained by the low quality of services offered by these institutions (or their limited relevance to milk producers), even if they were nearby. We might understand the lack of significance of access to a weekly market in light of the fact that milk producers require a more regular market outlet to sell daily output. If a large share of milk is sold at farmgate or at the homes of neighbors, this would further mute the effects of better access to markets, milk collection centers, or motorable roads.

Finally, households located in the semiarid agroecological zone—as opposed to arid or subhumid—were 20% more likely to participate in milk markets. This indicator primarily characterizes the water availability conditions—and, by extension, vegetative conditions—that best supports rainfed dairy cattle production, i.e. an annual length of growing period of 70–180 days (Sebastian, 2016). This zone covers most of the southern half of Mali, including all regions except Gao, Kidal, and Timbuktu.

■ CONCLUSION

Substantial growth in the market supply of Malian milk will be necessary to meet the rising demand for dairy products, while also improving the livelihoods of milk producers and strengthening the competitiveness of the Malian dairy sector against imports. In this study, we utilized a nationally representative household dataset to investigate the factors that can encourage such growth. Following other recent papers that focused on East Africa, we used a two-tiered econometric model, which allowed us to examine the probability of participation and volume of milk sold. This was the first study of its kind to analyze milk marketing in a major milk producing country of West Africa. Therefore, the results provided fresh policy insights for this region. Four key findings emerged.

Firstly, despite the great yield-enhancing potential of crossbred dairy cattle, the adoption of this technology has been extremely limited in Mali. In fact, the variability of crossbred cattle ownership in the dataset was insufficient to allow us to estimate statistically significant marginal effects. However, taking the statistically significant UAPE for the number of local breed cows as a rough lower-bound estimate of the marginal effect of each additional crossbred animal, we can conclude that the impacts on market participation should indeed be substantial. The Malian government should continue to increase producer access to crossbred cattle. However, in light of the fact that milk sales are already very concentrated in Mali, the government should develop improved breed adoption models that are appropriate for poorer households.

Our second finding pertains to another more fundamental productivity constraint: needed improvements to the health and nutrition of dairy herds. We found evidence that pest and disease control has a significant effect on market sales. The Malian government should improve the monitoring of its vaccination programs to understand better their effectiveness and to ensure that poorer producers are also benefiting. We also found significant effects associated with access to zero-grazing technologies (such as feeding troughs) and to year-round water sources. Although the particular measure for improved feed did not have a significant net effect on market participation, the significant and positive effect of being located in the semiarid zone, which partly reflects grazing conditions, points to the importance of herd nutrition. As pressures on grazing land continue to mount in Mali, the availability of high-quality feed alternatives will be increasingly important. Policy options include supporting the development of least-cost feed rations and the promotion of diverse farm systems that include the production of locally appropriate forage. For instance, the cowpea crop is well adapted to the agroclimatic conditions of Mali and can be used a feed, but it has received little attention from policy makers compared to starchy staples, such as rice and maize. Policy should also better support collection centers, which can facilitate producers' access to feed and veterinary services while providing a relatively secure market for producers (Corniaux et al., 2014).

Thirdly, gender has great influence on a household's participation in milk markets. Assuming that the household head plays a primary role in the management of milk production and use, female decision makers market more than twice the volumes than males, other factors held constant. However, other research conducted in Sahel countries has cautioned that women may get displaced from milk value chains as they modernize (Fokou et al., 2011), because women face inequitable access to productive resources (i.e. lack of ownership and control of dairy cattle, and weak access to grazing land, credit, and supporting institutions) (FAO, 2013). Overall, our finding suggests that milk commercialization policies could make substantial gains through better inclusion and empowerment of women in milk value chains. Impact studies from gender and agriculture programs suggest that distributing productive assets (e.g. dairy cattle) directly to women, while also explicitly strengthening their ownership and control over those assets within the household and community, can be especially effective for empowering women (Johnson et al., 2016).

Fourthly, the results provide evidence that Malian milk producers are responsive to price incentives, despite the considerable asset specificity and transaction costs that are present in milk marketing. This suggests that macroeconomic policies should have a positive pull on milk supply. This result also underlines the importance of market price information. The Malian government should prioritize the inclusion of milk prices in its regular market monitoring and information products.

Conflicts of interest

This study was carried out without any conflict of interest.

Author contributions statement

RV drafted the article and led statistical analysis; RV, RBR, and VT each contributed to the conception of the research, data analysis and interpretation, and critical review of the article.

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Résumé

Vroegindewey R., Richardson R.B., Thériault V. Facteurs clés pour accroître la participation des producteurs aux marchés : évidence du secteur laitier malien

Au Mali, une croissance substantielle de l'offre domestique est nécessaire pour répondre à la demande en produits laitiers, améliorer les conditions de vie des producteurs ainsi qu'augmenter la compétitivité du secteur laitier face aux importations. Un modèle Cragg à deux niveaux (Cragg *two-tiered model*) a été appliqué à une base de données de ménages agricoles, représentative au niveau national, afin d'examiner les facteurs clés influençant les décisions de participation et de ventes des producteurs laitiers. Quatre résultats clés ainsi que leurs implications politiques ont émergé. Premièrement, la taille du troupeau laitier était positivement associée à l'entrée sur les marchés et aux ventes de lait. L'accélération de la diffusion de races améliorées et à plus haut rendement, auxquelles moins de 10 % des ménages avaient accès, devrait se traduire par une augmentation encore plus importante de l'offre de lait. Deuxièmement, l'accès des troupeaux à l'eau, aux aliments et aux soins vétérinaires avait également un effet positif sur l'offre de lait, soulignant l'importance d'un investissement accru dans la santé et la nutrition animales. Troisièmement, les ménages dirigés par des femmes étaient plus susceptibles de participer aux marchés du lait et celles-ci vendaient de plus grandes quantités que les ménages dirigés par des hommes. Les femmes étant généralement confrontées à un accès inéquitable aux ressources productives, des politiques et des programmes prenant en compte le genre dans le secteur laitier devraient contribuer à stimuler l'offre de lait. Quatrièmement, comme anticipé, une augmentation du prix du lait était associée à une augmentation des ventes de lait. Cela indique que les producteurs de lait maliens sont sensibles aux incitations des prix et souligne l'importance d'inclure les produits laitiers dans les systèmes d'information existants des marchés.

Mots-clés : bovin, lait de vache, fonction d'offre, accès au marché, chaînes de valeur, Mali

Resumen

Vroegindewey R., Richardson R.B., Thériault V. Factores clave para aumentar la participación de finqueros en los mercados: evidencia del sector lechero maliense

Un crecimiento substancial de la oferta de leche maliense es necesario para satisfacer la creciente demanda de productos lácteos, al tiempo que mejora la calidad de vida de los productores y se refuerza la competitividad del sector lechero maliense frente a las importaciones. Aplicamos un modelo Cragg de dos niveles a una base de datos representativa a nivel nacional de los hogares de finqueros de leche, para examinar los factores que influyen las decisiones de participación en el mercado. Surgieron cuatro puntos clave y sus correspondientes implicaciones sobre las políticas. Primero, el tamaño del hato lechero estuvo asociado positivamente con la introducción en el mercado y las ventas de leche. El mejoramiento en la difusión de las razas mejoradas de alto rendimiento, a las cuáles menos de 10% de los hogares tuvieron acceso, debería resultar en un aumento del suministro de leche. Segundo, el acceso del hato a agua, alimento y cuidados veterinarios también tuvo un efecto positivo sobre el aumento del suministro de leche, subrayando la importancia de un aumento en la inversión en la salud y la nutrición animal. Tercero, los hogares dirigidos por mujeres fueron más propensos a introducir la leche en el mercado y vendieron mayores volúmenes que los hogares dirigidos por hombres. Debido a que las mujeres generalmente tienen un acceso no equitativo a los recursos de producción, las políticas y los programas en el sector lechero orientadas al género deberían ayudar a estimular el suministro de leche. Cuarto, un aumento en el precio de la leche estuvo asociado con un aumento en las ventas de leche. Esto proporciona evidencia de que los productores de leche malienses responden a incentivos de precio, mientras que subraya la importancia de incorporar productos lácteos en los sistemas de información del mercado existentes.

Palabras clave: ganado bovino, leche de vaca, funciones de la oferta, acceso al mercado, cadenas de valor, Malí