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ANALYSIS OF THE DETERMINANTS OF MILK PRODUCERS' PARTICIPATION IN OUTPUT MARKETS

By

Ryan Vroegindewey, Robert Richardson, and Veronique Theriault

Food Security Policy *Research Papers*

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AUTHORS

Ryan Vroegindewey (vroegin2@msu.edu) is a PhD graduate from the Department of Community Sustainability, Michigan State University, East Lansing, MI, USA.

Robert Richardson (rbr@msu.edu) is Professor in the Department of Community Sustainability, Michigan State University, East Lansing, MI, USA.

Veronique Theriault (theria13@msu.edu) is Associate Professor in the Department of Agricultural, Food, and Resource Economics, Michigan State University, East Lansing, MI, USA.

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ABSTRACT:

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. The objective of this paper is to understand the barriers that constrain Malian milk producers from entering and supplying markets, and to identify policy measures that can boost such market participation. We investigate this question by applying Cragg's two-tiered model to data from a population-based survey, the 2014 Mali Living Standards Measurement Study-Integrated Survey on Agriculture.

Our four key findings are robust to alternative model specifications. First, despite the great yield-enhancing potential of mixed-bred dairy cattle, adoption of this technology has been extremely limited in Mali. The Malian government should continue to increase producer access to mixed-bred cattle. Second, improvements to the health and nutrition of dairy herds also have great potential to improve market participation through increased productivity. Thus, policy should also aim to improve producer access to pest and disease control, zero-grazing technologies, and year-round water sources, and feed. Third, gender has great influence on a household's participation in milk markets: female decision-makers market more than twice the volumes of males, other factors held constant. This suggests that milk commercialization policies could make substantial gains by better inclusion of female producers. Fourth, Malian milk producers are responsive to price incentives, despite the considerable asset specificity and transaction costs that are present in milk marketing. This implies that macroeconomic policies, such as stronger import duties that increase the domestic price of fresh milk relative to that of imported substitutes, 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.

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ACRONYMS

APE	average partial effects
CAPE	conditional average partial effects
FAO	Food and Agricultural Organization
FCFA	Franc Communauté Financière Africaine:
FSP	Food Security Policy
HH	Household
IFPRI	International Food Policy Research Institute
km	kilometers
LSMS	Living Standards Measurement Study-Integrated Survey on Agriculture
MLE	maximum likelihood estimation
MSU	Michigan State University
UAPE	unconditional APE
UEMOA	Union Economique et Monétaire Ouest Africaine / West African Economic and Monetary Union
UP	University of Pretoria
USAID	United States Agency for International Development

1. INTRODUCTION

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. The aim of this paper is to understand the barriers that constrain Malian milk producers from entering and supplying markets, and to identify 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, a greater and more stable market supply of milk should have broad economic benefits, insofar as it strengthens the competitiveness of the local dairy value chain and contributes to greater availability and accessibility of diverse foods, perhaps especially in urban areas (Theriault et al. 2018).

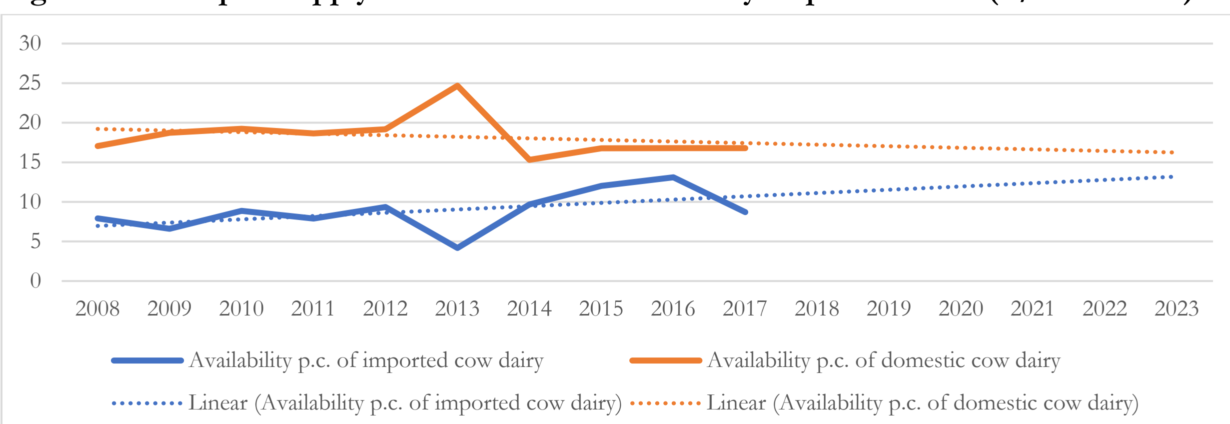
However, a body of evidence has showed that transaction costs are a significant impediment to the participation of African farmers in various agricultural markets (Barrett 2008). Transaction costs are *ex ante* costs that a household faces in searching for a market and negotiating a transaction, and the *ex post* costs of monitoring and enforcing the terms of the transaction (North 1990). 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 studies are from either Kenya (Burke et al. 2015; 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 (such as the level of education of a household's head) and geography-specific variables (especially access to milk buyers such as traders, cooperatives, and processors) strongly influence the probability and value of sales among milk producers, reflecting the pervasive impacts of transaction costs in milk markets (Barrett 2008). These studies also confirm the importance of productivity-enhancing technologies and conditions, namely household ownership of crossbred dairy cows, access to extension, and favorable agricultural-ecological (or agro-ecological) conditions.

This study focuses on Mali because the milk market participation literature 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 agricultural ecosystems. For example, the Kenyan dairy sector benefits from more favorable climactic conditions and, since 2002, has also enjoyed the protection of imports 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 schedule that taxes imported powdered milk at only 5%, and other products at up to 35% (UEMOA 2014).

To our knowledge, no other research has conducted econometric analysis of milk producer market participation in the Sahel region, and only one working paper has examined this issue in the broader West Africa region. Balagtas et al. (2007) use a Heckman selection model to study a limited sample of households in Ivory Coast. However, this paper defines milk market entry as household ownership of any cattle (versus household ownership of dairy cattle specifically or the production of milk) and uses a small nonrandom sample. This study uses a more precise definition of milk market participation, exploiting a randomly sampled and nationally representative household dataset, and by employing a rich set of control 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); thus, it provides an excellent case study for understanding commercial behaviors in the region's high-potential milk supply basins.

In West African countries, livestock plays a critical role in household incomes and the national economy. In Mali specifically, three-quarters of households own livestock of some kind and in 2011 the livestock sector contributed to about 8% of the national gross domestic product (Salla 2017). Focusing on the dairy sub-sector, consumer demand in Mali and the region has been climbing steadily with income growth and urbanization (Zhou and Staatz 2016). While this poses a huge opportunity to producers, regional supply has not been keeping apace. Zhou and Staatz (2016) estimate, even under conservative assumptions of future income growth, that by 2040 regional dairy supply 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 milk and imported dairy, based on the past decade of milk output and population growth.[1] Over time, domestic supply has been decreasing while imports have been rising to meet the deficit. At the household level, low rates of market participation help to explain this pattern: although 20% of Malian households produce milk, only 3% market any volume milk during the year (authors' calculations from World Bank 2015).

Figure 1. Per Capita Supply of Domestic Milk and Dairy Imports in Mali (L/Per Person)



Sources: Authors' calculations from Government of Mali (2007-2011, 2012b, 2013-2015, 2016b, 2017) and FAOSTAT (2019).

[1] 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 2013, 2012b). The opposite inflection of imported milk supply during this same period suggests the substitutionary relationship that domestic and imported dairy supply have with one another.

We investigate this household-level pattern in Mali. Section 2 presents the conceptual framework for understanding an agricultural household's participation in milk markets when transaction costs are present. Section 3 describes the data and empirical approach for applying this framework to the Malian context. In section four, we present the results, and then conclude by highlighting key findings and their policy implications for increasing milk supply in the Malian market.

2. CONCEPTUAL FRAMEWORK

Because the focus is understanding the supply behavior of milk producer households, the theoretical framework is 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 dairy producers face significant transaction costs in these markets, we must extend the model to account for market imperfections. Specifically, below we draw mainly from Barrett's (2008) articulation of the non-separable agricultural household model.[2]

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, p. 248). 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 household-specific characteristics (*Z*) and physical and institutional infrastructure (*G*), which together affect the search, information, transportation, and negotiation costs associated with carrying out a transaction. The transaction costs also depend on household-level productive assets (*A*), liquidity from non-farm income (*W*), and net sales (*NS*). The latter variable affects transaction costs when there is a fixed costs-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 defining feature of this model is that, because household-specific variables determine transaction costs, the decision prices that producers face are likewise household-specific. Consequently, in a given milk market we expect to observe differentiated participation in markets across households.[3] For milk-producing household *i*, the market participation decision has two parts. The first is the decision to participate (or not) as a seller, denoted by *M* which equals one for

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[2] 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.

[3] In addition to household-specific transaction costs, Barrett's (2008) market participation model specifies a second layer of transaction costs that are commodity and geography-specific. Because we focus on participation in milk markets, it is not necessary to control for commodity type. The geography-specific nature of transaction costs arises because local markets "are differentially integrated into the global economy because of spatial differences in costs of commerce, in the degree of competition among market intermediaries, or both" (Barrett 2008, p. 301). The incorporation of observed local market prices—which are determined by these factors—accounts for the geographically-differentiated nature of transaction costs.

market entry and zero otherwise. Second is the decision of sales volumes, denoted by the continuous variable *Q*, which is positive if and only if $M = 1$. We can express the reduced-form equation as:

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

3. MATERIALS AND METHODS

3.1 Data Sources

I apply the household market participation model to the Malian context by using data from the 2014 Mali Living Standards Measurement Study-Integrated Survey on Agriculture (LSMS), a 4,009 household cross-sectional survey that was implemented by the Planning and Statistics Unit of the Malian Ministry of Rural Development and the World Bank (World Bank 2015). The population-based survey has 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 (2016) provides detailed information on the stratified random sampling approach of the LSMS survey.

The analysis is based on 717 households that reported owning a 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 2016). Other modules cover household and community (i.e., enumeration area)-level characteristics, and were collected between July 2014 and February 2015.

3.2 Econometric Model and Estimation

The 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 problem, 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, applying this model to the subsample of milk producers involves estimating simultaneously the determinants of the probability and magnitude of the market participation outcome. This imposes the restrictive constraint 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 (Burke 2009). Other studies have showed that this is an unreasonable assumption in the context of milk marketing (e.g., see Burke et al. 2015).

There are two commonly used alternative models that more flexibly address the corner solution problem through a two-step procedure, but which also nest the Tobit model as a special case (Lin and Schmidt 1984). One approach, the Heckman (1979) sample selection model, treats non-participants as unobserved data resulting from nonrandom sample selection (see Balagtas et al. 2007) for an application in Ivoirian milk markets). However, because the data is a random sample, and because the theoretical model views the outcomes of both stages (including nonparticipation outcomes) as the result of a household decision-making process, the Heckman model is not appropriate for the analysis.

The other approach is the Cragg (1971) two-tiered (or double-hurdle) model, which treats zeroes as observed outcomes and allows for two different processes to estimate different parameters for the probability and value of sales separately (see Olwande et al. (2015) and Burke et al. (2015) for application in the Kenyan milk market, and Holloway et al. (2005) for an application in Ethiopia). Because these features are better suited to the theoretical model and dataset, we adopt the Cragg model for the analysis.

Specifically, we estimate regressions of the following form:

Stage 1: $P(M_i = 1) = P(Q_i > 0) = \boldsymbol{X}_i\boldsymbol{\alpha} + \varepsilon_i,$ and (2)

Stage 2: $Q_i = \boldsymbol{Z}_i\boldsymbol{\beta} + \mu_i.$ (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. $\boldsymbol{X}_i$ and $\boldsymbol{Z}_i$ are the two vectors of explanatory variables, according to the theoretical model depicted in Eq. (1), and $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are the marginal effects of these vectors of explanatory variables, for the first and second stage, respectively. We estimate Eq. (2) using maximum likelihood estimation and a probit model. We can estimate Eq. (3) by fitting the data to either a truncated normal distribution or a lognormal distribution (Cragg 1971). We assume that the errors in both equations are normally and independently distributed.

3.3 Variable Definitions

Table 1 defines the dependent and explanatory variables that we select for the model. In addition to the theoretical model, the choice of variables is 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 is binary, taking on unity when a household reports any milk sales made in the previous year, and zero otherwise. The second stage dependent variable represents the liters of milk that each household sold in the previous year, which we calculate 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.

Table 1. Variable Definition and Summary Statistics

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 (HH)-specific explanatory variables	
No. local dairy cows	No. female cows (of local breed) raised by HH
No. foreign dairy cows	No. female cows (of 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	A 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	Household owns a feed/drinking trough (dummy)
No. cell phones	Number of functioning cell phones owned by household
No. radios	Number of functioning radios owned by household
Transport	Household owns at least one means of transportation: bicycle, motorcycle, or car (dummy)
Ha. Land	Total hectares of land that is cultivable by HH
Log (nonfarm income, lagged)	Total annual non-farm income (1,000 FCFA/year) of HH during 12 mos. prior to survey period
Log (nonfarm income)	Total annual non-farm income (1,000 FCFA/year) of HH during 12 mos. during survey period
No. adult males	Number of household members who are adult males
No. adult female	Number of household members who are male and over the age of 18
No. children	Number of household 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 edu.	Number of years of formal schooling completed by HH head
Location-specific explanatory variables	
Log (milk price)	Ave. (of two survey rounds) of local median price (FCFA/L) of packaged fluid milk
Urban	Community is located in an urban area (dummy)
No. collection centers	Number of collection centers inventoried at the *cercle* level
% electricity access	Share of households sampled in community that have access to electrical grid (%)
Dist. weekly market	Distance (km) to nearest periodic market
Dist. daily market	Distance (km) to nearest permanent market
Dist. training center	Distance (km) to nearest agricultural training center
Dist. financial institution	Distance (minutes) to nearest micro finance institute
Dist. motorable road	Distance (km) to nearest clay or paved road
Average temperature	Average annual temperature (multiplied by 10 °C) during 1960-1990 period
Annual rainfall	Total annual precipitation (mm) during 1960-1990 period
Semi-arid	Community is in semi-arid (vs arid or sub-humid) agro-ecological zone (dummy)
Arid	Community is in arid (vs semi-arid or sub-humid) agro-ecological zone (dummy)

Notes: N(sample) =718; N(market participants) = 127; HH refers to household

3.3.1 Household-specific Explanatory Variables

Household-level productive assets and production technology (represented by *A* in Eq. (1)) raise farm output and productivity, thereby increasing marketable surplus (*NS*) and reducing per-unit production and transaction costs. Thus, we expect that household access to such resources will positively influence market participation. The number of female cows raised by the household is clearly a critical asset for milk production, and we distinguish between local-breed cows and mixed (and foreign) breed cows to also capture the yield-enhancing benefits of the latter type.

To capture household management of dairy herd health and nutrition, we include variables measuring (separately) the shares of the total cattle herd in the past year that was 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 include 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 indicate access to resources that are 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 include household ownership of other assets that improve 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 greatly reduce the time to market. Finally, we include the number of household adults and the number of farm hectares cultivated by the household, which may serve as important sources of labor and animal feed, respectively, in the context of imperfect factor markets. Similarly, in a context of imperfect credit markets, we also include 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 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, enters the market participation decision by constraining net surplus (NS). We attempt 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.[4] However, there is some ambiguity around the expected net effects of gender and household size. First, although women typically have more limited access to inputs and greater time and mobility constraints, compared to 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). Second, 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 indicates whether the household head is *Fulani*, which is the largest pastoral ethnic group in Mali. We also include 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.

3.3.2 Location-specific Explanatory Variables

Local market prices (P) are important determinants in a household's 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 select number of consumer commodities) from the local market of each enumeration area and in both survey rounds.[5] Consumer prices should be a sufficient indicator of households' market incentives because milk supply chains in Mali are relatively short, and many households do sell their

[4] 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 includes partial management by the household head. Thus, focusing on the gender of this individual is appropriate.

[5] Due to insecurity and other reasons, LSMS survey teams were unable to access 197 of 1,073 of the enumeration areas, which corresponds to about 15% of the sample of milk producers. We addressed missing community data (i.e., prices and infrastructure) by imputing median values from the next-largest geographic units.

milk directly to consumers. To approximate the local output milk price faced by producer households, we took the median consumer prices of packaged fluid milk for each enumeration area, and then averaged these medians from both survey rounds. Because households produce and market milk on a daily basis throughout the year, taking the average from two periods is appropriate. Also, for these reasons, estimating expected prices (instead of the use of realized prices) is 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 include a dummy for whether the household is located in an urban area, versus a rural area.[6] Because urban areas contain large and growing consumer markets (Zhou and Staatz 2016), this variable should encourage market participation. However, higher population densities place pressure on land that livestock might otherwise access for grazing or foraging; thus, we cannot 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 provide a market outlet for local producers, and often facilitate access to other services and inputs such as veterinary care, vaccinations, and feed. We include a variable indicating the total number of centers at the *cercle*-level, which we expect to positively affect market participation.[7] Access to electricity enables such centers to run lights, cooling tanks, and refrigerators, while relying less on more costly gas generators. Electricity also enables retailers to store milk in refrigerators, which should increase milk demand from these intermediary buyers. Thus, we estimate the share of households in each community that reported having access to electricity and include this variable in the regressions.

To capture access to other various public goods, we include variables representing community distance to the associated infrastructure. We hypothesize that access to a weekly market, and especially to a permanent (i.e., daily) market, will positively affect market participation, as each should reduce the transaction costs that households incur 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 might also positively affect market participation, by allowing producers to invest in lumpy assets (e.g., additional dairy cows). Household access to credit might 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 control for location-specific climactic and agro-ecological conditions by including several variables that geo-reference rainfall and temperature data from secondary databases.

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[6] Following government census definitions (Government of Mali 2012), the LSMS defines an enumeration area as urban if it both has at least 5,000 inhabitants and is administratively classified as an urban *commune*. In Mali, there are thirty-six urban communes and 667 rural communes.

[7] 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*. In Mali, *cercle* and *commune* are the second and third administrative units in Mali, respectively. Among Mali's eight regions, there are forty-nine *cercles* and 703 communes.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

In Table 2, we summarize the milk sales for each quintile of the weighted sample. The top 20% of household milk sellers account for 85% of all sales, while the bottom 20% account for only 1% . This distribution of sales is quite concentrated. For example, Olwande et al. (2015) calculated that the top quintile of milk sellers in Kenya accounted for 59% of sales in 2010.

Table 2. Distribution of Milk Sales across Quintiles, Weighted

	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%

Source: Authors.

Table 3 reports summary statistics of the explanatory variables for the LSMS sample, and disaggregates these statistics between milk market participants and non-participants. The average size of the local breed herd is less than eight cows for the entire sample, but it is twenty-two cows among the sub-sample of market participants. For both the sample and market participants, ownership of mixed-bred dairy cows is very low. There are reports that farmer adoption of crossbred cattle is increasing in peri-urban Bamako, through artificial insemination programs, direct breeding of local herds with crossbred bulls, and the direct importation of breed stocks (Government of Mali 2017). However, this adoption does not appear to be widespread in Mali as a whole.

Adoption of other productivity-enhancing technologies is also quite low. However, the average household land holding is almost 13 hectares. Average nonfarm household income was about 24 million FCFA (Franc Communauté Financière Africaine) during the year covered by the survey, and 7 million FCFA in the preceding year. The average household size is almost 14 people, with about half of that number made up of children under the age of sixteen. Household heads are usually male, and on average have less than one year of formal education. Twenty percent of producer households have a Fulani household head, but this share jumps to 44% among market participants.

Turning to location-specific characteristics, only 3% of producer households live in areas classified as urban, and about the same share has access to electricity. On the other hand, 80% of producers live in the semi-arid zone. On average, producer households live about twelve kilometers (km) from a weekly market, thirty-eight km from a daily market, thirty km from a training center, fifty km from a financial institution, and twenty-one km from a motorable road. Sixty-seven percent of households report owning some mechanical or motor-driven means of transportation for accessing these infrastructures and institutions, while the remainder would presumably walk or else use public, borrowed, or animal-powered transport. On average, households live in a cercle with 1.76 milk collection centers; however, due to the nature of this data it was not possible to estimate distances to a collection center.

Table 3. Summary Statistics

Variable	Sample (N=717) Mean	Std. Dev.	Min	Max	Non-participants (N=591) Mean	Participants (N=126) Mean
Household (HH)-specific explanatory variables						
No. local dairy cows	8.73	15.57	0.00	208.00	5.93	21.89
No. foreign dairy cows	0.27	1.46	0.00	22.00	0.24	0.40
% vaccinated	0.54	0.43	0.00	1.00	0.51	0.68
% treated for parasites	0.38	0.44	0.00	1.00	0.37	0.41
% treated for ticks	0.24	0.39	0.00	1.00	0.23	0.30
Water source	0.41	0.49	0.00	1.00	0.38	0.56
Oilseed cake	0.14	0.35	0.00	1.00	0.12	0.22
Trough	0.15	0.35	0.00	1.00	0.12	0.26
No. cell phones	2.16	2.34	0.00	15.00	2.14	2.26
No. radios	1.21	1.27	0.00	8.00	1.24	1.08
Transport	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	7,038.26	8,479.96	0.00	84,888.00	7,333.85	5,651.84
Nonfarm income	24,335.98	167,358.40	0.00	3,116,750.00	25,483.99	18,951.23
No. adult males	2.91	2.00	0.00	15.00	2.95	2.75
No. adult female	3.25	2.35	0.00	22.00	3.32	2.90
No. children	7.64	5.77	0.00	47.00	7.81	6.83
HH head gender	0.98	0.14	0.00	1.00	0.98	0.96
HH head Fulani	0.20	0.40	0.00	1.00	0.15	0.44
HH head yrs of edu.	0.72	2.42	0.00	16.00	0.73	0.67
Location-specific explanatory variables						
Milk price	440.81	126.15	133.29	1,225.00	435.89	463.93
Urban	0.03	0.16	0.00	1.00	0.03	0.02
No. 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	11.83	11.83	0.00	130.00	11.87	11.69
Dist. daily market	38.13	33.00	0.00	200.00	36.86	44.06
Dist. training center	30.48	31.92	0.00	240.00	29.73	33.96
Dist. financial institution	50.43	53.65	0.00	600.00	48.34	60.21
Dist. motorable road	21.15	22.77	0.00	185.00	20.89	22.39
Average temperature	275.97	7.34	261.00	300.00	276.19	274.93
Annual rainfall	715.95	293.23	78.00	1,299.00	708.81	749.45
Semi-arid	0.80	0.40	0.00	1.00	0.79	0.85
Arid	0.15	0.35	0.00	1.00	0.15	0.10

Notes: HH refers to household.

Adoption of other productivity-enhancing technologies is also quite low. However, the average household land holding is almost 13 hectares. Average nonfarm household income was about 24 million FCFA during the year covered by the survey, and 7 million FCFA in the preceding year. The average household size is almost 14 people, with about half of that number made up of children under the age of sixteen. Household heads are usually male, and on average have less than one year of formal education. Twenty percent of producer households have a Fulani household head, but this share jumps to 44% among market participants.

4.2 Econometric Results

Table 4 presents results from the two stages of the Cragg maximum likelihood estimation (MLE) model. We estimated each using robust standard errors. In order to facilitate interpretation of the MLE results of the probit regression, which is nonlinear, we compute the average partial effects APE) of each explanatory variable on the probability of market entry.[8] We first fitted the 2nd 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 2nd stage dependent variable, we fitted the data with a lognormal distribution. The results of the 2nd stage regression are 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 is in logarithmic form, the estimated coefficients represent elasticities for explanatory variables that are 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.[9]

To test for robustness, we also fitted the data with two alternative models. 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, displayed in Appendix A, show that the sign and significance of the parameters estimated in the original model are largely robust to these alternative specifications, with only a few minor differences.

First, the overall pattern of results confirms the hypothesis that each stage of market participation is driven by a different process: the signs and significance of almost all explanatory variables vary across the two equations. The two variables that represent exceptions—the number of local breed female cows and the gender of the household head—are discussed further below. Thus, the data justifies 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 ration test (Lin and Schmidt, 1984), which confirmed that the Cragg model is the better fit.

The number of female cows of local breed is positive and statistically significant in both stages. Across both stages and for the entire population of milk producers, the UAPE estimate indicates that the acquisition of one additional local breed cow increases milk sales by an average of 4%. However, the number of foreign or crossbred cows is 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

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[8] We estimate standard errors and derive significance for the APE statistics (from the probit model) and CAPE statistics (from the lognormal model) via the delta method.

[9] 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 shows that they are the same in significance and in value up to at least two decimal places.

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 own such a cow, and only half of these own more than one.

Herd vaccination rates, use of oilseed cakes in feed rations, and access to a trough, to land and to a year-round natural water source each have a positive and significant effect on the probability of market participation. However, none of these variables positively influence milk sales once households enter the market; further, oilseed cakes and vaccination have a negative effect on volumes sold. The herd share that is treated for ticks and the share that is treated for internal parasites each have a positive and significant effect on volumes sold. Of these productivity-enhancing resources and technologies, three have 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 is treated for ticks, dry season access to a natural water source, and ownership of a trough are each associated with increases in milk sales of 4%, 42%, and 44%, respectively.

Surprisingly, the number of radios and nonfarm income have a negative effect on volumes sold for households that have entered the milk market. It could be that milk sales are a less-preferred means of income-generation compared to other livelihoods (including nonfarm activities) that are more accessible to wealthier households, and that the number of radios partially captures 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 does not currently monitor, publish, or report the market prices of milk, as it does for other agricultural commodities.

Other household characteristics that influence market participation are the gender and ethnicity of the household head. In additional to the number of local breed cows, the gender of the household head is the only other variable to have a significant positive effect on both stages of market participation. Female-headed households are 14% more likely to participate in milk markets and are associated with a 122% increase in milk sales, compared to male-headed households.[10] Overall, the UAPE estimate indicates that such households are associated with a 110% increase in milk sales. Household heads that are of Fulani ethnicity are also 13% more likely to participate in milk markets, compared to others, and the UAPE estimate indicates that Fulani households are associated with an 82% increase in milk sales.

[10] In the sample of 717 producer households, fifteen households had a female head.

Table 4. Cragg Model Results and Average Partial Effects

	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 (HH)-specific explanatory variables												
No. local dairy cows	0.032	0.009	***	0.006	0.001	***	0.020	0.005	***	0.040	0.013	***
No. cross-bred dairy cows	0.039	0.032		0.007	0.006		-0.010	0.060		0.043	0.081	
% vaccinated	0.370	0.161	**	0.068	0.029	**	-1.173	0.390	***	0.223	0.204	
% treated for parasites	-0.140	0.173		-0.026	0.032		0.724	0.353	**	-0.035	0.237	
% treated for ticks	0.230	0.171		0.042	0.032		1.005	0.497	**	0.440	0.258	*
Water source	0.352	0.132	**	0.065	0.024	**	0.073	0.253		0.421	0.168	***
Oilseed cake	0.325	0.167	*	0.060	0.031	*	-0.763	0.327	**	0.243	0.194	
Trough	0.366	0.152	**	0.067	0.028	**	0.099	0.328		0.439	0.215	**
No. cell phones	0.042	0.033		0.008	0.006		-0.019	0.078		0.046	0.049	
No. radios	-0.091	0.074		-0.017	0.014		-0.206	0.112	*	-0.142	0.095	
Transport	-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	
No. adult males	-0.013	0.050		-0.002	0.009		0.162	0.138		0.014	0.079	
No. adult female	-0.002	0.048		0.000	0.009		-0.079	0.133		-0.017	0.074	
No. children	-0.019	0.021		-0.004	0.004		0.051	0.045		-0.013	0.030	
HH head gender	-0.765	0.418	*	-0.141	0.077	*	-1.215	0.556	**	-1.099	0.546	**
HH head Fulani	0.697	0.146	***	0.128	0.028	***	0.097	0.290		0.821	0.197	***
HH head yrs of edu.	-0.013	0.031		-0.002	0.006		0.031	0.057		-0.010	0.046	
Location-specific explanatory variables												
Log (milk price)	0.603	0.231	***	0.111	0.042	***	0.207	0.522		0.737	0.287	***
Urban	-0.179	0.465		-0.033	0.085		2.201	1.630		0.171	0.838	
No. 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	-0.004	0.007		-0.001	0.001		0.003	0.011		-0.005	0.010	
Dist. daily market	0.005	0.002	*	0.001	0.000	*	0.002	0.004		0.006	0.003	**
Dist. training center	0.001	0.002		0.000	0.000		-0.001	0.004		0.000	0.003	
Dist. financial institution	0.001	0.001		0.000	0.000		0.001	0.001		0.001	0.002	
Dist. motorable road	0.000	0.003		0.000	0.001		0.009	0.007		0.002	0.004	
Average temperature	-0.018	0.013		-0.003	0.002		-0.031	0.029		-0.026	0.018	
Annual rainfall	0.001	0.000		0.000	0.000		-0.002	0.001	**	0.000	0.001	
Semi-arid	1.086	0.525	**	0.200	0.098	**	-0.213	0.639		1.210	0.984	
Arid	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					

Notes: 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. ***, **, and * indicates p<0.01, p<0.05, and p<0.1, respectively.

Increases in the number of male, female, or children household members do 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 means 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 is surprising, assuming that these individuals only factor into the consumption aspect of household decision-making.

A 1% increase in the price of packaged milk is associated with an 11% increase in the probability of market participation. Although price does not have a significant effect in the second stage, its net effect on all producers (the UPAE) is a .7% increase in sales for every 1% increase in price, *ceteris paribus*. Although being located in an urban zone and community electrification shares are only statistically significant in the second stage at the 18% and 21% levels of confidence, respectively, their estimated effects are quite significant.

Surprisingly, none of the variables capturing access to market institutions or infrastructure is significant, with the exception of distance to a daily market. However, its estimated coefficient on the probability of market participation is positive. The UAPE estimate is also positive and significant, suggesting that, as a household's distance to a daily market increases by each additional kilometer, its milk sales also increase by an average of .6%, other factors held constant. It could be that a primary motivation for producing milk is to meet household milk demand, in which case it is the unconsumed surplus that is marketed. Access to daily markets could allow such households to outsource their milk supply, obviating the need to produce it themselves. If milk marketing is a less preferred means of earning income, compared to other activities that suddenly become more feasible with the presence of daily markets, it would strengthen this line of reasoning. 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 are 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 were 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 agro-ecological zone—as opposed to arid or sub-humid—are 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.

5. 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 have utilized a nationally representative household dataset to investigate the factors that can encourage such growth. Following other recent papers that have focused on East Africa, we use a double-hurdle econometric model, which allows me to examine separately the probability and the value of milk market participation. Because this is the first study of its kind to analyze milk marketing in a major milk producing countries of West Africa, we expect the results to provide fresh policy insights for this region. In particular, four key findings emerge.

First, despite the great yield-enhancing potential of mixed-bred dairy cattle, the adoption of this technology has been extremely limited in Mali. So much so, that the variability of mixed-bred cattle ownership in the dataset appears insufficient to allow me to estimate the 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 mixed bred animal, we can conclude that the impacts on market participation should indeed be substantial. The Malian government should continue to increase producer access to mixed-bred cattle.

Second, improvements to the health and nutrition of dairy herds also have great potential to improve market participation through increased productivity. The findings indicate that pest and disease control, access to zero-grazing technologies (such as feeding troughs), and to year-round water sources are especially key. Although the particular measure for improved feed did not have a significant net effect across both stages of market participation, the significant and positive effect of being located in semi-arid zone, which partly reflects grazing conditions, points to the importance of herd nutrition. Improving the availability of high-quality feed will be especially critical with the dissemination of mixed-bred cattle, which have more complex nutritional needs compared to local breeds.

Third, 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 of males, other factors held constant. This result, combined with the reality that women currently face unequitable access to productive resources, suggests that milk commercialization policies could make substantial gains by focusing on female producers. However, other research conducted in Mali has cautioned that women may get displaced milk value chains as they modernize (Schneider et al. 2007). Overall, this finding highlights the importance of mainstreaming gender into any milk-related policies.

Fourth, 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, such as stronger import duties that increase the domestic price of fresh milk relative to that of imported substitutes, 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.

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APPENDIX

Table A 1. Robustness Checks: Alternative Tobit and Cragg Model Specifications

	Alternative model #1: Tobit Regression Results			Alternative model #2: Cragg with regional dummies — Probit (1st Stage) Regression Results			Lognormal (2nd Stage) Regression Results		
	Coef.	Robust SE		Coef.	Robust SE		Coef.	Robust SE	
Household (HH)-specific explanatory variables									
No. local dairy cows	0.156	0.041	***	0.032	0.009	***	0.019	0.004	***
No. foreign dairy cows	0.211	0.177		0.032	0.033		-0.027	0.053	
% vaccinated	1.753	1.127		0.379	0.166	**	-1.118	0.335	***
% treated for parasites	-0.255	1.171		-0.101	0.175		0.681	0.303	**
% treated for ticks	1.964	1.154	*	0.235	0.176		0.979	0.417	**
Water source	2.155	0.927	**	0.388	0.137	***	-0.051	0.232	
Oilseed cake	2.389	1.113	**	0.326	0.172	*	-0.698	0.269	***
Trough	1.993	1.007	**	0.418	0.156	***	0.108	0.281	
No. cell phones	0.163	0.232		0.044	0.034		-0.006	0.068	
No. radios	-0.656	0.490		-0.090	0.075		-0.242	0.102	**
Transport	-1.151	1.110		-0.189	0.170		0.465	0.268	*
Ha. land	0.021	0.013		0.003	0.002		-0.002	0.004	
Nonfarm income, lagged	-0.322	0.270		-0.040	0.038		-0.028	0.062	
Nonfarm income	-0.379	0.247		-0.027	0.035		-0.163	0.075	**
No. adult males	0.164	0.364		-0.008	0.049		0.115	0.115	
No. adult females	-0.031	0.342		-0.017	0.048		-0.056	0.106	
No. children	-0.091	0.131		-0.019	0.021		0.050	0.034	
HH head sex	-5.418	2.837	*	-0.833	0.427	*	-1.383	0.490	***
HH head Fulani	4.933	0.949	***	0.747	0.148	***	-0.052	0.289	
HH head yrs of edu.	-0.117	0.221		-0.013	0.032		0.048	0.048	
Location-specific explanatory variables									
Milk price	4.403	1.623	***	0.602	0.239	**	-0.141	0.486	
Urban	-0.972	3.279		-0.155	0.471		2.085	1.339	
No. collection centers	0.064	0.215		0.017	0.033		-0.012	0.038	
% electricity access	5.370	3.228	*	0.340	0.565		1.559	1.109	
Dist. weekly market	-0.019	0.044		-0.005	0.007		0.004	0.010	
Dist. daily market	0.030	0.013	**	0.005	0.002	**	0.002	0.003	
Dist. training center	-0.001	0.015		0.001	0.002		0.000	0.003	
Dist. financial institution	0.007	0.007		0.001	0.001		0.000	0.001	
Dist. motorable road	0.014	0.021		0.000	0.003		0.007	0.006	
Average temperature	-0.119	0.091		-0.030	0.016	*	-0.003	0.029	
Annual rainfall	0.003	0.003		0.000	0.001		-0.002	0.001	***
Semi-arid	5.732	3.055	*	1.157	0.524	**	0.115	0.675	
Arid	4.738	3.965		1.219	0.695	*	-0.742	0.936	
Constant	-3.753	28.639		2.600	4.842		11.349	8.549	
Kayes				0.343	0.450		0.150	0.470	
Koulikoro				-0.135	0.464		0.017	0.576	
Sikasso				0.051	0.497		0.813	0.843	
Segou				0.139	0.480		0.086	0.659	
Mopti				-0.093	0.428		0.753	0.544	
Pseudo R-squared	0.127			0.292					
Observations	717			717			126		

Notes: 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. ***, **, and * indicates *p<0.01, p<0.05, and p<0.1*, respectively. In Alternative model #2, three regional dummies (Tombouctou, Bamako, and Gao) were omitted due to multicollinearit.