Spatial Aspects of Producer Milk Price Formation in Kenya: A joint household-GIS approach

S.J. Staal[1](USA), C. Delgado[2](USA), I. Baltenweck[1](France), R. Kruska[1],(USA)

[1]International Livestock Research Institute
PO Box 30709, Nairobi, Kenya

[2]International Food Policy Research Institute
2033 K St. N.W., Washington, DC, U.S.A.

*Correspondence should be sent to:
c.delgado@cgiar.org or s.staal@cgiar.org

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Abstract

Smallholder dairy production is a widespread and growing activity in the Kenyan highlands, and a potentially important source of livelihood for many poor farmers with road access to urban areas of East and Southern Africa. Yet both market participation and net prices received vary widely across households. It is hypothesized that transport difficulties over poor roads directly affect farmer ability and willingness to participate in this market for a highly perishable commodity, even where asset and information levels would otherwise permit such participation. Furthermore, otherwise identical milk sales in a given market can yield very different farm-gate milk prices across farms, for the same reason, depending on the location of the farm. A Heckman iterative selection model is fitted to explain market participation and milk prices received across households for 712 observations on marketing (or non-marketing) of milk by Kenyan smallholders in the greater Nairobi milkshed. GIS-derived variables for distance and transport costs are combined with survey-derived variables for household characteristics to model market participation and the formation of farm-level milk prices. Parameters are used to specify milk price distance decay functions. The results differentiate the effects of roads by type and distance, and highlight the importance of milk production density and market infrastructure. Policy implications are discussed.

Key words: Kenya/smallholder dairy/spatial analysis/market entry/price formation/GIS

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Small-scale dairy production is an important avenue for income generation for mainly subsistence farmers in the East African highlands. It offers high returns, the expectation of future growth, and a technology that can be adopted by resource-poor farmers. Barriers to smallholder participation in this activity nevertheless remain. Market factors are among the most important constraints for this highly perishable commodity. Poor roads and long distances, entailing high costs for transport, affect both the reliability of markets and prices available to farmers. Market access for smallholder African dairy producers is therefore hypothesized to be highly dependent on spatially-related factors, including distances to urban consumption centers and processing points, the quality of road infrastructure, and local agro-climatic conditions. GIS tools allow these spatial factors to be better incorporated into analysis of household market access and participation, and indeed in analysis of farm-gate milk prices themselves. This paper combines such tools with standard household survey instruments, in order to examine the determinants of smallholder milk market participation and of farm-gate milk price formation.

Spatial data on smallholder dairy in Central Kenya

A diagnostic survey to characterize the smallholder dairy system was conducted in Central, Eastern and Rift valley provinces of Kenya. Prospective study districts were grouped according to agro-ecological production potential (high or medium) and market access (high, medium, or low), from which eight districts were selected that were considered to represent an appropriate range of variation in both production and market factors. A stratified sampling method was then used based on administrative unit, recognized agro-ecological zones, and three population density classes. The sample in each stratification class was then weighted by existing household number estimates, resulting in a final sample size for present purposes of 1,379 households. Households were chosen along random transects, and each household was geo-referenced using a global positioning system (GPS) unit. All significant milk processing and collecting centers in the study area were also geo-referenced.

The derivation of GIS variables focused on road infrastructure and agro-climate. A detailed road network of the study area was digitized, based on a government topographic map. Three classes of roads were differentiated: 1) all weather, bound surface, 2) all weather, loose surface, and 3) dry weather only. This network of roads was supplemented with a 4-kilometer grid (assumed "feeder roads") to fill in the areas between existing roads. Major urban areas such as Nairobi and other towns were added to the network as nodes, as were the farm households and milk processing facilities. Assumed mean travel speeds were then assigned to each road type, with highest speeds for Type 1 roads.

A GIS Arc/Info package (ESRI 1998) was then used with the 22,000 resulting road sections to identify least travel time routes for a set of destinations, including Nairobi, the 2 nearest urban areas other than Nairobi, the 2 nearest formal milk collection centers. Least-time routes were identified for all 12,900 nodes in the network, and interpolated to produce smoothed accessibility surfaces for the whole study area, based on a simple inverse-weighted distance algorithm. The human population density layer was based on extrapolation of the 1989 Kenya census, and focal neighborhood functions were used to evaluate the mean population density within a 5 km radius for every point in the study area. Agro-climatic information (precipitation / potential evapotranspiration - PPE) was taken from the database contained in the Almanac Characterization Tool (Corbett 1999).

The survey also yielded information on the characteristics of 371 households overlapping the GIS households. Both households that sold milk and did not re-sell were revisited, but not uniformly. A data set of 712 observations was obtained, of which 259 pertained to households that did not sell milk. In some cases, where farmers reported selling to more than one outlet, multiple observations were included for the same household. Thus minor clustering in the form of more than one (rarely more than two) observations per household was observed.

Smallholder dairy production and marketing in Central Kenya

In the Nairobi milkshed, the present survey (KARI, 1998) and previous results suggest that dairy production is typically conducted on a farm of a few acres landholding, with a herd of 1-3 crossbred cows, European dairy stock crossed with local Zebu. Cows are fed planted fodder, crop residues, and grain millings or compounded dairy feed. Milk production per animal is low, typically 4-7 liters per day (Owango *et al.* 1998).. Labor for dairy production is provided mainly by family members, with women bearing the largest share. About 80% of marketed milk is sold raw, without processing; instead, it is boiled by the consumer before consumption (Staal, Delgado, and Nicholson 1997). Avoiding processing cost, raw milk markets offer higher prices to producers and lower prices to consumers.

The household survey conducted here shows some 15% higher farm-gate prices and 25-50% lower retail prices in the raw milk market compared to the formal packed milk channel. Not surprisingly, survey results show that the largest single market outlet for farmers, comprising some 36% of marketed milk, consists of direct sales of raw milk from producer to consumer, typically through farmer delivery to nearby households. Important players are also small milk traders, who handle another 28% of marketed milk, and who deliver milk to consumers or other retail outlets. In the more formal market, dairy farmer cooperatives are the largest players, with another 28% of the market, while private dairy processors are thought to capture only some 19%. Dairy cooperatives play an intermediary role, by supplying both informal traders and dairy processors. These relative market shares have been changing through the 1990s, with an increasing role for the informal market.

Model

The decision to participate in the milk market was represented as a binary variable depending on whether households sold milk or not. It is thought to depend on household characteristics, such as access to assets (including family labor) and information, and on the location of the farm relative to sales points, final markets, and agro-ecology. Household assets were modelled by landholdings, a weighted average of dairy herd size (adjusted for productive potential of different cows), and demographic variables. Access to information and human capital was also modelled by demographic variables, and by measures of experience and education. Agro-ecological and economic activity level differences were controlled for by inclusion of a variable consisting in the ration of annual precipitation over total potential evapo-transpiration, and by a local population density variable. Participation was also hypothesized to depend on distances to milk collection centers by different kinds of roads.

Price formation was also hypothesized to depend on 12 of the 18 explanatory variables in the selection equation, in addition to 24 variables not included in the selection equation. Variables thought to influence participation but not prices received were: land owned, agro-ecology, and distances to collection points (as opposed to distances to final markets). Variables thought to influence prices received but not participation were a series of distance variables relative to the Nairobi market, by different kinds of road, contractual details such as whether this was a recurring contract sale or a spot sale, whether credit was involved, and size of sale.

Estimation

An iterative Heckman sample selection model was fitted, using full-information maximum likelihood procedures (FIML). This and the identification assumptions discussed in the previous section permitted consistent estimation of the parameters of both the decision to participate in the dairy market and the determinants of the price per unit received. Robust techniques were used to control for the clustering effect of having some household being represented more than once in the transaction data set.

Results – milk market participation

Statistically significant results of the stage 1 analysis of milk market participation are shown in Table 1. The coefficients are interpretable primarily with respect to sign and significance. The variables with significant and large positive effects on the probability of milk market participation are the number of cattle, the agro-climatic index (ANNPPE), and the level of education of the household head, represented by dummy variables for progressively higher educational levels. Variables with small positive effects are age of household head, years of dairy experience, and the road type 1 (all weather sealed surface road) component of the distance to the two nearest formal milk collection centers. The agro-climatic index is shown to be particularly important, which in this case represents the positive effect of higher rainfall on production potential, as well as neighborhood effects resulting from high cattle and milk density, resulting in good availability of animals and milk market density. Human capital, represented by education, has a large positive effect on participation, which may be linked to better ability to manage an enterprise requiring timely daily delivery, or to greater entrepreneurship. The small positive effect of distance by main road (type 1), is unexpected.

The only variable with a strong negative effects on milk market participation is the road type 2 (all weather loose surface) component of mean distance to collection centers, which is as expected. This shows clearly the importance for participation of upgrading milk market infrastructure, and also the differential effect of poorer quality roads (loose surface) on market access.

Results – milk price formation

A tabulation of prices received by farmers shows that they are higher on average, *ceteris paribus* in the informal market, at a mean of 16.6 Kenya shillings (Kshs)/lt[1], compared to 15.2 Kshs/lt in the formal market, some 1.4 Ksh/lt higher and significant at the 1% level (488 observations.)

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[1] In Oct. 1999, the Kshs/US$ exchange rate was about 72.

The regression results show strong positive effects on farm milk price of gender, age, and education of the household head, number of people in household, and several of the variables related to type of market outlet. Results also suggest that female-headed household more frequently use the informal market for sales, which offers higher prices. If this effect is not fully captured in the market outlet variables, then that may explain the higher prices reported by female-headed households. Age and education reflect human capital that may positively influence the ability of a farmer to seek and secure outlets that offer better prices. It is not clear how the number of household members is related to higher price, but may again be related to increased propensity of those households to use the informal market. The dummy variables show that much higher prices are available through sales on credit, which may reflect the cost of credit as well as the cost of increased non-payment risk that credit sales represent. Sales by bicycle yield higher prices, which can be simply attributed to the bike transport allowing farmers to move down the market chain, and sell milk in places or market channels that otherwise would be typically served by intermediaries.

The main large negative effects on milk price result from the road distance measures, in this case from Nairobi, the main milk consumption center. These indicate, sensibly, that the further the farm from the main consumption center, the lower the price the farmer is paid. An additional kilometer of road type 1 (al weather sealed surface) away from Nairobi reduces the price on average by .105 Kshs/lt. These reflect the additional per kilometer costs of transport and transport risk, which leads to the higher coefficient estimates for roads type 2 and 3, as poorer quality roads are likely to incur higher costs. Moreover, the relationship is not linear: the positive squared terms indicate that the negative distance cost effect is ameliorated over longer distances, so the marginal overall per kilometer cost is less further away. Although road type 2 unexpectedly has a greater negative price effect than poor quality road type 3, when the squared terms are included the overall effect of road quality differences is as expected.

Milk producer prices reach a minimum at 139 km distant from Nairobi on road type 1 (best roads) , at 25 km on road type 2, and at17 km on road type 3 (worst roads). The ascending part of the curve reflects the decreasing attractiveness of Nairobi market, which happens quickly on the poorest roads, with prices falling to a "reservation level" below which participation ceases.

Discussion and conclusions

The analysis of milk price formation provides results that fit closely with expectations, and quantify in a very explicit manner the differentiated impacts of road types on market access and prices. The much reduced range of the milk market over poorer quality roads, 139 km compared to 25 km and 17 km, underlines strongly the impact on market performance of infrastructure. These factors can be combined to predict prices across the area surveyed. Figure 1 maps predicted farm milk prices in the survey area, using only those variables for which continuous GIS coverage can be estimated, including the road network. As illustrated, the prices differ markedly over space, and are even predicted to be negative in some remote areas. Given the strong effect of roads, particularly type 3 roads passable only in dry weather, policies towards strengthening road infrastructure in areas suitable for dairy production will raise prices and farmer welfare.

Overall, the results demonstrate the important role of spatial factors for smallholder milk production, both in terms of the prices they receive and in terms of the overall environment for market participation. Policies aimed towards freeing the informal market, improving tertiary road infrastructure, and enabling the development of private livestock services would all work to increase smallholder farmer welfare. .

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Table 1: Stage 1 results of sample selection model: significant effects on probability of selling milk

Dependent variable:	SELLMILK, dummy that is 1 if milk is sold and 0 otherwise, N= 712, K= 18	
Variable Name	**Coefficient**	**Variable Description**
Constant	-1.585	
COW_W	0.318	Number of cows weighted by production potential.
POP_MEAN	0.0004	Human population mean density within 5km of farm.
AGE	0.009	Age of head of household.
YRSEXP	-0.013	Years of dairy farming experience of head of household.
TOTLAND	-0.004	Total acreage owned by household.
ANNPPE	1.185	Ratio of annual precipitation over total potential evapo-transpiration.
IEDUC_1	0.212	Dummy, 1 if head of household has primary school education; base is no education.
IEDUC_2	0.484	Dummy, 1 if head of household has secondary school education; base is no education.
IEDUC_3	0.747	Dummy, 1 if head of household has post secondary school education; base is no education.
IEDUC_4	0.348	Dummy, 1 if head of household has technical college education; base is no education.
IEDUC_6	0.785	Dummy, 1 if head of household has university education; base is no education.
DIST1COL	0.004	Average total distance of segments of road type 1 on least travel-time route to 2 nearest formal collection centers (kms)
DIST2COL	-0.019	Average total distance of segments of road type 2 on least travel-time route to 2 nearest formal collection centers (kms)

Notes: Probit model estimated with maximum likelihood. Only significant variables at 10% are reported.

Table 2: Stage 2 results of sample selection model: significant effects on farm price of milk.

Dependent variable: PCE_OBS, observed price of a liter of milk (Ksh), N= 712, K=37, censored observation = 259

Variable Name	Coefficient	Variable Description
Constant	17.521	
GENDER	1.362	Dummy, 1 if head of household is female.
AGE	0.032	Age of head of household.
YRSEXP	-0.039	Years farming experience of head of household.
C_HHT	0.211	Number of people in household.
R1_DIST	-0.105	Total distance of segments of road type 1 on least travel-time route from farm to Nairobi (kms)
R1_DIST2	0.000379	Above variable, squared.
R2_DIST	-0.278	Total distance of segments of road type 2 on least travel-time route from farm to Nairobi (kms)
R2_DIST2	0.005619	Above variable, squared.
R3_DIST	-0.147	Total distance of segments of road type 3 on least travel-time route from farm to Nairobi (kms)
R3_DIST2	0.004232	Above variable, squared.
DFFREQ	-0.175	Number of transaction for each milk buyer type.
IEDUC2	1.286	Dummy, 1 if head of household has secondary school education; base is no education.
IEDUC3	2.308	Dummy, 1 if head of household has post secondary school education; base is no education.
IEDUC4	1.565	Dummy, 1 if head of household has technical college education; base is no education.
IBFRNP_3	2.374	Dummy, 1 if sale was on credit, informal contract; base is cash single sale.
IBFRNM_2	1.677	Dummy, 1 if mode of milk transport to buyer was bicycle; base is on foot.
IBFRNM_4	1.525	Dummy, 1 if mode of transport is vehicle
IDFBUY_3	2.069	Dummy, 1 if buyer is private dairy processor; base is individual consumer.

Notes: Sample selection model estimated with maximum likelihood. Standard errors adjusted for clustering on household number. Only significant variables at 10% are reported.

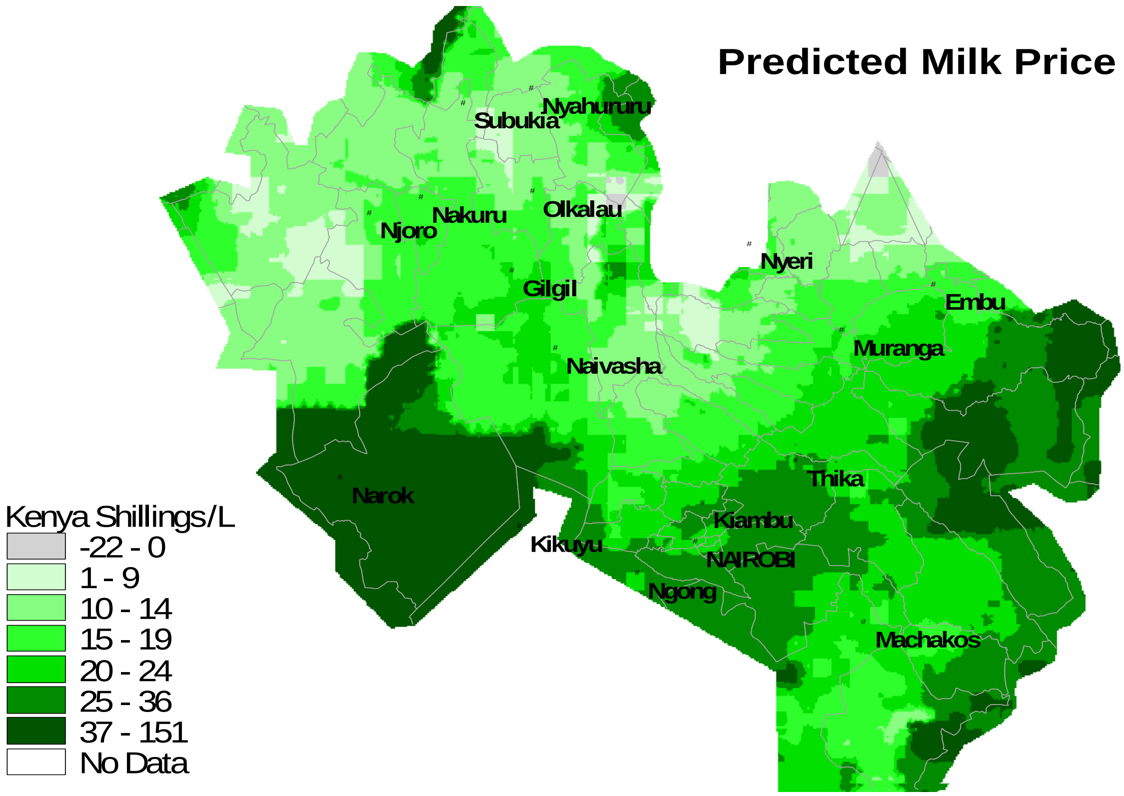

Figure 1: Predicted farm milk price in area of survey, based on parameters estimated in price formation model.