Liquid Milk: Cash Constraints and Intertemporal Choice among Dairy Farmers in Kenya

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Abstract

This paper tests whether cash constraints affect preferences over the timing of income, using high-frequency panel data of intertemporal choice among Kenyan dairy farmers. When selling milk, these farmers choose between a cooperative, which defers payments by approximately one month, and the market, which pays upon delivery. As such, intra-household variation in the choice where to sell milk will reflect variation in the marginal rate of substitution and cash needs should hence induce farmers to sell relatively more milk in the market. Semi-parametric panel data estimates yield robust evidence of this theory. Although the market pays on average less than the cooperative, a substantial number of farmers sell in the market, especially in weeks with less cash at hand, and in weeks with increased cash needs due to uninsured health shocks. Financial instruments that can help relax cash constraints may encourage farmers in need of cash to keep selling to the cooperative, which potentially improves farmers' loyalty to welfare-enhancing collective marketing arrangements.

JEL codes: C23; D91; O16; Q13.

Keywords: Liquidity constraints; Side-selling; Panel data; Semi-parametric estimation.

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1 Introduction

In South Asia and sub-Saharan Africa, where the majority of farmers have small land holdings, low productivity in traditional agriculture is a major barrier to rural income growth. Although high-value agricultural commodities such as fruits, vegetables, meat and milk provide an opportunity to increase income for smallholder farmers, their ability to market these commodities is challenged by high transaction costs, limited information regarding production methods and market opportunities, a lack of credit and financial capital, low bargaining power and price volatility (Gulati et al., 2007). Collective marketing, for instance through cooperatives, can help relax some of these constraints with significant welfare gains for smallholder farmers (Reardon et al., 2009; Minot and Sawyer, 2014). Cooperatives can leverage economies of scale to reduce transaction costs, improve bargaining power vis-à-vis larger processing companies, and provide access to high-quality inputs as well as financial service.

To leverage economies of scale, cooperatives rely on their members to deliver reliable volumes of output. Many cooperatives therefore have bylaws or other informal agreements in place that require farmers to deliver their output to the cooperative. However, these agreements are typically non-enforceable. As a result, farmers often sell their output in the market instead of delivering it to the cooperative, harming the performance of cooperatives. Literature on contract farming attributes such side-selling to differences between cooperative and market prices (Minot and Sawyer, 2014). When cooperative prices drop below market prices, for instance because of high local demand for the outputs, farmers are commonly assumed to deviate from the cooperative agreement and sell their output outside the cooperative.

This paper provides and tests an alternative explanation, namely that farmers' decisions where to market their agricultural output is influenced by access to financial services, including access to savings accounts, insurance and credit. Unlike traders and other buyers in the spot market, cooperatives typically defer payments, which helps savings-constrained farmers accumulate savings; and farmers in fact do sell to cooperatives even when cooperative prices are lower than prices offered in the market (Casaburi and Macchiavello, 2015). Further, in the absence of formal insurance, smallholder farmers are exposed to uninsured risk, and they borrow at high interest rates to cope with unexpected cash needs (Collins et al., 2009). This is consistent with the theory that they face not only savings constraints, but also credit constraints. We argue that in the absence of sound financial instruments to cope with shocks, farmers may sell their output in the market when they are in financial need, even at lower prices than those offered by the cooperative.

We test this hypothesis using Health and Financial Diaries data, that is, high-frequency high-detail panel data on household members' health and financial transactions, including milk production and consumption. We measure the degree to which a household needs cash by net cash flows from non-dairy activities and by milk production in the last month, which is an exogenous proxy for cash at hand from selling milk in the past. The analyses relate these variables to the quantity of milk sold in the market, the share of milk sold to the cooperative, estimated milk prices, and the share of dairy income received from the cooperative, i.e. the share of dairy income with deferred payments.

Controlling for various covariates as well as household and month-village fixed effects, both semi-parametric and parametric regressions indicate that households receive a higher share of their dairy income from the cooperative in weeks that follow periods of higher levels of milk production and net income. In other words, a household appears to sell more milk to the cooperative and less to other buyers in weeks with more cash at hand. This effect is strongest after weeks of low milk production. As alternative measure of cash at hand, we analyze the effect of health shocks. Side-selling increases in the aftermath of a health shock. Consistent with our cash constraint hypothesis, we do not observe this effect when medical bills are covered by health insurance.

These findings suggest that households use side-selling as a coping strategy when they are in need of cash. In order to assess whether households forgo income by using this coping strategy, we test whether cash at hand has an effect on estimated prices at which farmers sell their milk in the market, and the price at which they sell milk on average, taking into account also the price received from the cooperative. Surprisingly, a reduction in non-dairy income is associated with the farmer receiving a significantly higher market price, even when we control for the median price at which others in the same village sell milk. Knowingly or unknowingly, the market provides farmers with more cash in weeks that they need it most, acting as an informal insurance mechanism.

This paper contributes to the existing literature in three ways. First, we model collective marketing decisions in the presence of both savings and credit constraints. Our model predicts that when cash at hand is high, savings-constrained farmers prefer selling to the cooperative to defer payments in order to save for future expenditures and smooth consumption. However, when cash at hand is low, limited access to credit induces them to sell in the market, in order to obtain immediate cash. Independently, Casaburi and Macchiavello (2015) derive the first result. Nevertheless, their model does not analyze the effects of cash at hand, and hence does not explain why the same farmer will either save with the cooperative, or sell in the market, depending on how cash-constrained the farmer is at a given point in time. We thereby extend theory how to interpret experimental measures of time preferences in a context of imperfect financial markets (Dean and Sautmann, 2016; Epper, 2015), showing the potential importance of corner solutions, threshold effects and nonlinearities.

Second, we contribute empirically by testing our theoretical predictions using high-detail high-frequency panel data. We thereby analyze real-life choices and demand for liquidity outside the stylized context of a laboratory. Casaburi and Macchiavello (2015) and Kramer and Kunst (2016) elicit demand for cash milk payments from cooperatives in the context of an experiment. This provides higher control over observed choices, but also comes with the disadvantage that not all farmers will be cash-constrained at the time of the experiment, and that the decision to sell to the experimenter - or the cooperative collaborating with the experimenter - is not the same as side-selling to receive cash in the market. By using yearlong panel data, we are able to observe households' behavior in weeks with more versus less cash at hand, and test whether differences in cash at hand are related to subsequent milk marketing decisions. The finding that cash constraints matter in the decision where to sell milk - and hence when to be paid - is consistent with recent field experiments showing that individuals with less wealth reveal less patient preferences (Dean and Sautmann, 2016; Janssens et al., 2016), but we show this for predictable, earned, income allocations as opposed to unexpected surprise windfall gifts.

A third contribution is that we test these predictions using semi-parametric techniques that have to our best knowledge not been applied previously on microeconomic panel data. Semi-parametric models include a non-parametric part with key explanatory variables as well as a parametric part with controls. Because such models do not presume any functional form for key explanatory variables, no potential misspecification biases the results. This is important given our theoretical prediction that net income affects the decision where to sell milk differently depending on a household's level of milk production and vice versa. In the semi-parametric setting, both variables enter nonparametrically, which allows for a specification-free, point-wise, data-driven estimation of the individual and joint effects of these two variables. In addition, controlling for fixed effects in the parametric part minimizes an omitted variable bias. Compared to fully non-parametric regressions, this approach increases estimation precision and mitigates the "curse of dimensionality". We find that the semi-parametric estimates often provide a more nuanced picture than a fully parametric model with a linear interaction term for lagged milk production and lagged net income, illustrating the use of semi-parametric models when two variables have potential interaction effects.

The remainder of this paper is structured as follows. The next section presents a conceptual framework that we will use to derive our main hypotheses. Section 3 describes the data and semi-parametric estimation method that we will use to test these hypotheses. Section 4 presents semi-parametric results and compares our results with a fully parametric linear estimator, followed by a number of robustness checks to further interpret the results. The final section provides a number of concluding remarks.

2 Conceptual framework

This section models the choice where to sell milk in the presence of both savings and credit constraints. We model a setting in which farmers decide how much milk to deliver to the cooperative, which defers payment, and how much milk to sell in the market, where milk is paid immediately. We predict that when cash at hand is high, savings-constrained farmers prefer selling to the cooperative to defer payments as a savings device. However, when cash at hand is low, limited access to credit induces them to sell in the market, in order to obtain immediate cash.

Consider the following infinite-horizon framework with periods $t \in \{0, ..., \infty\}$. Every period, the farmer decides how much milk to sell in the local spot market, s_t, and how much to deliver to the cooperative, $m_t - s_t$, where m_t represents period-t milk production.[1] The local spot market provides dairy income immediately, in

[1] Note that by writing the quantity of milk delivered to the cooperative as $m_t - s_t$, we abstract from home consumption of milk and milk spillage.

period t, while the cooperative does not pay until period $t+1$. Hence, period-t cash at hand is predetermined by non-dairy cash income, y_t, as well as cooperative payments for milk delivered in the past, which depend on past milk production, m_{t-1}. We will analyze the effect of these two predetermined variables.

In period t, farmers face the following budget constraint:

$$c_t = y_t + p_t s_t + m_{t-1} - s_{t-1},$$

where c_t represents food consumption or expenditures in period t, y_t non-dairy cash income net of non-food expenditures, s_t is the quantity of milk sold in the market at a (relative) price of p_t, the cooperative milk price is normalized to one, and $m_{t-1} - s_{t-1}$ is the quantity of milk delivered to the cooperative in the previous period, $t-1$, which is received as income in period t.

We assume that non-dairy net income is predetermined. As a result, households can only smooth food consumption, c_t, by changing the quantity of milk sold to the cooperative versus other buyers. Treating food consumption instead of non-food expenditures as an endogenous variable is motivated by two factors. First, food consumption can vary substantially among cash-constrained households, since these households have precautionary savings motives to smooth assets instead of consumption (Zimmerman and Carter, 2003). Second, although empirically, cash-constrained households may be able to increase their labor supply or forgo non-food expenditures, the conceptual framework abstracts from this coping strategy. In the setting of interest, dairy farming and crop farming are the main sources of income, with limited opportunities for casual labor or other income-generating activities that provide cash on an emergency basis. Further, unavoidable spending on health care, school fees, and agricultural inputs such as seeds or animal feed constitute a large share of non-food expenditures. We hence model food consumption as an endogenous choice variable, while net income is included as a predetermined variable.

Another assumption implicit in the budget constraint is that the farmer has no access to savings devices outside the cooperative milk payments, and that borrowing is not possible. In other words, the farmer cannot save or borrow to smooth consumption; she can only smooth consumption by varying where she sells her milk. We impose this assumption for ease of representation but it also reflects the notion that smallholder farmers have poor access to formal savings and credit instruments. Further, although households can receive transfers from their social network when in financial need, Ide et al. (2016) show that our target population is unable to fully smooth consumption in the presence of health shocks, suggesting that informal insurance mechanisms are incomplete.

Given this budget constraint, farmers face the following decision-making problem:

$$\max_{0 \le s_t \le m_t} \sum_{t=0}^{\infty} \beta^t u\left(y_t + p_t s_t + m_{t-1} - s_{t-1}\right), \tag{1}$$

where $u(\cdot)$ is a standard increasing, concave, and twice differentiable utility function, and β is an exponential discount factor. Note that households utilize the quantity of milk delivered to the cooperative, $m_{t-1} - s_{t-1}$,

Table 1: Theoretical predictions on how cash at hand affects buyer choice.

Case 1: $\bar{s}=0$ ($\bar{p}<\beta$)
a). Increase in current non-dairy income and/or past milk production
$y_t > \bar{y}, \quad m_{t-1} > \bar{m} \quad \Longrightarrow \quad s_t = 0$
b). Decrease in current non-dairy income and/or past milk production
$y_t < \bar{y}, \quad m_{t-1} < \bar{m} \quad \Longrightarrow \quad s_t > 0$
Case 2: $\bar{s}=\bar{m}$ ($\bar{p}>\beta$)
a). Increase in current non-dairy income and/or past milk production
$y_t > \bar{y}, \quad m_{t-1} > \bar{m} \quad \Longrightarrow \quad s_t < \bar{m}$
b). Decrease in current non-dairy income and/or past milk production
$y_t < \bar{y}, \quad m_{t-1} < \bar{m} \quad \Longrightarrow \quad s_t = \bar{m}$
Case 3: $\bar{s}\in(0,\bar{m})$ ($\bar{p}=\beta$)
a). Increase in current non-dairy income and/or past milk production
$y_t > \bar{y}, \quad m_{t-1} > \bar{m} \quad \Longrightarrow \quad s_t < \bar{s}$
b). Decrease in current non-dairy income and/or past milk production
$y_t < \bar{y}, \quad m_{t-1} < \bar{m} \quad \Longrightarrow \quad s_t > \bar{s}$

Notes: $\bar{x}$ stands for the equilibrium level of variable x.

as their only saving device. The theoretical predictions will focus on the effect of the two main components that drive a household's cash at hand - changes in current non-dairy net income, y_t, and predetermined milk production, m_{t-1} - on the quantity of milk sold in the market, s_t.

Table 1 summarizes the theoretical predictions for three equilibrium cases that exist under conditions specified in Lemma 1 (see Appendix A for a proof):

Lemma 1. *Consider the utility maximization problem given in* (1)*. An equilibrium exists in which: (1) if $\bar{p}<\beta$, the farmer sells all milk to the cooperative, i.e., $\bar{s}=0$; (2) if $\bar{p}>\beta$, the farmer sells all milk in the local spot market, i.e., $\bar{s}=\bar{m}$; (3) if $\bar{p}=\beta$, the farmer is indifferent where to sell, i.e., $\bar{s}\in(0,\bar{m})$.*

In the first case, the market price is below the discounted cooperative price. As a result, farmers sell all milk to the cooperative in equilibrium. In the second equilibrium case, the market offers a lower price than the cooperative does, but because it pays farmers sooner, at a price that is above the discounted cooperative price, farmers prefer to sell all milk in the market. In the third case, the market price equals the discounted price that the cooperative pays. As a result, farmers are indifferent in equilibrium as to whether they sell the milk in the market or to the cooperative.

Appendix A derives the response to changes in current income, y_t, and past milk production, m_{t-1}, for each of these three cases. In the first case, the cooperative offers a relatively high price, even when taking into account farmers' discount rates. As a result, farmers prefer selling all milk to the cooperative instead of selling it in the market. The quantity of milk sold in the market hence does not change with an increase in (y_t, m_{t-1}); both result in an increase in cash at hand, reducing farmers' demand for sooner payments which they could obtain from the market. By contrast, a decrease in (y_t, m_{t-1}) *can* induce farmers to sell in the market, because the farmer has less cash at hand than expected, and needs more cash in order to smooth consumption. Appendix A shows that reductions in current income and past milk production have this effect under the following condition:

Lemma 2. *Consider the utility maximization problem given in* (1) *in the equilibrium when $\bar{p} < \beta$ such that $\bar{s} = 0$. Then, (1) if there is an increase in current income, $y_t > \bar{y}$, and/or past milk production, $m_{t-1} > \bar{m}$, $s_t = 0$; (2) if there is a decrease in y_t and/or m_{t-1}, such that $u'(y_t + m_{t-1})/u'(\bar{y} + \bar{m}) > \beta/\bar{p}$, then $s_t > 0$. Further, if the response s_t satisfies $u'(\bar{y} + \bar{m} - s_t)/u'(\bar{y} + \bar{m}) > \beta/\bar{p}$, then also $s_{t+1} > 0$.*

Intuitively, if cash at hand, $y_t + m_{t-1}$, is sufficiently low relative to the equilibrium level, $\bar{y} + \bar{m}$, so that the marginal rate of substitution between the current and next period exceeds the threshold $\beta/\bar{p}$, then farmers will sell milk in the market. This threshold is increasing in the market price, meaning that as this price is further below the cooperative price, cash at hand needs to drop by a more substantial amount in order to induce farmers to sell in the market. The effect of a drop in y_t or m_{t-1} can perpetuate into the future, since in the next period, milk payments from the cooperative - and hence cash at hand - will again be below the equilibrium level. As a result, farmers will be induced to sell a strictly positive, but decreasing, quantity of milk in the market for a prolonged period of time, limiting the quantity of milk sold to the cooperative.

We find a similar result, although in the opposite direction, in Case 2. When farmers sell all milk in the market, a sufficient increase in (y_t, m_{t-1}) - and hence an increase in cash at hand - reduces demand for immediate cash, making it optimal to sell some milk to the cooperative. Appendix A shows that this occurs under the following condition:

Lemma 3. *Consider the utility maximization problem given in* (1) *in the equilibrium when $\bar{p} > \beta$ such that $\bar{s} = \bar{m}$. Then, (1) if there is a decrease in current income, $y_t < \bar{y}$, and/or past milk production, $m_{t-1} < \bar{m}$, $s_t = \bar{m}$; (2) if there is an increase in y_t and/or m_{t-1}, such that $u'(y_t + \bar{p}\bar{m} + m_{t-1} - s_{t-1})/u'(\bar{y} + \bar{p}\bar{m}) < \beta/\bar{p}$, then $s_t < \bar{m}$. Further, if the response s_t satisfies $u'(\bar{y} + \bar{p}\bar{m} + \bar{m} - s_t)/u'(\bar{y} + \bar{m}) < \beta/\bar{p}$, then also $s_{t+1} < \bar{m}$.*

In this case, the cooperative pays a higher price than the market, but the higher price cannot compensate the farmer sufficiently for the strong discounting of deferred payments. Hence, in equilibrium, the farmer prefers selling in the market. Nonetheless, an increase in current income or milk production increases the amount of cash at hand compared to future periods. Instead of spending all cash on consumption in the current period, farmers will prefer to save and smooth consumption over time by selling some milk to the cooperative. This is why not only current income, but also an increase in lagged milk production, results in higher cash at hand in the current period, and as in the previous case, shocks to income or milk production can hence have a prolonged effect.

In the third and final case, farmers are indifferent as to where to sell the milk. Now, the quantity sold in the market (s_t) will respond inversely with the change in (y_t, m_{t-1}): an increase in current income or milk production increases the amount of cash at hand and hence lowers the demand for sooner payments, resulting in increased quantities of milk sold to the cooperative, while a decrease in income or milk production lowers the amount of cash at hand, resulting in a higher demand for sooner payments. This also affects the amount of cash at hand in future periods, resulting in perpetuating effects, but of a smaller magnitude.

Lemma 4. *Consider the utility maximization problem given in* (1) *in the equilibrium when* $\bar{p} = \beta$ *such that* $\bar{s} \in (0, \bar{m})$. *Then, (1) if there is a decrease in current income,* $y_t < \bar{y}$*, and/or past milk production,* $m_{t-1} < \bar{m}$*, then* $\bar{s} < s_t < s_{t+1} < \cdots$*, but* $\{s_t\}$ *does not necessarily converge to* $\bar{m}$ *depending on the property of underlying utility function; (2) if there is an increase in* y_t *and/or* m_{t-1}*, then* $\bar{s} > s_t > s_{t+1} > \cdots$*, and* $\{s_t\}$ *does not necessarily converge to 0.*

The above analysis also indicates that in theory, our outcome variables are related to lagged milk production and current income in a nonlinear way. As long as the relative milk price in the market does not equal the discount factor, changes in net income or lagged milk production have to pass a certain threshold in order to affect the quantity of milk sold in the market.[2] This suggests that s_t is likely to be a piece-wise function of the two indicators for cash at hand. In addition, Appendix A shows that this relation is piece-wise linear only when we impose a quadratic, non-concave utility function, which is an unlikely empirical scenario.

Although we focus on the case where markets offer lower prices than the cooperative, $\bar{p} < 1$, this argument generalizes to a situation in which the cooperative pays a lower price than the market, $\bar{p} > 1$. The quantity of milk sold in the market will generally respond in a similar way, and the conditions derived in Appendix A will not change.

Note that we model past milk production, m_{it-1} (determining the cash payment from the cooperative for milk delivered in the previous period), and net income from non-dairy activities, y_{it}, as perfect substitutes. Empirically, these variables are however not necessarily perfectly fungible for several reasons. First, households may engage in mental accounting in order to plan their financial lives. This could result in a different treatment of dairy versus non-dairy income. Second, different household members may control income from non-dairy activities versus (different types of) dairy income. Men typically control payments from the cooperative and non-dairy activities, while women's main source of income is the milk that they can sell in the market.[3]

[2]Appendix A gives thresholds for each case.

[3]Also from a more practical perspective, past milk production measures cash inflows from dairy farming as accurately as we measure cash inflows from non-dairy activities only when we would focus on the quantity sold to the dairy cooperative. However, while past milk production is an exogenous variable, the quantity sold to the cooperative is a lagged endogenous variable, and introducing this variable would bias the coefficients. In addition, the cooperative pays dairy farmers only once per month and we do not measure the exact timing of the milk payment.

3 Methods

3.1 Context and Data

We test our theoretical predictions empirically using high-detail high-frequency panel data collected year-long for a sample of 120 dairy farmers and their families. All farmers were members of a dairy cooperative in Nandi County. This county near Eldoret in western Kenya has a population of 752,965 individuals and agriculture is the main economic activity. Dairy farming is an important income source for a large proportion of the population. Other than this, Nandi County is an ideal area for tea, maize and sugarcane farming. The poverty rate in the county is 47.4%, which is about equal to the country's average. The share of the population living in urban areas is 13.6% and approximately 67.3% of the population has completed primary education.

The dairy cooperative, named Tanykina, collects milk through several milk transporters and collection centers.[4] At the start of the month, Tanykina agrees with larger milk processing companies on a price for milk collected from Tanykina that month, and the processor picks up all milk from Tanykina collection centers on a daily basis. However, to reduce transaction costs, they pay Tanykina only once per month, after assessing the actual quantity of milk collected in a given month. Once the processor has determined how much Tanykina will receive, the cooperative can start preparing farmers' milk payments. Due to this process, Tanykina defers milk payments until the next month.

In preparing farmers' milk payments, Tanykina takes into account the total quantity of milk a farmer delivered in a given month as well as any deductions for the costs of shares and any services utilized from Tanykina. Other than collectively marketing milk, Tanykina operates a store with agricultural inputs such as animal feed and fertilizers, as well as veterinary services. Farmers can pay for these inputs through their milk account. Further, through its Savings and Credit Cooperative Organization (SACCO), Tanykina provides financial services including agricultural loans and savings accounts. In practice, these services are underutilized. For a similar sample of dairy farmers, Jack et al. (2016) find a very low 2.4 percent take-up of SACCO loans with comparable stringent borrower requirements. Further, these loans are mainly used for agricultural investments, not to cope with financial shocks such as health expenditures, or non-agricultural expenditures. Savings are mainly used to meet deposit requirements for accessing loans. Our conceptual framework hence abstracts from these savings and credit provisions.

Finally, at the time of the study, Tanykina members could enroll in a health insurance plan named The Community Health Plan (TCHP). At the time of the study, the TCHP was offered by the AAR Insurance, a Kenyan insurance provider, with support from the PharmAccess Foundation and Health Insurance Fund.[5]

[4] Formally, Tanykina is not a cooperative but a private company with limited by shares. Because its shares are owned by farmers, and because otherwise the company acts as a cooperative, we will henceforth refer to Tanykina or the cooperative to indicate Tanykina Dairies, Ltd.

[5] Initially the program targeted Tanykina members and their families but the program has transitioned into a program that is accessible for the general public.

For members deciding to enroll their family into the TCHP, the premium was deducted automatically from the monthly milk payment. In case of insufficient funds, the farmer could pay the premium in cash or through mobile money. Households who did not pay the monthly premium were suspended the next month and could not benefit from the insurance policy. To reinstate coverage, the household could pay a double premium in the next month; otherwise, the household was dropped from the TCHP for the rest of the year. Ide et al. (2016) describe the TCHP in more detail and show that the program provides financial protection from health shocks and results in improved food security, in particular among households with weaker social networks.

The study selected three dairy collection areas to implement data collection: Salien, Surungai and Lemook. From each of these collection areas, the study randomly selected seven villages with a minimum of 25 Tanykina member households: three from Salien, two from Surungai and two from Lemook. The study randomly selected 120 Tanykina member households from these seven villages. The number of selected Tanykina members within a village is proportional to the total number of Tanykina members in that village. Further, the sample is stratified by insurance status, with half of the households having insurance at baseline. The proportion of insured versus uninsured households sampled within a village is proportional to the total number of insured households in a village.

The data were collected between October 2012 and October 2013 as part of the Health and Financial Diaries project (Janssens et al., 2013). The goal of this yearlong study was to gain understanding of health-seeking behavior and financial lives in the TCHP target population. For the 120 selected households, enumerators interviewed all 207 financially active household members, both males and females, separately and in private. They did so every week for the duration of a year. Respondents were interviewed about all financial transactions since the last interview. This included their savings, gifts, loans, income and expenditures. For each transaction, the diaries collected information on the transaction item ('what'), the date ('when'), the transaction partner ('who'), the transaction mode ('how'; e.g. whether a payment was in cash, via mobile money or on credit), and the transaction value ('how much'). We use these records to identify the weekly value of milk sold to the cooperative versus other buyers in the market.[6] In addition, the diaries collected information about family members' health, milk production and milk consumption. Because these data are recorded at the household level, we treat households instead of individuals as the unit of observation. We will therefore aggregate individuals' financial transactions at the household level as well.

Despite the high intensity of data collection, attrition was low; only two households dropped out during the study. The goal was to interview the remaining households every week throughout the year. This was feasible in the vast majority of weeks, with the exception of the two weeks around Christmas, the week of the elections, when no data collection occurred for security reasons, and the final month of data collection. We exclude these weeks from the analyses. We also exclude household i in week t if no household member was

[6] The questionnaires recorded the value of every transaction but not the number of items or the price per item. As a result, we do not have primary data on milk prices and the quantity of milk sold at the household level.

available for an interview in week t. This was the case for 7.3 percent of all potential household interview-weeks. If not all but at least one household member completed an interview in week t, and if this person reported selling milk, we do include this observation. However, the individual financial transactions for absent household members are missing in those weeks. To avoid omitting these weeks, we impute income and expenditures for an absent respondent by his or her yearly average.

The analyses will also use a baseline survey, which was completed with all respondents prior to the start of the Health and Financial Diaries, and a separate data set containing information on monthly enrollment, renewal and suspension of the individuals in our sample into the TCHP program. We consider a household to have insurance coverage if and only if at least one family member has (non-suspended) insurance coverage.

3.2 Econometric strategy: Semi-parametric model and estimation

Our conceptual framework suggests that the relation between cash at hand and the choice when to be paid is nonlinear with threshold effects. We therefore estimate a semi-parametric model, including both a non-parametric part for cash at hand and a parametric (linear) part for other variables and household fixed effects. The advantage of this semi-parametric model is that the non-parametric part allows for a specification-free, point-wise, data-driven estimator for the effect of cash at hand, while the linear part avoids a curse of dimensionality when controlling for potential confounds. As such, a semi-parametric model can yield a better description of how the variables included in the non-parametric part affect the quantity of milk sold in the market. This also increases the precision of the estimated coefficients for variables included in the linear part.

We thereby focus on a semi-parametric model that can include two variables as opposed to only one variable in the non-parametric part. The main variables determining cash at hand - past milk production and non-dairy income - may not be perfect substitutes. As such, they cannot be aggregated and are not perfectly fungible. The model allows for nonlinearities and threshold effects separately for these two variables. In a fully linear model with an interaction term, the individual effects of the two predetermined variables are presumed to be linear in the other variable and are sensitive to the level at which the other variable is centered, while the semi-parametric estimates are not subject to this constraint.

We consider the following partially linear model with fixed effects, which was originally proposed by Su and Ullah (2006):

$$S_{it} = \alpha_i + m(m_{it-1}, y_{it}) + x_{it}'\beta + v_{it}, \quad i = 1, \cdots, n, \quad t = 1, \cdots, T, \tag{2}$$

where S_{it} is an indicator of the milk selling decision of household i in week t; α_i is a household-specific effect, controlling for unobserved heterogeneity in household characteristics; $m(\cdot)$ is an unknown smooth function of past milk production (m_{it-1}) and net non-dairy income (y_{it}); x_{it} is a $p \times 1$-vector of controls, including the median milk price in the village and its lag (to control for changes in p_t), household consumption (c_t), health shocks, insurance coverage and their interaction (as alternative source of variation in cash needs), and month-center fixed effects (to control for unobserved spatial variation over time); and v_{it} represents unobserved time-varying heterogeneity in the decision where to sell milk, which we assume is i.i.d. Since $m(\cdot)$ is an unknown smooth function, past milk production and net non-dairy income - our two main determinants of cash at hand - enter the model nonparametrically.

We analyze the following indicators of milk selling behavior, S_{it}: (1) the quantity of milk sold in the market (*MilkOth*), (2) the share of milk sold to the cooperative (*ShareMilkTan*), (3) the price at which a farmer sells in the market (*PriceOth*), (4) the average price that farmers receive for their milk (*PriceAve*), and (5) the share of dairy income from the cooperative (*ShareTan*). Cooperatives are interested in minimizing the quantity sold in the market and maximizing the share of milk sold to the cooperative, while farmers will be more interested in maximizing the average price at which they sell their milk. Policy-makers aiming at strengthening the formal dairy value chain through cooperatives will want to maximize *ShareTan*, as it takes into account not only the quantity of milk delivered to the cooperative, but also the price offered by the cooperative relative to the market price.

The share of milk sold to the cooperative, *ShareMilkTan*, and the share of dairy income from the cooperative, *ShareTan*, are both decreasing in the quantity of milk sold in the market. Hence, our conceptual framework predicts that both variables are increasing in non-dairy net income, y_{it}, and past milk production, m_{it-1}, with potential threshold effects and nonlinearities. Further, under the condition that the cooperative offers a higher price than buyers in the market, $p_t < 1$, the same will hold for the average price that farmers receive for their milk, *PriceAve*. In our empirical application, the cooperative indeed does offer higher prices than the average buyer in the market. In that case, the choice whether to sell milk to the cooperative or in the market involves a trade-off between later-larger and smaller-sooner rewards, and we predict that they will opt for the smaller-sooner rewards especially when they have less cash at hand.[7]

Nonetheless, the estimated value per liter of milk sold in the market may temporarily increase for farmer i, $p_{it} \geq 1$, when a farmer for instance receives a higher price when selling a larger quantity of milk, asks for a cash gift that she includes in her total dairy income from the vendor, or when she dilutes the milk. For each of these cases, our conceptual framework predicts a negative correlation between the average price at which a farmer sells milk, *PriceAve*, and cash at hand. In that case, selling milk to the cooperative will not optimize total dairy income.

The remainder of this section discusses in more detail how we estimate the model. For identification, assume $\sum_{i=1}^{n} \alpha_i = 0$[8], and $\mathrm{E}(v_{it}|x_i, m_i^{-1}, y_i, \alpha_i) = \mathrm{E}(v_{it}|x_{it}, m_{it-1}, y_{it}) = 0$, where $x_i = (x_{i1}, \cdots, x_{iT})'$. Determi-

[7] Casaburi and Macchiavello (2015) and Kramer and Kunst (2016) do not replicate this result. They measure higher milk prices in the market, and in their study, farmers potentially sell to the cooperative due to a lack of alternative savings instruments. In our case, farmers may prefer to sell part of their milk in the market even if not cash-constrained in order to maintain access to these traders for liquidity in more constrained weeks.

[8] We don't include a constant term in Equation (2) since we would be unable to identify a constant separately from the unknown function $m(\cdot)$, unless we would constrain $m(\cdot)$ to have e.g. a zero mean. Because the sum of the n household fixed effects is zero

nants of cash at hand, m_i^{-1} and y_i are analogously defined. Su and Ullah (2006) propose consistent estimators for β, $m(\cdot)$ and $\dot{m}(\cdot)$, where $\dot{m}(\cdot)$ is the first derivative of $m(\cdot)$, and establish their asymptotic properties with fixed T and n going to infinity. Estimation is based on the profile likelihood method, specifically, profile least squares, which builds on the following idea. If the linear parameters were given, we could rearrange Equation (1) as $y_{it} - \alpha_i - x_{it} = m(m_{it-1}, y_{it})$ and obtain an explicit expression for the estimator of the non-parametric part, with $y_{it} - \alpha_i - x_{it}\beta$ as the new dependent variable. This estimator is however unfeasible since the linear parameters, α_i and β, are unknown. In the original estimating equation, we can nonetheless substitute $m(\cdot)$ for the unfeasible non-parametric estimator. We can then rearrange again such that we obtain parametric estimators using traditional ordinary least squares. The feasible non-parametric estimator, given the parametric estimator, then follows immediately.

The appendix describes this estimation process more formally, and provides a brief introduction to the local linear estimation procedure and asymptotic properties of $\hat{\beta}$ and $\hat{m}(\cdot)$, based on which we construct the confidence intervals. We also give details regarding to the implementation of the non-parametric estimation including bandwidth selection procedure. Consistent estimators of the covariance matrices are given. We refer readers to Su and Ullah (2006) for detailed proofs.

3.3 Sample description and variable definitions

Table 2 presents an overview of household characteristics at the start of the financial diaries, omitting the two households that dropped out of the study. Because our model includes household fixed effects, identification relies on variation in our outcome variable within households over time. The analyses are hence restricted to the 88 households with variation in the proportion of dairy income received from Tanykina. Columns (1)-(2) describe these households; Columns (3)-(4) describe the 30 households who sell their milk only to the cooperative, or only in the market; and Columns (5)-(6) compare the two samples.

Columns (1)-(2) describe our analysis sample with variation in the share of of dairy income received from Tanykina. In 70.5 percent of the households, the main decision-maker is male. The average age of the household head is 52.4 years of age. A very common pattern among Kenyan dairy farmers is that men sell milk produced in the morning to the cooperative, while women sell milk produced in the afternoon in the market. Consistent with this, approximately half of all households have at least two different members who report selling milk at some point during the year. The average household has 4.2 cows, while at most one in three households is keeping bulls. Households have around 4.5 calves, of which the majority are female as well.

In half of the sample, the main household member selling milk is not the (male) household head but his wife. She is on average five years younger than the household head. Around half of all dairy farmers

(and can hence not capture any of the sample mean), the non-parametric part $m(\cdot)$ and the other linear part will capture the sample mean.

completed at most primary education and never went to secondary school. The sample is mostly protestant. At baseline, 95.3 percent of main dairy farmers reports being engaged in livestock activities, but not all of them report dairy farming at that time. If engaged in dairy farming, 86.1 percent keeps some of the dairy income, and nearly all can decide how to spend that money. Expected dairy income is 1,821 Sh (approximately US$ 18.21) in the next month, or 29.5 percent of total expected income for the main dairy farmer. Over the year, expected dairy income is Sh 26,770 (approximately US$ 267.70), or 16.9 percent of total expected income.

Columns (3)-(4) describe households without variation in the share of income from Tanykina and Columns (5)-(6) compare this sample with the sample of households in the analyses. Households without variation in the share of income from Tanykina either sell always to the cooperative, or always in the market. These households are more likely to have a female household head, fewer household members sell milk, and they have on average one cow less at baseline. The main dairy farmer is significantly more likely to be the household head, and less likely to be married, consistent with the observation that these are often female-headed households. For these households, dairy farming makes up a higher share of household income than for households in the analysis sample.

Figure 1 draws a number of variables related to the subsequent analyses over time. The figures draw for every week the sample mean along with a 95 percent confidence interval for households in the analysis sample, conditional on them selling milk that week. The first two graphs present our two main explanatory variables. For past milk production, m_{it-1}, we use average milk production (in liters per week) in the last month. This variable is a proxy for payments from the cooperative, given that the cooperative pays farmers only once per month for all milk delivered in the previous month. For incoming cash from non-dairy activities, i.e. net income, y_{it}, we take the ratio of gross non-dairy cash income and non-food expenditures (both in 1,000 Kenyan Shillings) in the current week, $NetInc$.[9] Non-food expenditures are largely related to agriculture and business, making our net income measure a proxy for net non-dairy income. Food expenditures are treated endogenously. For both measures of cash at hand, we apply a log transformation to reduce the impact of outliers on our estimates.

Notice that milk production increases from the start of the diaries in October until seven weeks later, which is early December. It then reduces gradually over time, until Week 22 in March; when it starts increasing again until Week 44 in August. As such, milk production closely follows rain patterns in the region: milk production reduces after periods of drought, given that in those periods, there is less feed available. The log ratio of non-dairy cash income and non-food expenses does not correlate as much over time. It is particularly low in the weeks around Christmas (Weeks 11 and 14), and in the second week of May (Week 31), after which it starts to increase.

The next two graphs present the quantity of milk sold in the market, and the share of milk sold to Tanykina. We do not observe these variables directly, but estimate these variables from the quantity of milk

[9]The value of 1,000 Kenyan Shillings was approximately US$ 11.50 at the time of data collection.

sold (measured as milk production minus consumption) and earnings for milk sold to the cooperative. To do so, we first estimate the quantity of milk sold to the cooperative by dividing earnings from the cooperative by its fixed monthly milk price. We then *subtract* this quantity *from* the total quantity of milk sold to estimate the quantity of milk sold in the market, and we *divide* it *by* the total quantity of milk sold to estimate the share of milk sold to the cooperative. The quantity of milk sold in the market increases over time, while the share of milk sold to the cooperative moves in the opposite direction.

The last two graphs analyze the log average price that farmers receive when selling milk (including milk sold to both Tanykina and buyers in the market), and the share of dairy income received from Tanykina (as opposed to buyers in the market). The total value of milk sold to the cooperative versus other buyers were reported directly. We estimate the average price at which farmers sell their milk by dividing the total value of milk sold by the estimated quantity of milk sold. This variable exhibits a positive tredn, while the average share of dairy income received from Tanykina decreases from 60 to 40 percent. We do, however, observe large variation between households in all variables.

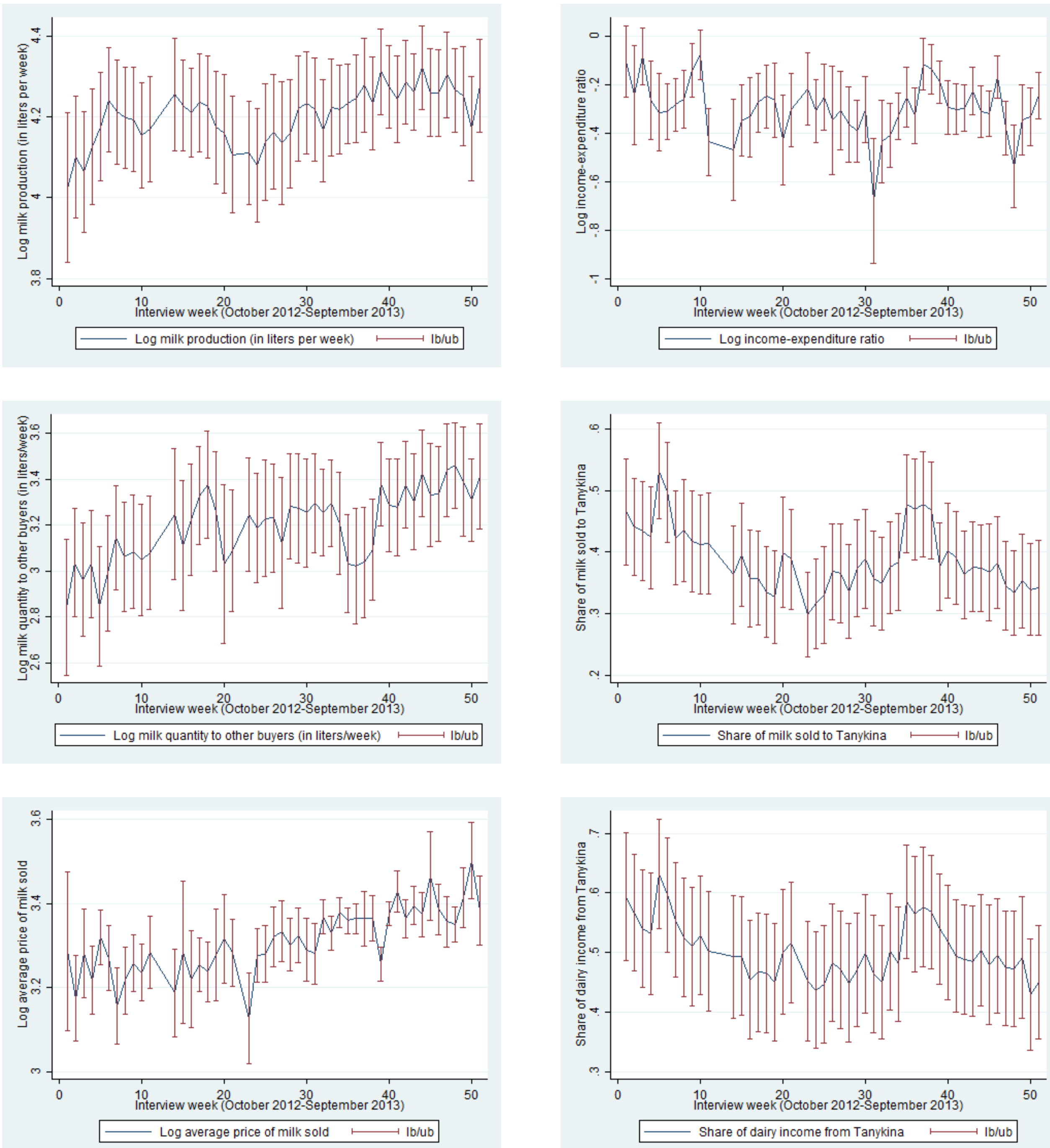
Table 3 summarizes statistics aggregated over the year for these and other variables used in the analyses. Columns (1)-(3) and (4)-(5) distinguish between households with and without variation over time in the proportion of dairy income received from Tanykina, respectively. Columns (6)-(7) present the difference in means between these two samples and the p-value from a t-test for differences in means, with standard errors clustered at the household level.

Average non-dairy household income in cash is on average around 2,000 Sh (US$ 20) per week. Non-food expenditures are on average 2,500 Sh (USD 25), and weekly food expenditures amount to approximately one-fifth of this. The analyses also control for current milk production and last week's milk production. The average household produces 72 liters of milk per week, and around one third of this milk is consumed by the household. The remainder is sold. We observe dairy sales in 85 percent of all weeks. The analyses will further control for the median price for milk sold outside Tanykina for farmers in the same village (*PriceMed*) and its one-week lag (*L1PriceMed*), as well as community-month effects.

As an alternative measure of cash needs, we will also estimate how health problems affect milk selling decisions for households without and with health insurance coverage. In around one quarter of all weeks, at least one household member faces a health problem, and in about one third of all weeks, households have health insurance coverage. Given that at baseline, around half of the sample was covered by health insurance, this means that a substantial number of households drops out of the scheme during the study year. In the face of health problems within the household, those without health insurance will need cash in order to pay their medical bills. Our hypothesis is hence that health problems - especially those without health insurance coverage - increase the quantity of milk sold in the market. We will analyze the effect of health problems in the current or past week, given that households may not immediately seek health care, and that even if they seek health care in the same week, they may need to pay their medical bills in the following week.[10]

[10]We use an indicator for whether at least one member of the household has insurance coverage. Thus, there is a possibility that

Figure 1: Main independent and dependent variables by week



In weeks that households sell milk, total dairy income is around 1,500 Sh, filling the net gap between non-dairy income and total non-food and food expenditures. Even though Tanykina offers a higher milk price on average than the market, only half of total dairy income is received from Tanykina; the remainder is received from other buyers. Only in 6.4 percent of all weeks, farmers sell their milk to other buyers who defer the payment. As a result, the share of dairy income to be received from selling milk on credit versus cash are closely correlated with the share of dairy income from selling milk to Tanykina versus other buyers.

Figure 2: Milk price paid by Tanykina versus average milk price in market.

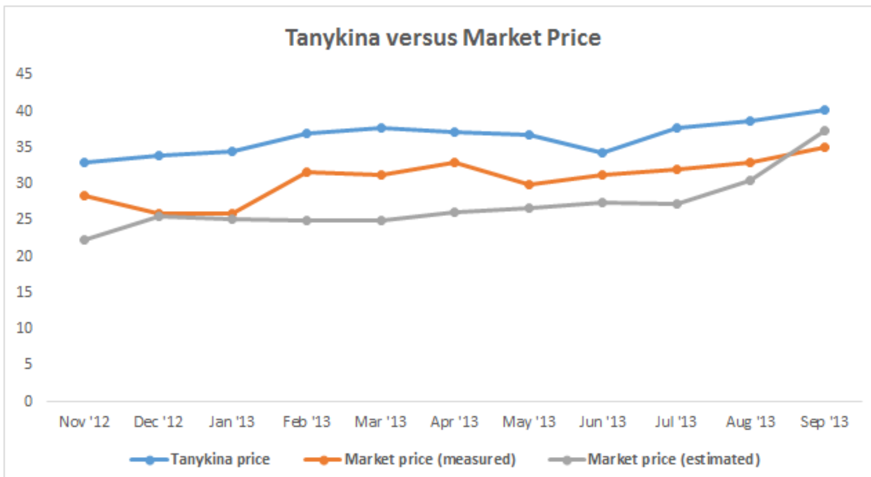
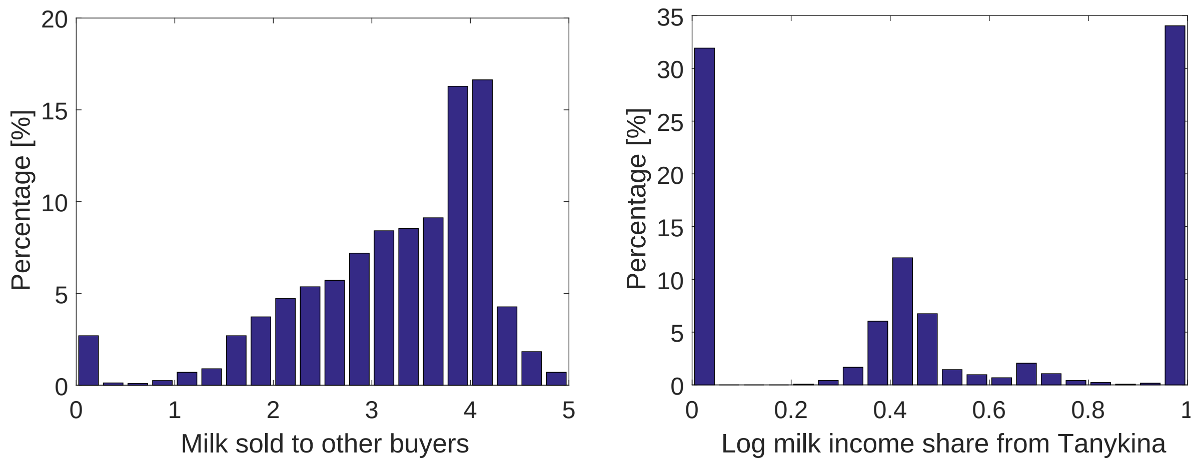


Figure 2 plots by month the milk price offered by Tanykina and the average market milk price. The measured market price was collected through a monthly consumer price survey with three market vendors. The estimated price is inferred from the value of milk sold in the market, divided by the estimated quantity of milk sold in the market. Since farmers receive a lower milk price than the price at which vendors sell their milk, making this likely an upper bound for the actual average market price. The estimated market price is nonetheless close to the measured market price. Further, note that the cooperative milk price is higher than both estimated and measured market price averages throughout the study period.

As a final descriptive, Figure 3 presents the percentage histograms for a number of dependent variables. We present the quantity of milk sold to other buyers (in logs), and the share of dairy income that is received from Tanykina. Households typically sell either no milk to Tanykina, or all milk; alternatively, around half of their dairy income is received from Tanykina. It is very common for households to sell milk produced in the morning to Tanykina, while milk produced in the afternoon is sold in the market.

the sick individual is not insured, even though the household is recorded as insured.

Figure 3: Percentage histograms for dairy marketing decisions



4 Results

4.1 Fully linear model

We first provide a fully linear approximation to Equation (2). Linear models can capture non-linearities and threshold effects in $m(\cdot)$ to some extent by interacting our two measures of cash at hand, past milk production and non-dairy income:

$$S_{it} = \alpha_i + m_{it-1}\gamma_1 + y_{it}\gamma_2 + m_{it-1} \times y_{it}\gamma_3 + x'_{it}\beta + v_{it}, \quad i = 1, \cdots, n, \quad t = 1, \cdots, T. \tag{3}$$

This specification is not based on theoretical economic foundations, but is a good candidate for a fully parametric model of how different sources of cash at hand affect on average farmers' preferences on where to sell their milk. We will later analyze to what extent our semi-parametric estimates overlap with the fully linear estimates presented here.

Table 4 estimates Equation (3), controlling for household fixed effects, current milk production, the median market price in the village and its one-week lag, the incidence of health problems, insurance coverage, an interaction of the two, and center-month effects. Given the inclusion of an interaction term, estimates for γ_1 and γ_2, i.e. the individual effects of past milk production, m_{it-1}, and non-dairy income, y_{it}, respectively, will depend on the level at which these two variables are centered. Panels A, B and C therefore estimate these two coefficient after centering past milk production and non-dairy income at the 25th, 50th and 75th percentile, respectively. Estimates for the interaction term are insensitive to where we center these two variables, and are hence presented only once.

Column (1) estimates the effects of last month's milk production and non-dairy income as a ratio of non-food expenditures on the quantity of milk sold in the market. In all three panels, an increase in past milk production is associated with a large significant reduction in the quantity of milk sold in the market. If past production increases by one percent, the median farmer sells 15% points less milk in the market. The interaction with net income is small and insignificant. Net income itself is associated with a significantly higher estimated quantity of milk sold in the market.

The absolute quantity of milk sold in the market is potentially confounded by the total quantity sold. Column (2) hence tests whether cash at hand also influences the share of milk sold to Tanykina (as opposed to the market). Past milk production now has a positive and statistically significant effect, independent of whether the variables are centered at the 25th, 50th or 75th percentile. For the median farmer, a one-percent increase in milk production is associated with a 10.8% points increase in the share of milk sold to Tanykina (see Panel B). Net income does not influence the share of milk sold to Tanykina. Thus, on average, cash inflows from dairy farming influence the decision where to sell milk, but net income from other activities have no effect on this decision.

Column (3) presents estimates for the log price of milk sold in the market. An increase in past milk production - increasing the share of milk sold to Tanykina, and reducing the quantity sold in the market - is associated with higher prices, potentially due to increased bargaining power. Interestingly, the log income-expense ratio also has a statistically significant coefficient in all three panels, but with a negative sign. For the median farmer, a one-percent increase in the income-expense ratio increases the price for milk in the market by 10.5%. We find qualitatively similar effects on the average price at which farmers sell their milk in Column (4). Thus, an increase in past milk production is associated with higher profit margins, but an increase in non-dairy income is associated with lower profit margins.

Finally, Column (5) analyzes the share of dairy income from Tanykina (as opposed to buyers in the market). Past milk production is associated with significantly more income coming from Tanykina relative to other buyers. Due to the negative and statistically significant interaction with non-dairy income, this effect is largest when the latter is at its minimum level. Thus, an increase in cash inflows from dairy farming has the strongest effect for farmers with the least cash inflows from non-dairy activities. The income-expense ratio by itself does not have a significantly positive effect on the share of income received from Tanykina.

4.2 Semi-parametric estimates: Non-parametric part

This section presents the semi-parametric regression results, focusing on our two proxies of cash at hand: past milk production (an exogenous measure of cash inflows from milk sold in the past), and current non-dairy income as a share of total non-food expenditures (to measure cash inflows from non-dairy activities). Both variables enter the model non-parametrically. Estimated coefficients for variables that enter the linear part of our semi-parametric model will be presented in the next section.

We first estimate Equation (2) for the quantity of milk that a farmer sells in the market, conditional on selling milk. To visualize the joint effects of milk production and net income, Figure 4 presents a three-dimensional graph, plotting the fitted quantity of milk sold in the market ($\hat{m}(\cdot)$) against net income and past production. These fitted values control for household fixed effects and variables included in x_{it}. For ease of comparison across specifications, values are rescaled to have the same mean as the raw dependent variable. The plot is derived using point-wise estimates of $m(\cdot)$ and its slopes at 100×100 evenly spaced points across the $10\% - 90\%$ quantile of past milk production and the income-expenditure ratio.

The quantity of milk sold in the market is at its highest point in weeks with high net non-dairy income and low past milk production, and is decreasing in past milk production. In order to give a closer examination of the individual effect of each covariate, and compare the semiparametric estimates with those from the fully linear model, Figure 5 presents the fitted *slopes* of the quantity of milk sold in the market, $\dot{m}(\cdot)$. We draw these slopes with respect to last month's milk production (top panel), and non-dairy income (bottom panel), together with 95% confidence intervals. The figure evaluates these slopes at different levels of last month's milk production (varied on the horizontal axis, with vertical dotted lines indicating the 25%, 50% and 75% quantile) and net income (at the 25%, 50% and 75% quantile in the left, middle and right figures, respectively).

In the fully linear model, milk production in the last month reduces the quantity of milk sold in the market by approximately 15 percent. We observe a negative slope in last month's milk production also in the top panel of Figure 5. Thus, also in the semiparametric model, an increase in past production is associated with a lower quantity of milk sold in the market. The slope is however significant only for below-median levels of past milk production, and especially so in the right two figures, with net income at its 50th and 75th percentile. Reduced milk production in the past induces farmers to sell more milk in the market only when cash at hand from other income sources is sufficiently high, while cash flowing in from dairy farming needs to be sufficiently low. The fully linear model failed to reveal this heterogeneity.

The fully linear model further estimates that the log income-expense ratio increases the quantity of milk sold in the market by approximately 5 percent. The bottom panel of Figure 5 presents semiparametric estimates of this effect. The slope is positive but not statistically significant when net income is at the 25th percentile. With net income at its 50th and 75th percentile, the slope becomes even negative. Thus, the positive effect of income on the quantity of milk sold in the market occurs only at very low levels of net income; and although the slopes are relatively large, they are significant at only a few levels of past milk production.

Next, we estimate Equation (2) for the proportion of milk sold to Tanykina (as opposed to local traders and vendors). Figure 6 again presents a three-dimensional graph for the fitted proportion of milk sold to Tanykina ($\hat{m}(\cdot)$). Fitted values are at their lowest point in weeks with low net non-dairy income and low lagged milk production. In weeks with higher inflows of cash from non-dairy activities, and in weeks that follow a period of higher milk production, households sell a relatively larger share of milk to Tanykina. They do not respond linearly to changes in net income; the share of milk sold to Tanykina increases in net income mainly at higher levels of net income. In other words, cash at hand needs to be sufficiently large before it affects farmers' decision where to sell their milk. This threshold effect is not present in the fully linear model.

Figure 4: Fitted quantity of milk sold in the market against net income and past production

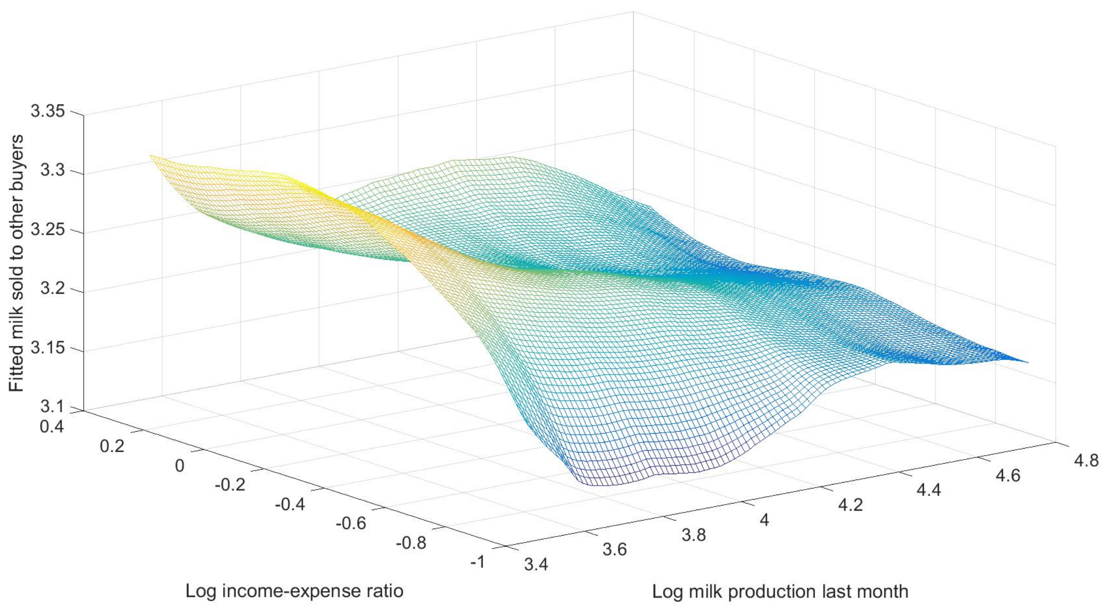


Figure 5: Fitted slopes of the quantity of milk sold in the market and 95% confidence intervals

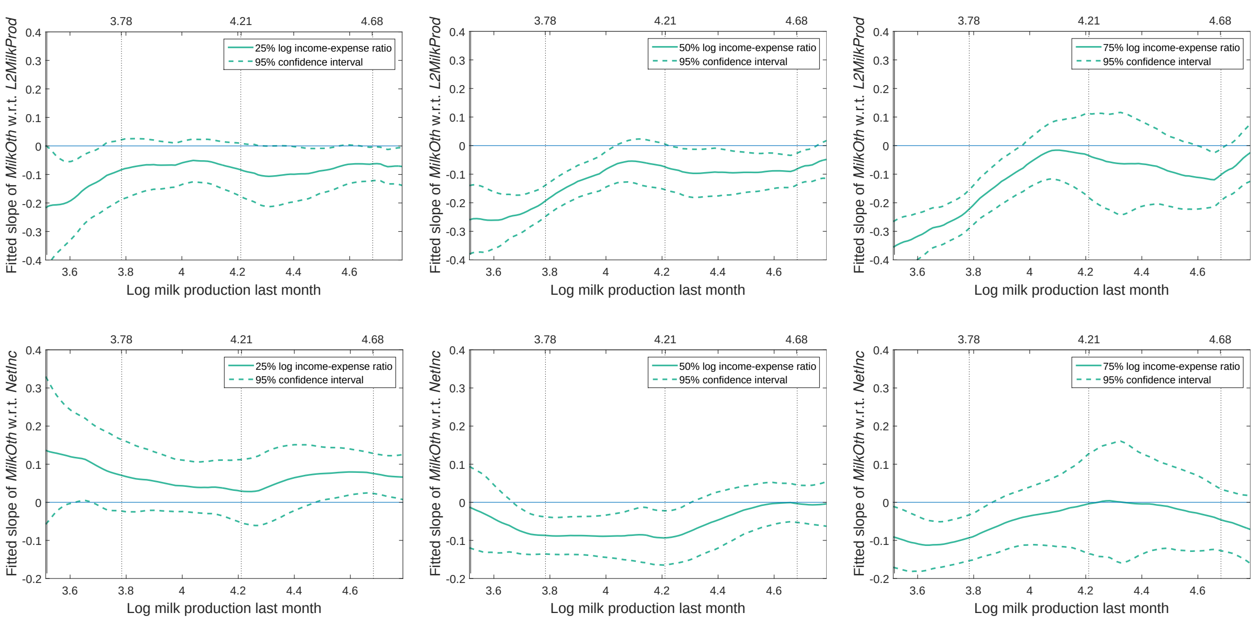


Figure 7 draws slopes for the proportion of milk sold to Tanykina with respect to last month's milk production (top panel), and net income (bottom panel). In the top panel of Figure 7, we observe a positive slope for below-median levels of past milk production in the left two figures, with net income at its 25th and 50th percentile. The share of milk sold to Tanykina is also increasing in past milk production at higher levels of net income, but only when past production is between the 25th and 50th percentile. For the median farmer, increasing past production by one percent increases the share of milk sold to Tanykina by around 10% points, which is comparable to the linear estimates. In other words, farmers sell relatively more milk in the market in weeks that they receive less cash from dairy farming, consistent with our theoretical predictions.

The bottom panel of Figure 7 presents fitted slopes for the share of milk sold to Tanykina with respect to disposable income from non-dairy activities. The slope is close to zero and not statistically significant when net income is at the 25th percentile, irrespective of the lagged milk production level. We do, however, find a positive effect of net income at the 50th and 75th percentile of net income, with more precise estimates at below-median levels of milk production. In those weeks, a one-percent increase in the income-expenditure ratio raises the share of milk sold to Tanykina by nearly 10 percentage points.

Next, Figures 8 and 9 estimates the relation between cash at hand and the value of milk sold in the market, i.e. an estimate of the price at which farmers sell milk in the market. This analysis only includes weeks in which the farmer sells milk in the market, since otherwise the market price is not defined. Note that we control for the median price at which farmers in the same village sell milk.

These two figures provide a very clear picture. First, the price at which farmers sell in the market appears to be increasing in past milk production, and the effects are strongest at low as well as high levels of last month's milk production. Second, the market price is decreasing in non-dairy income, and this effect is most pronounced when last month's milk production is low. We observe this effect even in regions where non-dairy income affects neither the absolute quantity of milk sold in the market nor the share of milk sold to cooperative.

In a similar way, Figures 10 and 11 present fitted levels and slopes for the average price at which farmers sell their milk in a given week, now again including weeks in which the household sells milk to the cooperative but not the market. These graphs mirror the pattern in Figures 8 and 9, albeit less pronounced. In Figure 11, the average price at which households sell their milk is *increasing* in past milk production only when the lagged level is below-median (top panel). The average price is *decreasing* - but not as strongly as the market price in Figure 9 - in net income from non-dairy activities (bottom panel).

In other words, a reduction in cash at hand from non-dairy activities is associated with an increase in the average price at which households sell their milk, due to the higher price that farmers receive in the market in weeks with lower incomes. Perhaps buyers provide informal insurance when net income from non-dairy activities declines, either knowingly - by providing extra cash when farmers ask for it - or unknowingly - for instance by purchasing diluted milk. We will later discuss potential reasons for why we do not observe this insurance mechanism after a period of lower dairy production.

Figures 12 and 13 present fitted levels and slopes of the share of dairy income received from Tanykina,

Figure 6: Fitted share of milk sold to Tanykina against net income and past production

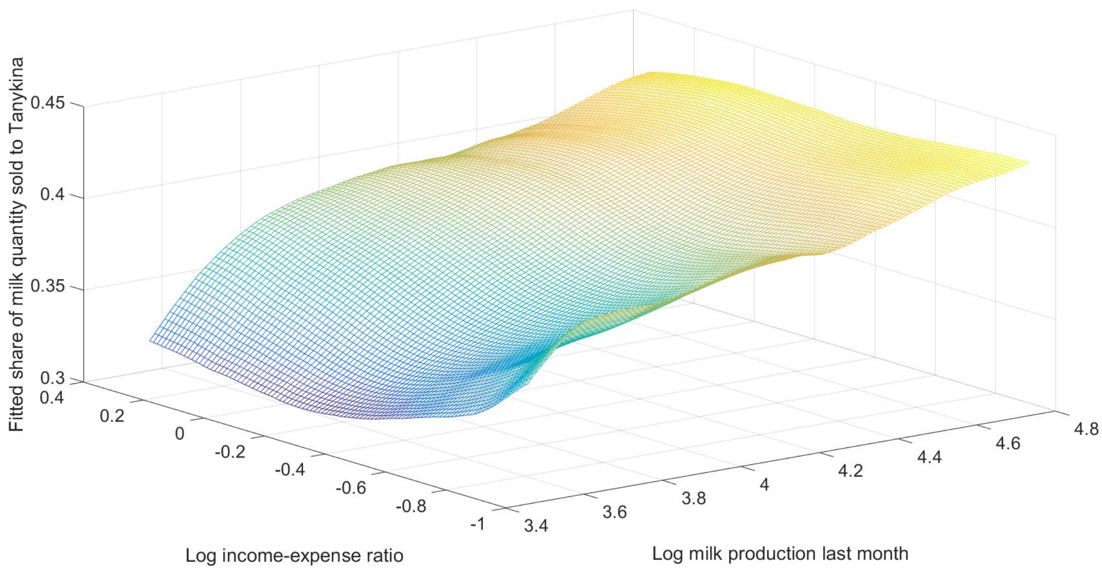


Figure 7: Fitted slopes of the share of milk sold to Tanykina and 95% confidence intervals

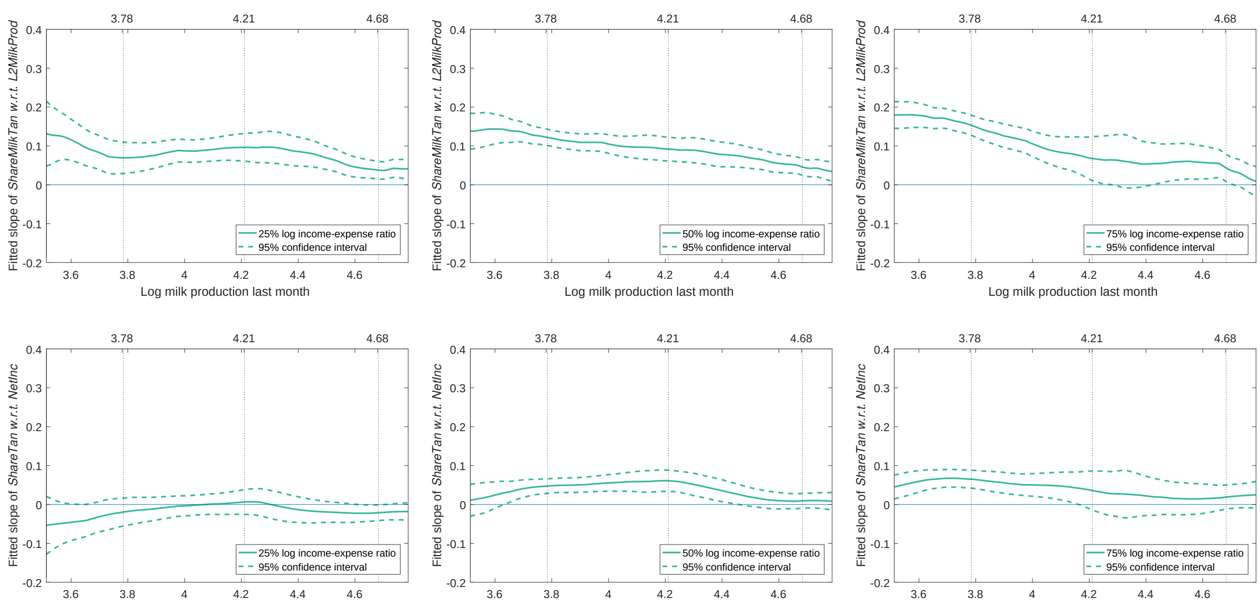


Figure 8: Fitted value of milk sold in the market against net income and past production

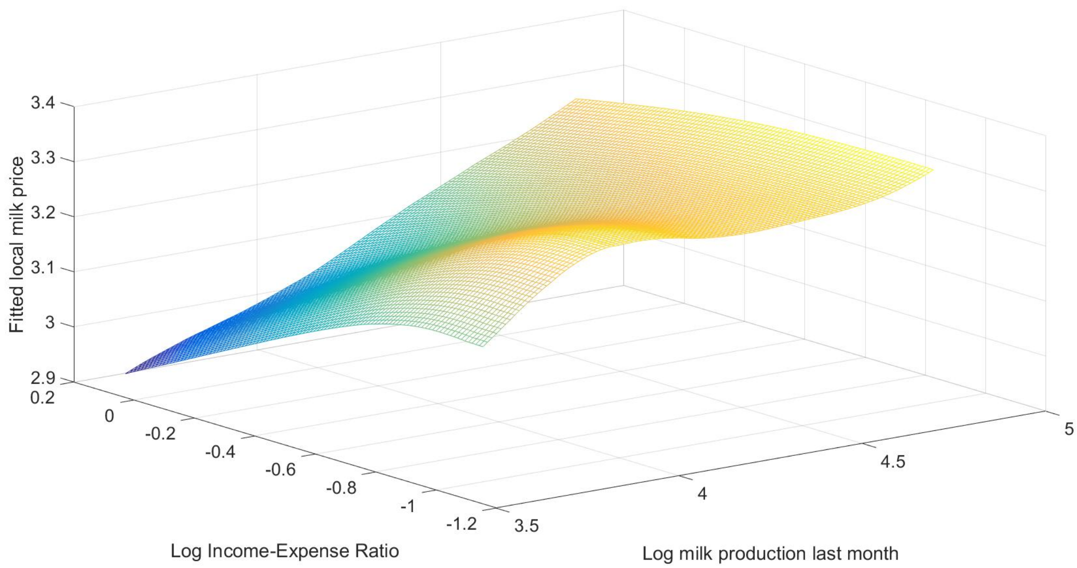


Figure 9: Fitted slopes for value of milk sold in the market and 95% confidence intervals

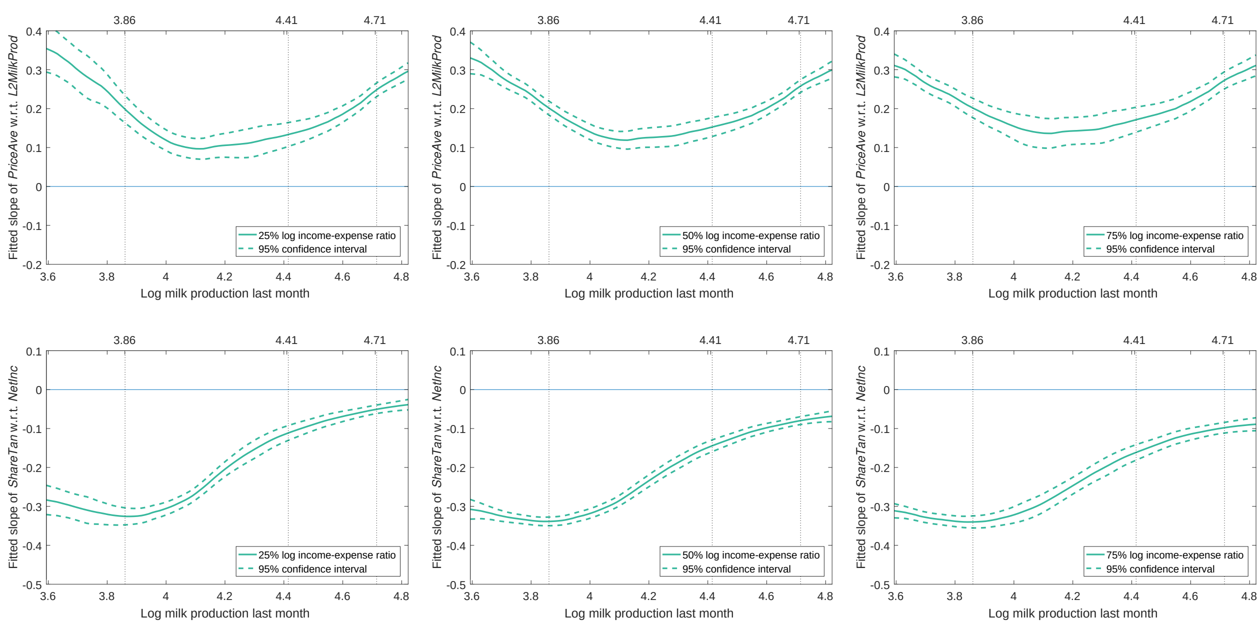


Figure 10: Fitted price received on average for milk sold against net income and past production

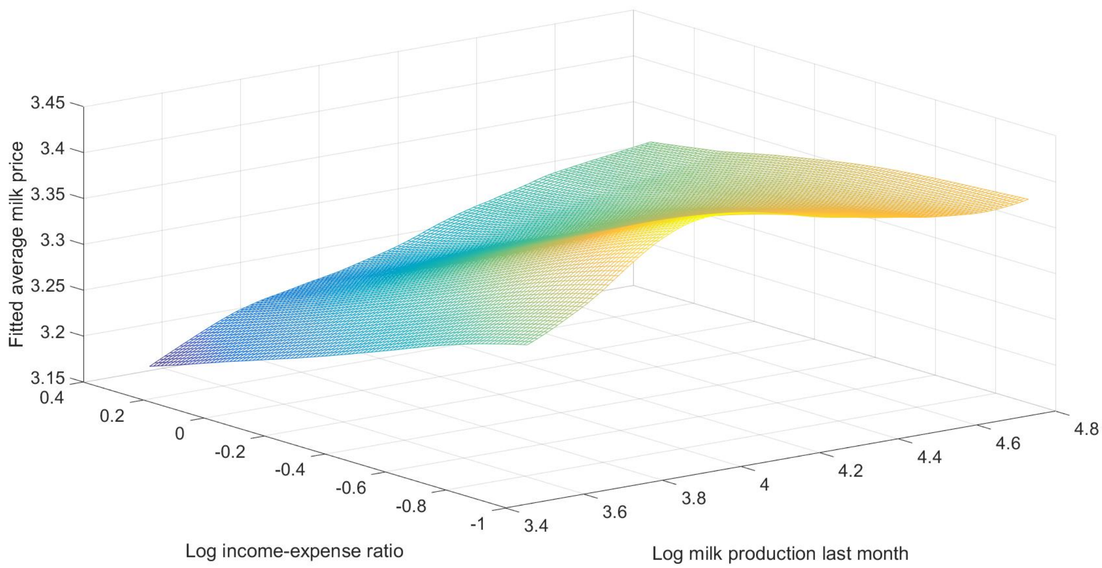
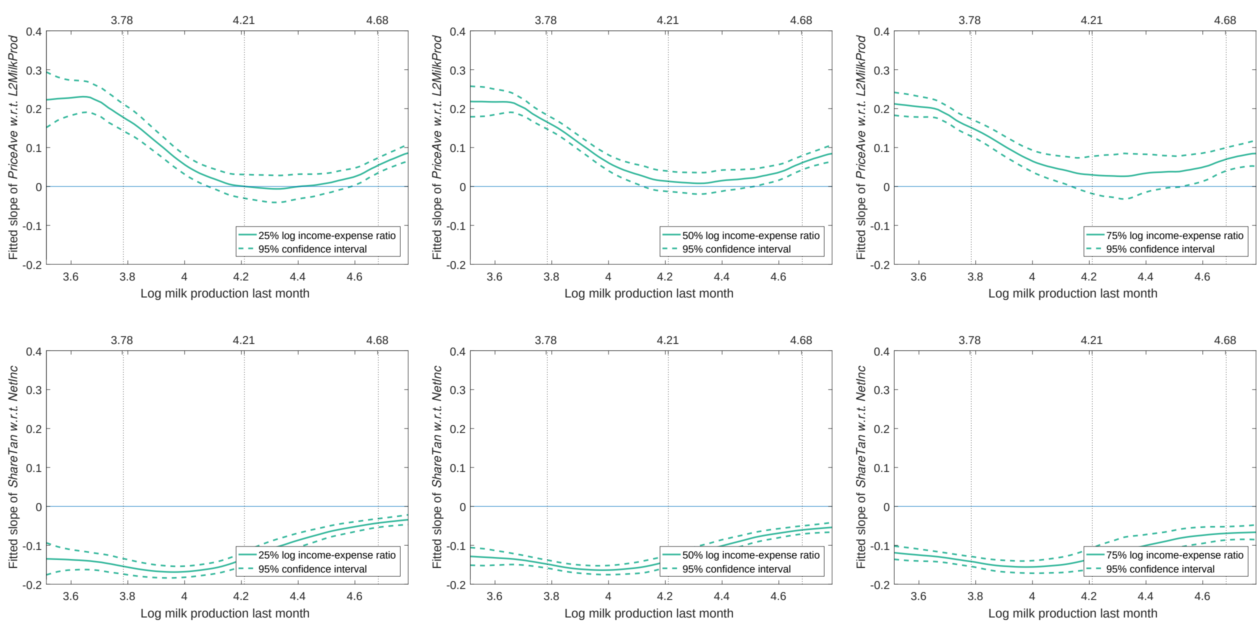


Figure 11: Fitted slopes of average price of milk sold and 95% confidence intervals



respectively. In the top panel of Figure 13, we find for all levels - except for relatively high levels of past production and non-dairy income - that past milk production has a significant and positive effect. Findings are less pronounced than for the share of milk sold to Tanykina in Figures 6 and 7 because an increase in last month's milk production is also associated with an increase in market prices. Further, in the bottom panel, an increase in net income is associated with a higher share of dairy income from Tanykina at above-median levels of net income, due to both an increased share of milk sold to Tanykina, and a reduction in market prices.

One of the key differences between Tanykina and buyers in the market is that the former defers payments until the next month, while the latter tend to pay cash immediately. However, 6.4% of transactions with buyers in the market involved a deferred payment. Appendix Figure 15 therefore estimates Equation (2) for the share of dairy income to be received on credit, i.e. the share of dairy income for which the farmer defers payments. Figure 16 draws the slopes with respect to past milk production and net income. Findings are very comparable to those in Figures 12 and 13. In weeks with less cash at hand, households receive relatively less dairy income not only from Tanykina, but also from other buyers who defer payments.

4.3 Semi-parametric estimation: Linear part

Table 5 provides the estimates for variables that are included in the linear part of the semi-parametric model. In Column (1), the quantity of milk sold in the market is increasing significantly in current milk production. The share of milk sold to Tanykina is hence decreasing in this variable in Column (2). An increase in production is also associated with a lower market price in Column (3), potentially due to lower bargaining power, since we control for the median price at which farmers in the village sell their milk. As a result, the price received on average is decreasing in current production in Column (4), while the share of dairy income received from Tanykina is increasing in this variable due to decreasing market prices. Thus, Tanykina appears more important in weeks with low milk production.

Lagged food expenditures are endogenous, and farmers may increase food consumption when they have more cash at hand; that is, when they are inclined to sell relatively more milk to Tanykina, and when they receive on average lower prices. Alternatively, an increase in food consumption may induce farmers to sell more in the market in order to obtain cash. We find more evidence of the former hypothesis. The quantity of milk sold in the market is decreasing in food expenditures, whereas all other variables are increasing in this variable.

We also control for the median price at which farmers in the same village sell their milk. Higher prices are associated with lower quantities sold in the market, most likely due to reverse causality, that is, increased milk supplies will depress prices. In weeks with higher prices in the market, farmers also sell a larger share of milk to Tanykina, but due to market prices being higher, the share of dairy income received from Tanykina is not affected.

The lagged village market price is predetermined and can be interpreted as an alternative proxy for cash

Figure 12: Fitted share of dairy income received from Tanykina against net income and past production

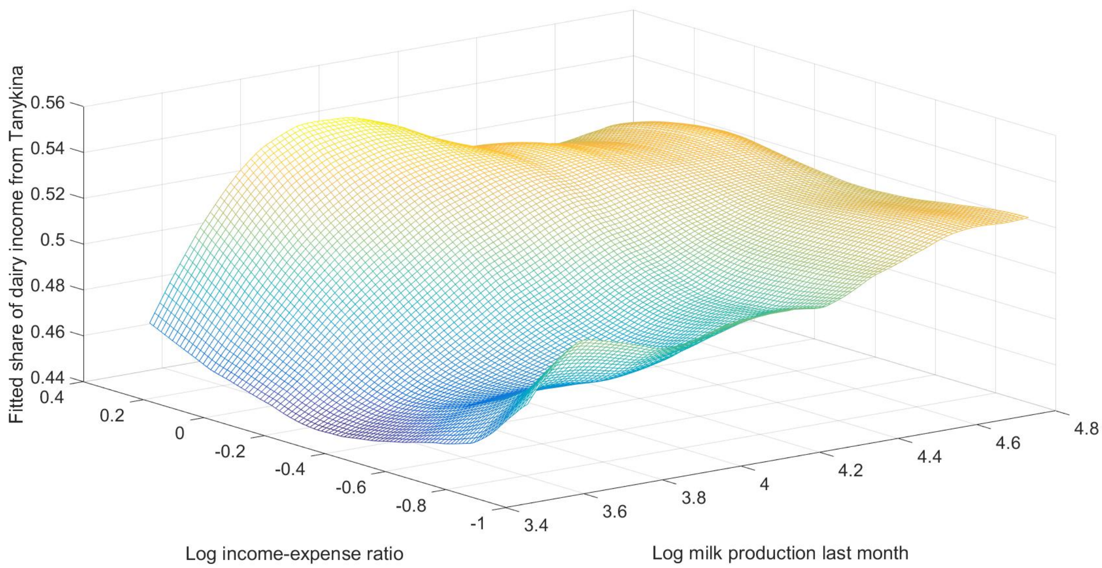
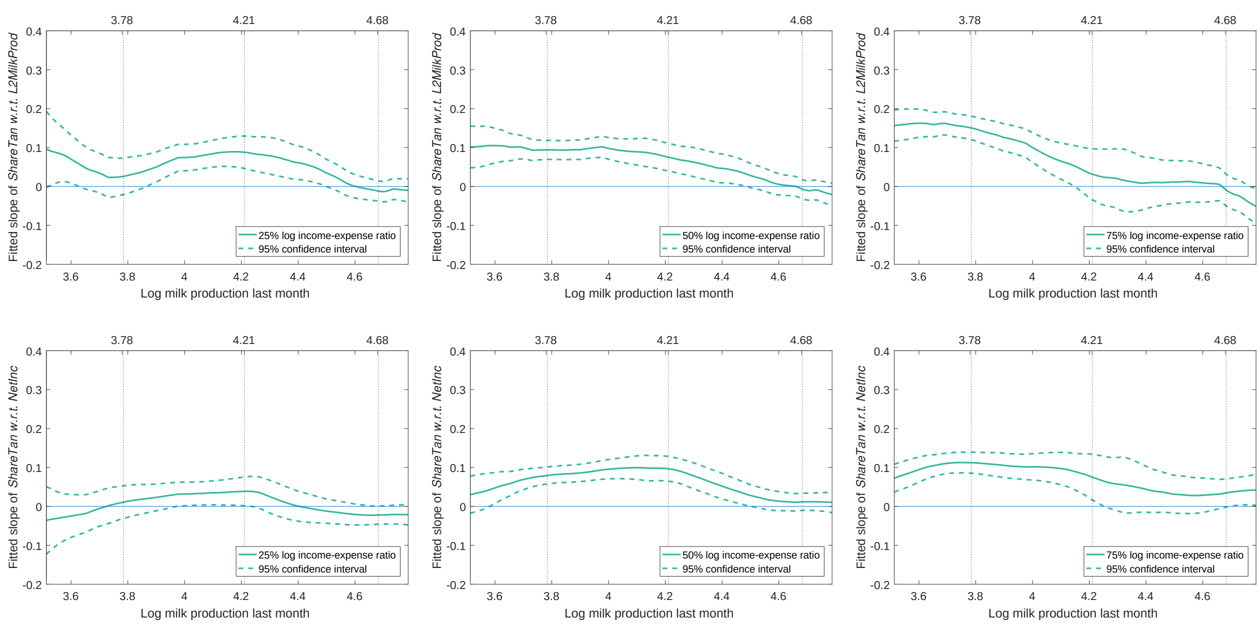


Figure 13: Fitted slopes of the share of dairy income received from Tanykina and 95% confidence intervals



at hand. If the market price was higher in the past week, farmers will have more cash at hand from selling milk in the market that week. This variable indeed has a negative effect on the quantity of milk sold in the market, and a positive effect on the share of milk sold to Tanykina. As a result, the share of dairy income received from Tanykina is increasing in this variable as well.

As a final proxy for cash needs, we analyze how households respond to health shocks. Health shocks have a significant effect on where farmers sell their milk for households without health insurance coverage. Experiencing a health symptom increases the quantity of milk sold in the market by 9.5 percent, and reduces the share of milk sold to Tanykina by 4.0% points. Although market prices are not reduced substantially, the cooperative pays more than the market, reducing the average price that farmers receive for their milk by 6.9 percent.

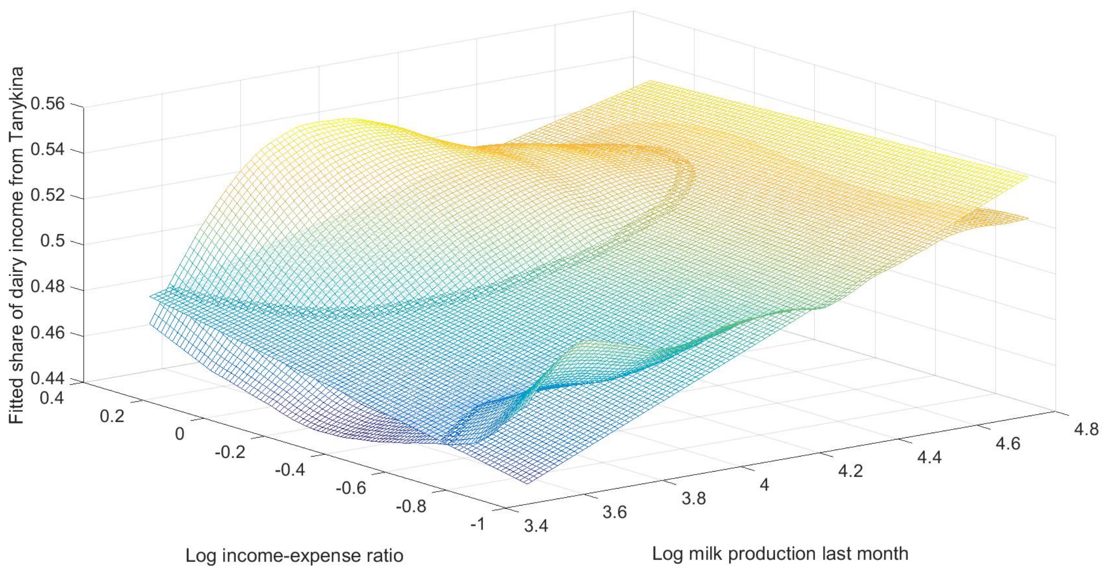
It is very likely that in weeks with health shocks, households sell more milk in the market - at the expense of receiving a lower price - in order to obtain cash to pay their medical bills. Consistent with this interpretation, we do not observe a negative effect of past health symptoms on marketing decisions for households with health insurance coverage; the interaction term of health insurance coverage and health symptoms is significantly positive and outweighs the negative effect of health symptoms in Columns (2) and (5). Thus, insurance coverage reduces households' tendency to sell their milk in the market in order to cope with health problems. As such, insurance potentially improves compliance with informal collective marketing arrangements.

In sum, our findings indicate that farmers receive relatively more dairy income from the market (as opposed to the cooperative) in weeks that follow a period of lower milk production, and in weeks they earn less from non-dairy activities, i.e. weeks in which a household has less cash at hand. These effects as well as the interaction of our two proxies for cash at hand are not linear. Due to threshold effects and nonlinearities, the fully linear estimates often provide an incomplete - and sometimes even inaccurate - summary of how cash at hand is related to the decision to defer milk payments.

Interpretation of these differences between the linear and semi-parametric results is straightforward but important. The linear model allows the income-expense ratio effect to vary only in log milk production, not in its own level, and only linearly. In other words, the effect of a one-percent increase in past production (estimated to increase the share of milk sold by 6.7 pp at the median level of net income) is assumed to be the same across the entire range of past production levels. Further, a one-percent increase in the income-expense ratio is assumed to decrease this effect by a constant 2.5 percent. The non-parametric estimator allows this effect to vary in both production and net income in a non-linear manner. As a result, it is largest around the median of log milk production when the income-expense ratio is not high, and smallest when milk production is at the two tails of its distribution, or the income-expense ratio is high. The linear specification averages out these local effects, biasing the estimates and inference.

To visualize the main difference between our semi-parametric and fully linear estimates, Figure 14 stacks graphs for the fitted share of dairy income from Tanykina using the semi-parametric estimates and the linear coefficient estimates of the lagged milk production, non-dairy net income, and their interaction term.

Figure 14: Fitted share of dairy income received from Tanykina - Comparing fully linear and semiparametric predictions



Both graphs are rescaled to have the same mean for the ease of comparison. In stark contrast to the flat plane estimated using the linear model, the non-parametric estimation captures the varying effect of lagged milk production by itself. In particular, after weeks with low milk production, an increase in milk production raises the share of dairy income from Tanykina substantially more than in weeks after a period of high milk production. The linear estimate can be interpreted as an average of the non-parametric estimates across both explanatory variables, leaving out more detailed information from local effects.

4.4 Robustness checks

This section presents a number of robustness checks. First, we will assess to what extent effects occur on the intensive margin (i.e. households already selling to Tanykina now selling more) versus the extensive margin (i.e. households not yet selling to Tanykina starting to sell some once they have more cash at hand). Second, we analyze what determines whether households sell any milk, and what proportion of milk they sell (as opposed to consuming the milk). We then describe heterogeneity in our main findings for different types of households, and different points in time.

4.4.1 Intensive versus extensive margin

First, we analyze whether changes in cash at hand mainly induce changes in milk marketing at the intensive or extensive margin. Table 6 estimates the same linear model as Table 4. However, as dependent variable, we use indicators for the share of income from Tanykina being zero (so that the household sells no milk to Tanykina), between zero and one (so that the household sells some but not all milk to Tanykina), and one (so that all milk sold went to Tanykina). Panels A, B and C center last month's milk production and the non-dairy income-expense ratio at the 25th, 50th and 75th percentile, respectively.

Past milk production affects the probability that a household sells no milk to Tanykina in Column (1), that a household sells some but not all milk to Tanykina in Column (2), and that a household sells all milk to Tanykina in Column (3). At the median level of past milk production, a one-percent increase in last month's milk production is associated with a 5.3 pp lower probability of selling no milk to Tanykina, and a 3.3 pp lower probability of selling some but not all milk; and as a result, the probability of selling all milk to Tanykina increases by 8.6 pp. Hence, households with increasing income from past milk production switch from selling none or some milk to Tanykina into delivering all their milk to the cooperative.

Likewise, the effects of the income-expense ratio are strongest for the probability of selling all milk to Tanykina. Columns (1) and (2) show that as net income increases, both the probability of selling no milk and the probability of selling some milk reduce by a small and statistically insignificant amount. However, in Panel A Column (3), a one-percent increase in the income-expense ratio from the 25th percentile increases the probability of selling all milk to Tanykina by 2.8 pp. Because of the negative and statistically significant interaction terms, we do not observe this effect at higher levels of net income.

4.4.2 Milk consumption by the household versus selling milk

The decision to sell milk is potentially a trade-off between household income and milk consumption. Table 7 tests to what extent this trade-off is influenced by cash at hand. We estimate the fully linear model, Equation (3), for milk production in Column (1), an indicator whether the household sold any milk in Columns (2)-(3), and the share of milk production sold (as opposed to consumed) in Columns (4)-(5). The first three columns include all observations, including weeks in which the household did not sell any milk. The last two columns only include weeks in which the household sold milk. Columns (3) and (5) control for current milk production. Column (1) shows that current milk production is correlated with past milk production, and current milk production is likely to have a direct effect on whether or not the household sells milk, or conditional on selling milk, the share of milk production sold. Thus, Columns (3) and (5) improve upon Columns (2) and (4) by controlling for indirect effects of past milk production via current milk production.

In Column (3), controlling for current milk production, the decision whether to sell is not related to the quantity of milk produced in the last month, while an increase in net income decreases the propensity to sell. When centering variables at the 50th percentile, a one-percent increase in the income-expenditure ratio reduces the probability that the household sells any milk by 2.1 percentage points. This is consistent with the hypothesis that households face a trade-off between home consumption and selling milk, and that when income is higher, they can substitute milk for other foods, enabling the household to sell their milk. In Column (5), conditional on selling milk, the share of milk production sold by the household (as opposed to consumed) is decreasing in net income only in Panel A, when variables are centered at the 25th percentile.

Thus, consumption-marketing trade-offs appear to occur mainly at the extensive margin, in the decision whether or not the household will sell some of its milk.

4.4.3 Heterogeneity in household type and time of the year/month

Table 8 presents estimates of Equation (3) for the share of milk sold to Tanykina (Panel A), the log price per liter of milk sold (Panel B) and the share of dairy income from Tanykina (Panel C) for different types of households. In Columns (1) and (2), we split the sample into households with only one person selling milk, versus two or more members who report selling milk. Columns (3)-(4) vary whether the main dairy farmer (with the highest dairy income during the year) is male or female. Columns (5)-(6) compare households in which the main dairy farmer is the household head versus households in which this is another person. Columns (7)-(8) compare households in which the main dairy farmer reports at baseline that he/she can take decisions over cattle income. Both explanatory variables are centered at the median level.

In Columns (1)-(2), the share of milk sold to Tanykina is affected in very similar ways for households with only one dairy farmer versus those with at least two members selling milk. In Panel B, the average price at which farmers sell milk is increasing in past production only for households with one household member selling milk; in other households, past milk production is negatively (but statistically insignificant) correlated with the average milk price. Households with only one household member selling milk sell a smaller share of milk to Tanykina, and receive on average a lower price for milk. Thus, for these households, there is more gain to improve their price by selling more to the cooperative. The person selling milk in these households is most often female, and always the household head who decides on cattle income, making Columns (1), (4), (5) and (7) very comparable.

In Columns (6) and (8), focusing on households in which the main dairy farmer is not the household head or not the person who decides on cattle income - for instance those in which the female spouse is the one who sells milk - we find somewhat different patterns. For these households, milk production in the last month does not significantly affect the share of milk sold to Tanykina in Panel A, the average price at which the household sells milk in Panel B, or - in Column (6) - the share of dairy income from Tanykina in Panel C. When the main farmer is not the household head, the household sells a smaller portion of milk to Tanykina. The monthly payment from the cooperative is hence less important in these households, which potentially explains why last month's milk production does not affect our main outcome variables. However, for households in which the main dairy farmer is not the household head, net income does affect the share of milk sold to Tanykina. A one-percent increase in the income-expense ratio increases the share of milk sold to Tanykina by 5.2 percentage points, suggesting that in these households, the ability to sell milk in the market is an important consumption smoothing device. This also potentially explains why we do not observe the insurance mechanism for last month's milk production.

Table 9 analyzes heterogeneity by time of the month and year. Columns (1)-(2) vary whether observations are from the first or second half of the month. Columns (3)-(4) vary whether observations are from the middle of the month versus either the first or last week in the month. Columns (5)-(6) vary whether observations are from the first half of the study year (which was the dry season with lower milk production) versus the second half of the year (which was the wet season with higher milk production).

Milk production in the last month has a significant effect on the share of milk sold to the cooperative, the average price at which households sell their milk, and hence the share of dairy income from Tanykina, but only when restricting the sample to observations in either the first half or the middle of the month. The cooperative pays households for milk delivered in the previous month at this time, and households with larger levels of milk production will in this period have had higher levels of cash at hand. By contrast, net income increases the share of milk sold to the cooperative mainly in the second half of the month, especially in the last week.

Finally, in Columns (5)-(6), we find the strongest effects of past milk production during the second half of the year, which is the wet season with higher levels of milk production. During this season, dairy farming will be a more important source of income. Further, farmers tend to rely more on their cooperatives to pay good prices, since milk is abundant and traders in the market have strong bargaining power. As a result, the cooperative payments may be a more important source of household income, and hence a stronger determinant of whether the household can defer payments by a few more weeks. By contrast, in the dry season, other sources of income are more important, explaining why we observe a positive effect of the log income-expense ratio in Panel C only for that season.

5 Conclusion

This paper analyzed to what extent cash at hand affects dairy farmers' compliance with collective marketing arrangements. While cooperatives typically defer payments, buyers in the market are used to paying farmers in cash. As a result, a cash-constrained farmer may decide to sell milk in the market even when the market offers a lower price than the cooperative. Our conceptual framework formalizes this hypothesis, and further shows that the share of milk sold to the cooperative is a nonlinear function of cash at hand with thresholds to surpass for cash at hand to affect farmers' decision where to sell their milk.

We then test our hypothesis using high-frequency high-detail panel data for a sample of dairy farmers in western Kenya, whereby we rely on semi-parametric specifications. We proxy the extent to which a household is cash-constrained by measuring levels of last month's milk production - as a proxy for cash inflows from the cooperative - and non-dairy income net of non-food expenditures - as a proxy for net inflows of cash from income-generating activities other than dairy farming. We estimate a semi-parametric model that includes household fixed effects. As such, we explore how within the same household time variation in cash at hand influences our main outcome variables, i.e., the share of milk sold to the cooperative, the share of dairy income from the cooperative, and the total dairy income. The semi-parametric model provides a richer description by evaluating effects locally, which is appropriate given that we expect our outcome variables to be a non-linear function of cash at hand, characterized by threshold effects.

Using this approach, we find that the share of milk sold to - and the share of dairy income from - the cooperative are increasing in lagged milk production at below-median levels; this holds true for all levels of net income. Thus, after a month in which households were able to sell more milk, increasing their net cash flow from dairy farming, they are less likely to sell outside the cooperative. Net income affects these two outcome variables but only at the 75% percentile - suggestive of threshold effects - and only in weeks with below-median milk production. Nonetheless, an increase in net income is associated with a reduction in the price that farmers receive when selling their milk in the market. In other words, in weeks that farmers are cash-constrained, they receive higher market prices, suggesting that markets provide an important source of liquidity.

We also find evidence of households coping with health shocks by selling more milk to buyers in the market, who pay in cash, than to the cooperative, where payments are deferred. However, this coping strategy is not observed when households are covered by health insurance. Health expenditures and income losses associated with health shocks will make households more cash-constrained, in particular when they are not covered by health insurance and have limited access to other coping strategies. In this light, these findings provide further evidence of the implications that cash at hand can have for the decision where to sell milk. Further, because health insurance shields households from expenditures, and is not associated with increased side-selling, our findings highlight linkages between agriculture and health; that is, the potential of health insurance to strengthen collective marketing arrangements. To our best knowledge, such linkages have not been documented in previous literature.

In conclusion, our findings indicate that cash constraints influence where farmers sell their milk. When relatively cash-constrained, they sell larger quantities of milk in the market, where they are paid cash immediately, while higher levels of cash at hand allow them to deliver their milk to the cooperative and save for future expenditures. The cooperative offers a price that is on average higher than the price for milk sold in the market. As a result, we find that a reduction in past milk production - associated with lower payments from the cooperative in the current period - lowers farmers' income, which may reinforce farmers' preference for selling milk in the market. Access to financial instruments that can help relax cash constraints, for instance health insurance, can thereby improve farmers' loyalty to the cooperative agreement, and have positive externalities beyond improving farmers' health.

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Table 2: Summary statistics of household characteristics

	Variation in share of income from Tanykina		No variation in share of income		Difference in means	
	Mean (1)	s.e. (2)	Mean (3)	s.e. (4)	Mean (5)	*p*-value (6)
Household head is male	0.705	0.459	0.500	0.509	0.205	0.0425
Age of the household head	52.38	14.15	51.03	19.13	1.342	0.6839
Number of HH members selling milk	1.489	0.547	1.300	0.466	0.189	0.0935
Number of cows at baseline	4.227	2.509	3.200	1.669	1.027	0.0390
Number of cows lent out at baseline	0.125	0.333	0.069	0.258	0.056	0.4094
Number of bulls at baseline	0.356	0.849	0.333	0.606	0.023	0.8916
Number of male calves at baseline	1.227	1.444	0.833	1.234	0.394	0.1841
Number of female calves at baseline	3.318	10.22	1.233	1.073	2.085	0.2684
Number of weeks with an interview	45.42	4.085	46.03	2.141	-0.613	0.4344
Main dairy farmer:						
Is male	0.216	0.414	0.300	0.466	-0.084	0.3541
Age	47.57	14.34	46.40	17.38	1.168	0.7161
Is household head	0.477	0.502	0.733	0.450	-0.256	0.0148
Is spouse of household head	0.500	0.503	0.200	0.407	0.300	0.0038
Is married	0.830	0.378	0.600	0.498	0.230	0.0095
Went to secondary school or higher	0.531	0.502	0.423	0.504	0.108	0.3435
Is protestant	0.830	0.378	0.933	0.254	-0.104	0.1649
Is engaged in livestock activities	0.953	0.213	0.967	0.183	-0.014	0.7539
Is engaged in cattle activities	0.765	0.427	0.833	0.379	-0.069	0.4378
Is engaged in other livestock activities	0.635	0.484	0.567	0.504	0.069	0.5104
Can keep part of cattle income	0.659	0.477	0.793	0.412	-0.134	0.1789
Decides how to spend cattle income	0.655	0.478	0.793	0.412	-0.138	0.1677
Number of households	88		30			

Notes: The sample excludes two households with high attrition and strong outliers. Further, in assessing whether there is variation over time in the share of income received from Tanykina, we omit weeks with high attrition due to Christmas (2 weeks), Easter (1 week) and the last fieldwork month (4 weeks). The main dairy farmer is the household member reporting the highest value of dairy income received throughout the year.

Table 3: Summary statistics of time-varying characteristics

	Variation in share of income from Tanykina			No variation in share of income		Difference in means	
	Mean (1)	s.e. (2)	within (3)	Mean (4)	s.e. (5)	Mean (6)	*p*-value (7)
Weekly non-dairy cash income in 1,000 Sh	2.009	4.065	2.924	2.031	4.907	-0.052	0.9201
Weekly non-food expenditures in 1,000 Sh	2.493	4.457	3.754	1.907	6.030	0.542	0.2866
Weekly food expenditures in 1,000 Sh	0.537	0.912	0.844	0.549	1.372	-0.014	0.8907
Prop. of weeks with health problem	0.263	0.440	0.391	0.271	0.445	-0.004	0.9239
Prop. of weeks with insurance coverage	0.344	0.475	0.245	0.390	0.488	-0.056	0.5379
Liters of milk produced per week	71.50	37.49	19.16	52.97	34.44	17.70	0.0083
Liters of milk consumed per week	18.16	7.022	4.772	14.46	6.384	3.587	0.0002
Share of milk that is consumed	0.316	0.196	0.137	0.339	0.186	-0.021	0.4649
Prop. of weeks that household buys milk	0.004	0.065	0.056	0.004	0.060	0.001	0.8815
Tanykina milk price (monthly price in Sh)	36.19	2.217	2.208	36.20	2.221	-0.039	0.3437
Market milk price (average for 3 buyers)	30.52	2.614	2.603	30.54	2.622	-0.050	0.2776
Prop. of weeks with dairy sales	0.847	0.360	0.276	0.697	0.460	0.150	0.0127
Conditional on selling milk that week...							
Total dairy income in 1,000 Sh	1.572	0.936	0.523	1.325	1.025	0.226	0.2414
- Share received by main dairy farmer	0.926	0.260	0.222	0.941	0.235	-0.016	0.5637
Dairy income from Tanykina in 1,000 Sh	0.871	0.917	0.551	1.031	1.216	-0.173	0.4482
- Share of total dairy income	0.503	0.413	0.232	0.629	0.483	-0.132	0.1881
Dairy income from other buyers in 1,000 Sh	0.700	0.609	0.346	0.295	0.426	0.399	0.0001
- Share of total dairy income	0.497	0.413	0.232	0.371	0.483	0.132	0.1881
Dairy income received on credit in 1,000 Sh	0.904	0.935	0.556	1.118	1.164	-0.228	0.3087
Dairy income received in cash in 1,000 Sh	0.667	0.606	0.335	0.207	0.400	0.453	0.0000
- Share received by main dairy farmer	0.950	0.218	0.169	1.000	0.000	-0.051	0.0010
Conditional on selling milk, share of milk...							
- sold to Tanykina*	0.300	0.309	0.227	0.395	0.419	-0.099	0.1235
- sold in local market*	0.329	0.290	0.169	0.228	0.312	0.104	0.1144
- consumed by the household	0.274	0.116	0.074	0.292	0.127	-0.016	0.4264
Number of households (total observations)	88	(3997)		30	(1381)		

Notes: The sample excludes two households with high attrition and strong outliers. Further, in assessing whether there is variation over time in the share of income received from Tanykina, we omit weeks with high attrition due to Christmas (2 weeks), Easter (1 week) and the last fieldwork month (4 weeks). The main dairy farmer is the household member reporting the highest value of dairy income received throughout the year. * Estimated from dividing total sales value by the Tanykina and other buyers' milk prices, respectively. October milk prices were not collected and have been imputed by November milk prices.

Table 4: Fully parametric (linear) estimates for milk marketing decisions

	Log liters of milk sold in market	Share of milk sold to Tanykina	Log price of milk sold in market	Log price received on average	Share of dairy income from Tanykina
	(1)	(2)	(3)	(4)	(5)
Panel A. Centered at 25% quantile					
Log production last month	-0.145***	0.089***	0.192***	0.070***	0.064***
	(0.043)	(0.017)	(0.043)	(0.025)	(0.019)
Log income-expense ratio	0.057*	-0.009	-0.143***	-0.107***	0.023
	(0.031)	(0.012)	(0.030)	(0.018)	(0.014)
Panel B. Centered at 50% quantile					
Log production last month	-0.150***	0.089***	0.221***	0.090***	0.057***
	(0.043)	(0.016)	(0.043)	(0.025)	(0.019)
Log income-expense ratio	0.050**	-0.010	-0.105***	-0.081***	0.014
	(0.022)	(0.008)	(0.021)	(0.013)	(0.010)
Panel C. Centered at 75% quantile					
Log production last month	-0.157***	0.089***	0.256***	0.114***	0.048**
	(0.044)	(0.017)	(0.045)	(0.026)	(0.020)
Log income-expense ratio	0.039**	-0.010	-0.040***	-0.037***	-0.002
	(0.018)	(0.007)	(0.013)	(0.010)	(0.008)
Interaction term	-0.018	-0.001	0.104***	0.070***	-0.025*
	(0.033)	(0.013)	(0.029)	(0.019)	(0.015)
Controls	Yes	Yes	Yes	Yes	Yes
R-squared within households	0.426	0.114	0.381	0.252	0.094
Mean dependent variable	3.220	0.386	3.200	3.316	0.498
Number of observations	3114	3114	2051	3114	3114
Number of households	88	88	83	88	88

Notes: The analysis is restricted to households with variation in the share of milk sold to Tanykina, and weeks in which these households sell milk. The log of variable x is proxied by $\log(x+1)$. Controls include current milk production (in logs), median market milk price in the village (current and first lag, both in logs), prop. health shocks in last two weeks (current and last week), prop. of last two weeks with insurance coverage, an interaction of these two variables, and center-month fixed effects. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Semi-parametric estimates for milk marketing decisions (linear part)

	Log liters of milk sold in market	Share of milk sold to Tanykina	Log price of milk sold in market	Log price received on average	Share of dairy income from Tanykina
	(1)	(2)	(3)	(4)	(5)
Log milk production	1.473***	-0.062***	-0.834***	-0.514***	0.071***
	(0.054)	(0.019)	(0.094)	(0.045)	(0.015)
Log food expenditures in 1,000 Sh	-0.100**	0.028**	0.079***	0.054***	0.029**
	(0.045)	(0.012)	(0.030)	(0.019)	(0.013)
Village market price	-0.380***	0.114***	0.725***	0.366***	0.014
	(0.070)	(0.018)	(0.135)	(0.089)	(0.017)
Lagged village market price	-0.515***	0.094***	0.075***	0.090	0.058***
	(0.052)	(0.018)	(0.064)	(0.067)	(0.019)
HH member has health symptoms	0.095***	-0.040***	-0.022	-0.069***	-0.029
	(0.033)	(0.016)	(0.027)	(0.019)	(0.021)
HH has insurance coverage	0.010	-0.001	0.128***	0.085***	0.004
	(0.040)	(0.018)	(0.033)	(0.030)	(0.023)
... *X* HH member has health symptoms	-0.033	0.050**	-0.049	-0.012	0.059**
	(0.053)	(0.021)	(0.044)	(0.032)	(0.028)
Center-month effects	Yes	Yes	Yes	Yes	Yes
R-squared within households	0.437	0.141	0.407	0.271	0.130
Mean dependent variable	3.220	0.407	3.200	3.316	0.498
Number of observations	3114	3114	2051	3114	3114
Number of households	88	88	83	88	88

Notes: The analysis is restricted to households with variation in the share of milk sold to Tanykina, and weeks in which these households sell milk. The log of variable x is proxied by $\log(x+1)$. We report R^2 in the semiparametric regressions by the squared correlation coefficient between the demeaned y (minus household mean across time) and fitted value of demeaned y, $\tilde{y}_{it}$ and $\hat{\tilde{y}}_{it}$: $\tilde{y}_{it} \equiv y_{it} - \bar{y}_i$ and $\hat{\tilde{y}}_{it} \equiv (x_{it} - \bar{x}_i)'\hat{\beta} + \hat{m}(z_{it}) - \bar{\hat{m}}_i$, where $\bar{y}_i \equiv 1/T \sum_{t=1}^{T} y_{it}$, $\bar{x}_i \equiv 1/T \sum_{t=1}^{T} x_{it}$, and $\bar{\hat{m}}_i \equiv 1/T \sum_{t=1}^{T} \hat{m}(z_{it})$. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Factors influencing dairy income conditional and unconditional on selling milk

	Sells no milk to Tanykina (1)	Sells some milk to Tanykina (2)	Sells all milk to Tanykina (3)
Panel A. Centered at 25% quantile			
Log production last month	-0.057**	-0.038**	0.095***
	(0.025)	(0.018)	(0.025)
Log income-expense ratio	-0.014	-0.014	0.028*
	(0.016)	(0.012)	(0.016)
Panel B. Centered at 50% quantile			
Log production last month	-0.053**	-0.033*	0.086***
	(0.025)	(0.018)	(0.024)
Log income-expense ratio	-0.009	-0.007	0.016
	(0.011)	(0.008)	(0.011)
Panel C. Centered at 75% quantile			
Log production last month	-0.048*	-0.027	0.075***
	(0.026)	(0.019)	(0.025)
Log income-expense ratio	-0.000	0.004	-0.004
	(0.009)	(0.006)	(0.009)
Interaction term	0.014	0.018	-0.032**
Controls	Yes	Yes	Yes
R-squared within households	0.122	0.115	0.114
Mean dependent variable	0.319	0.347	0.335
Number of observations	2962	2962	2962
Number of households	88	88	88

Notes: The analysis is restricted to households with variation in the share of milk sold to Tanykina, and weeks in which these households sell milk. The log of variable x is proxied by $\log(x+1)$. Controls include current milk production (in logs), median market milk price in the village (current and first lag, both in logs), prop. health shocks in last two weeks (current and last week), prop. of last two weeks with insurance coverage, an interaction of these two variables, and center-month fixed effects. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Factors influencing milk production and consumption

	Unconditional on selling milk			Conditional on selling milk	
	(1)	(2)	(3)	(4)	(5)
	Log production (liters/week)	Household sold any milk this week		Share of milk production sold to any buyer	
Panel A. Centered at 25% quantile					
Log production last month	0.302***	0.054**	-0.010	0.033***	0.002
	(0.018)	(0.022)	(0.022)	(0.007)	(0.006)
Log income-expense ratio	-0.048***	-0.037***	-0.026**	-0.016***	-0.007*
	(0.011)	(0.013)	(0.012)	(0.004)	(0.004)
Panel B. Centered at 50% quantile					
Log production last month	0.315***	0.061***	-0.006	0.038***	0.004
	(0.018)	(0.021)	(0.022)	(0.006)	(0.006)
Log income-expense ratio	-0.031***	-0.027***	-0.021**	-0.009***	-0.003
	(0.008)	(0.009)	(0.009)	(0.003)	(0.003)
Panel C. Centered at 75% quantile					
Log production last month	0.331***	0.069***	-0.001	0.044***	0.008
	(0.018)	(0.021)	(0.022)	(0.007)	(0.006)
Log income-expense ratio	-0.002	-0.012	-0.011	0.002	0.003
	(0.008)	(0.009)	(0.009)	(0.002)	(0.002)
Interaction term	0.047***	0.025*	0.015	0.018***	0.010**
	(0.012)	(0.014)	(0.014)	(0.004)	(0.004)
Controls	Yes	Yes	Yes	Yes	Yes
Milk production	No	No	Yes	No	Yes
R-squared within households	0.602	0.346	0.367	0.319	0.446
Mean dependent variable	4.170	0.851	0.851	0.732	0.732
Number of households	88	88	88	88	88
Number of observations	3480	3480	3480	2962	2962

Notes: The analysis is restricted to households with variation in the share of milk sold to Tanykina, and weeks in which these households sell milk. The log of variable x is proxied by $\log(x+1)$. Controls include current milk production (in logs), median market milk price in the village (current and first lag, both in logs), prop. health shocks in last two weeks (current and last week), prop. of last two weeks with insurance coverage, an interaction of these two variables, and center-month fixed effects. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Heterogeneity by household type

	Number of HH members selling milk		Main dairy farmer is male		Main dairy farmer is household head		Main dairy farmer decides on cattle income	
	1	≥ 2	Yes	No	Yes	No	Yes	No
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Share of milk sold to Tanykina								
Log production last month	0.133***	0.128*	0.166***	0.137***	0.247***	0.060	0.182***	0.087
	(0.027)	(0.074)	(0.049)	(0.032)	(0.061)	(0.047)	(0.046)	(0.062)
Log income-expense ratio	-0.002	0.005	0.010	-0.008	-0.034	0.052**	-0.018	0.029
	(0.013)	(0.030)	(0.021)	(0.014)	(0.023)	(0.023)	(0.019)	(0.029)
... *X* Log production last month	-0.005	0.026	-0.009	0.031	0.056	-0.069**	0.013	-0.027
	(0.018)	(0.051)	(0.031)	(0.021)	(0.040)	(0.031)	(0.033)	(0.040)
R-squared within households	0.208	0.177	0.177	0.277	0.199	0.147	0.183	0.214
Mean dependent variable	0.368	0.429	0.399	0.386	0.454	0.341	0.427	0.346
Panel B. Log price per liter of milk sold								
Log production last month	0.104***	-0.052	-0.004	0.181***	0.145***	-0.019	0.087**	-0.073
	(0.033)	(0.052)	(0.037)	(0.049)	(0.041)	(0.046)	(0.036)	(0.058)
Log income-expense ratio	-0.046***	-0.084***	-0.073***	-0.051**	-0.070***	-0.065***	-0.070***	-0.086***
	(0.015)	(0.021)	(0.016)	(0.021)	(0.015)	(0.022)	(0.015)	(0.028)
... *X* Log production last month	0.057***	0.062*	0.053**	0.072**	0.098***	0.037	0.076***	0.070*
	(0.021)	(0.036)	(0.024)	(0.032)	(0.027)	(0.030)	(0.025)	(0.038)
R-squared within households	0.241	0.313	0.276	0.242	0.177	0.310	0.201	0.320
Mean dependent variable	3.308	3.286	3.287	3.323	3.327	3.271	3.314	3.273
Panel C. Share of income from Tanykina								
Log production last month	0.072**	0.078**	0.113***	0.111***	0.126***	0.040	0.053*	0.108**
	(0.030)	(0.039)	(0.030)	(0.035)	(0.034)	(0.036)	(0.030)	(0.044)
Log income-expense ratio	0.018	0.014	0.017	0.015	0.012	0.025	0.017	-0.010
	(0.014)	(0.016)	(0.013)	(0.015)	(0.013)	(0.017)	(0.012)	(0.021)
... *X* Log production last month	-0.028	-0.014	-0.033*	-0.001	0.007	-0.043*	-0.029	0.018
	(0.020)	(0.027)	(0.019)	(0.023)	(0.022)	(0.024)	(0.021)	(0.028)
R-squared within households	0.188	0.205	0.184	0.270	0.167	0.211	0.145	0.245
Mean dependent variable	0.483	0.512	0.491	0.507	0.573	0.425	0.537	0.432
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	1628	1334	2053	909	1421	1541	1809	1153
Number of households	47	41	62	26	42	46	55	33

Notes: The analysis is restricted to households with variation in the share of milk sold to Tanykina, and weeks in which these households sell milk. The log of variable x is proxied by $\log(x+1)$. Controls include current milk production (in logs), median market milk price in the village (current and first lag, both in logs), prop. health shocks in last two weeks (current and last week), prop. of last two weeks with insurance coverage, an interaction of these two variables, and center-month fixed effects. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Heterogeneity by time of the year/month

	First half of the month		Middle of the month		First half year (dry season)	
	Yes	No	Yes	No	Yes	No
Panel A. Share of milk sold to Tanykina						
Log production last month	0.265***	0.014	0.184***	0.046	0.143***	0.183***
	(0.059)	(0.041)	(0.055)	(0.034)	(0.047)	(0.068)
Log income-expense ratio	-0.045*	0.041**	-0.031	0.039**	0.017	-0.029
	(0.024)	(0.020)	(0.024)	(0.017)	(0.019)	(0.027)
... *X* Log production last month	0.052	-0.032	0.044	-0.061**	-0.034	0.078*
	(0.035)	(0.032)	(0.035)	(0.026)	(0.028)	(0.043)
R-squared within households	0.277	0.121	0.238	0.176	0.163	0.124
Mean dependent variable	0.406	0.384	0.399	0.391	0.385	0.411
Panel B. Log price per liter of milk sold						
Log production last month	0.122**	-0.019	0.063	-0.029	0.019	0.151***
	(0.048)	(0.036)	(0.042)	(0.038)	(0.034)	(0.058)
Log income-expense ratio	-0.090***	-0.070***	-0.109***	-0.025	-0.039***	-0.092***
	(0.020)	(0.018)	(0.018)	(0.019)	(0.014)	(0.023)
... *X* Log production last month	0.090***	0.040	0.117***	0.003	0.030	0.118***
	(0.029)	(0.028)	(0.027)	(0.029)	(0.020)	(0.037)
R-squared within households	0.264	0.264	0.275	0.207	0.199	0.134
Mean dependent variable	3.300	3.296	3.292	3.305	3.339	3.237
Panel C. Share of income from Tanykina						
Log production last month	0.096**	0.044	0.100***	0.029	0.005	0.121***
	(0.038)	(0.031)	(0.030)	(0.037)	(0.035)	(0.034)
Log income-expense ratio	0.003	0.022	0.002	0.042**	0.032**	0.013
	(0.015)	(0.015)	(0.013)	(0.019)	(0.014)	(0.014)
... *X* Log production last month	-0.004	-0.042*	-0.005	-0.063**	-0.047**	-0.016
	(0.022)	(0.024)	(0.019)	(0.028)	(0.021)	(0.022)
R-squared within households	0.182	0.164	0.162	0.172	0.105	0.197
Mean dependent variable	0.503	0.489	0.492	0.501	0.493	0.501
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	1541	1421	1646	1316	1772	1190
Number of households	88	88	88	88	86	81

Notes: The analysis is restricted to households with variation in the share of milk sold to Tanykina, and weeks in which these households sell milk. The log of variable x is proxied by $\log(x+1)$. Controls include current milk production (in logs), median market milk price in the village (current and first lag, both in logs), prop. health shocks in last two weeks (current and last week), prop. of last two weeks with insurance coverage, an interaction of these two variables, and center-month fixed effects. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix

There are three parts in this appendix. In part A, we give a detailed analysis of the effect of changes in predetermined milk production, m_{t-1}, and non-dairy net income, y_t, on the amount of milk sold in the market, s_t. In part B, we provide a brief introduction to the local linear kernel estimator and give asymptotic properties of $\hat{\beta}$ and $\hat{M}(z)$, based on which we construct confidence intervals. Consistent estimators of the covariance matrices and bandwidth selection method are also provided. Part C provides additional tables and figures that are not included in the main text.

A Analysis of the effect of changes in m_{t-1} and y_t on s_t

The first-order derivative of life-time utility (1) in s_t is

$$p_t u'\left(y_t + p_t s_t + m_{t-1} - s_{t-1}\right) - \beta u'\left(y_{t+1} + p_{t+1} s_{t+1} + m_t - s_t\right). \tag{A.1}$$

In order to analyze the effect of changes in m_{t-1} and y_t in this framework with an infinite horizon, we first suppose that income, prices and milk production are stable over time, which we denote by $\bar{y}$, $\bar{p}$, and $\bar{m}$ respectively. In that case, the quantity sold in the local spot market should also be stable. Denote this quantity $\bar{s}$. Then the first-order derivative (A.1) becomes

$$\bar{p}u'(\bar{y} + \bar{p}s_t + \bar{m} - \bar{s}) - \beta u'(\bar{y} + \bar{p}\bar{s} + \bar{m} - s_t). \tag{A.2}$$

Lemma 1 illustrates where farmers sell their milk in equilibrium under various conditions. Assume that the optimal s_t is determined only by the contemporaneous first-order condition (A.2), taking s_{t+1} at the equilibrium level $\bar{s}$.

Lemma 1. *Consider the utility maximization problem given in* (1). *An equilibrium exists in which: (1) if $\bar{p} < \beta$, the farmer sells all milk to the cooperative, i.e., $\bar{s} = 0$; (2) if $\bar{p} > \beta$, the farmer sells all milk in the local spot market, i.e., $\bar{s} = \bar{m}$; (3) if $\bar{p} = \beta$, the farmer is indifferent where to sell, i.e., $\bar{s} \in (0, \bar{m})$.*

Proof. Suppose the farmer always sells to the cooperative, $\bar{s} = 0$. In a given period, the first-order derivative evaluated at $s_t = 0$ reduces to

$$\bar{p}u'(\bar{y} + \bar{m}) - \beta u'(\bar{y} + \bar{m}) < 0, \qquad \forall\, \bar{p} < \beta, \tag{A.3}$$

and the farmer will not sell any milk in the local spot market. Likewise, suppose the farmer always sells in the local spot market, $\bar{s} = \bar{m}$. In a given period, the first derivative of utility evaluated at $s_t = \bar{m}$ is

$$\bar{p}u'(\bar{y} + \bar{p}\bar{m}) - \beta u'(\bar{y} + \bar{p}\bar{m}) > 0, \qquad \forall\, \bar{p} > \beta, \tag{A.4}$$

and the farmer will not sell any milk to the cooperative. Thus, with stable income, prices and milk production, farmers will deliver their milk to the cooperative if $\bar{p} < \beta$, when the market price is relatively low and future payments are not discounted heavily, while they sell their milk in the local spot market if $\bar{p} > \beta$, when discounting is stronger and the market offers a relatively higher price. Finally, if $\bar{p} = \beta$, farmers are indifferent where to sell but the equilibrium is unstable since slight $\bar{s}$ will fluctuate between 0 and $\bar{m}$ due to changes in y_t or m_{t-1}, as will be shown later in Section A.3. □

The remainder provides a qualitative analysis of how the quantity of milk sold in local spot markets (s_t) vary in the net non-dairy income and predetermined milk production (y_t, m_{t-1}). We consider the three cases in equilibrium: one in which farmers sold all milk to the cooperative, and one in which all milk was previously sold in the local market, together with the third case in which farmers are indifferent where to sell the milk.

A.1 Farmers sold all milk to the cooperative, $\bar{s} = 0$

Consider the case in which $\bar{p} < \beta$. Lemma 2 analyzes how farmers respond to changes in (y_t, m_{t-1}), when they sold all milk to the cooperative in the previous period. Assume that the potential compensating effect of s_{t-1} caused by changes in m_{t-1} is smaller than changes of m_{t-1} in itself.

Lemma 2. *Consider the utility maximization problem given in* (1) *in the equilibrium when $\bar{p} < \beta$ such that $\bar{s} = 0$. Then, (1) if there is an increase in current income, $y_t > \bar{y}$, and/or past milk production, $m_{t-1} > \bar{m}$, $s_t = 0$; (2) if there is a decrease in y_t and/or m_{t-1}, such that $u'(y_t + m_{t-1})/u'(\bar{y} + \bar{m}) > \beta/\bar{p}$, then $s_t > 0$. Further, if the response s_t satisfies $u'(\bar{y} + \bar{m} - s_t)/u'(\bar{y} + \bar{m}) > \beta/\bar{p}$, then also $s_{t+1} > 0$.*

Proof. When there is an increase in y_t and/or m_{t-1}, it is straightforward that s_t remains at zero since the negative first-order derivative (A.3) now becomes even more enforced due to (a) an increase in y_t and/or m_{t-1}; (b) concavity of the utility function; and (c) the assumption that changes in s_{t-1} caused by m_{t-1} is not enough to compensate changes of m_{t-1} in itself, which is generally true.[11]

Now suppose that income in the current period t reduces to $y_t < \bar{y}$, and/or milk production at time $t-1$ reduces to $m_{t-1} < \bar{m}$. In that case, the marginal utility of selling milk in the spot market at the time t, evaluated at $s_t = 0$ (so that the next period, the farmer earns $\bar{y} + \bar{m}$, and will again not sell any milk in the

[11] s_{t-1} might deviate from zero if the increase in m_{t-1} is significantly large.

local spot market, $s_{t+1}=0$), is[12]

$$\bar{p}u'(y_t+m_{t-1})-\beta u'(\bar{y}+\bar{m})>0, \quad \textit{iff} \quad u'(y_t+m_{t-1})/u'(\bar{y}+\bar{m})>\beta/\bar{p}>1. \tag{A.5}$$

As a result, if y_t and/or m_{t-1} drops significantly far away from their equilibrium values such that $u'(y_t+m_{t-1})/u'(\bar{y}+\bar{m})$ is larger than $\beta/\bar{p}$, it will be optimal to sell some milk in the local spot market, even when prices in the local spot market are a factor β below prices offered by cooperatives. In that case, in the next period, income from the cooperative will be lower, and if the reduction in dairy income is large enough such that at time $t+1$,

$$\bar{p}u'(\bar{y}+\bar{m}-s_t)-\beta u'(\bar{y}+\bar{m})>0, \quad \textit{iff} \quad u'(\bar{y}+\bar{m}-s_t)/u'(\bar{y}+\bar{m})>\beta/\bar{p}>1, \tag{A.6}$$

farmers will continue selling some milk in the local market ($s_{t+1}>0$). Note that since responses of s_t due to changes in (y_t,m_{t-1}) in general is smaller than changes of (y_t,m_{t-1}) in themselves, condition (A.6) is much harder to be satisfied than condition (A.5) unless there is a trend in changes in milk production or net income.

Thus, in response to an unexpected drop in current non-dairy income, y_t, and/or predetermined milk production, m_{t-1}, farmers who delivered all milk to the cooperative will *increase* the quantity of milk sold in the local market. This, however, reduces future payments from the cooperative. Lower cash at hand in future periods may induce the farmer to keep selling some of its milk in the local market. □

A.2 Farmers sold all milk in the local market, $\bar{\mathbf{s}}=\bar{\mathbf{m}}$

Now consider the case where $\bar{p}>\beta$, so that the farmer sells all milk in the local market.

Lemma 3. *Consider the utility maximization problem given in* (1) *in the equilibrium when $\bar{p}>\beta$ such that $\bar{s}=\bar{m}$. Then, (1) if there is a decrease in current income, $y_t<\bar{y}$, and/or past milk production, $m_{t-1}<\bar{m}$, $s_t=\bar{m}$; (2) if there is an increase in y_t and/or m_{t-1}, such that $u'(y_t+\bar{p}\bar{m}+m_{t-1}-s_{t-1})/u'(\bar{y}+\bar{p}\bar{m})<\beta/\bar{p}$, then $s_t<\bar{m}$. Further, if the response s_t satisfies $u'(\bar{y}+\bar{p}\bar{m}+\bar{m}-s_t)/u'(\bar{y}+\bar{m})<\beta/\bar{p}$, then also $s_{t+1}<\bar{m}$.*

Proof. By a similar analysis as Lemma 2 in previous section, a decrease in y_t and/or m_{t-1} will not deviate s_t from its equilibrium level $\bar{m}$ since the positive first-order derivative (A.4) becomes more enforced. We consider the effect of an increase in current net income, $y_t>\bar{y}$, and/or predetermined milk production, $m_{t+1}>\bar{m}$. The first-order derivative, evaluated at $s_t=\bar{m}$ (so that the next period is not affected, leaving $s_{t+1}=\bar{m}$), is now[13]

$$\bar{p}u'(y_t+\bar{p}\bar{m}+m_{t-1}-s_{t-1})-\beta u'(\bar{y}+\bar{p}\bar{m})<0 \quad \textit{iff} \quad u'(y_t+\bar{p}\bar{m}+m_{t-1}-s_{t-1})/u'(\bar{y}+\bar{p}\bar{m})<\beta/\bar{p}<1.$$

[12] s_{t-1} remains at zero with a decrease in m_{t-1}.

[13] s_{t-1} increases with m_{t-1}, but not necessarily equals to m_{t-1}, since farmers might want to smooth consumption by delivering some milk to the cooperative.

As a result, if the increase in y_t and/or m_t are large enough such that $u'(y_t + \bar{p}\bar{m} + m_{t-1} - s_{t-1})/u'(\bar{y} + \bar{p}\bar{m})$ is less than $\beta/\bar{p}$, it will be optimal to sell some milk to the cooperative instead of selling all in the local market. Thus, for farmers selling all milk in the local market, an sufficient increase in net income and/or milk production will induce them to start selling milk to the cooperative.

Moreover, farmers will continue to prefer selling some milk to the cooperative in the next period $t+1$ if the deferred payment for milk delivered at time t is above a certain threshold such that

$$\bar{p}u'(\bar{y} + \bar{p}\bar{m} + \bar{m} - s_t) - \beta u'(\bar{y} + \bar{m}) < 0, \quad \textit{iff} \quad u'(\bar{y} + \bar{p}\bar{m} + \bar{m} - s_t)/u'(\bar{y} + \bar{m}) < \beta/\bar{p} < 1.$$

In that case, an increase in either past milk production or current non-dairy income continues to improve the quantity of milk delivered to the cooperative, also in future periods. □

A.3 Farmers are indifferent where to sell the milk, $\bar{\mathbf{s}} \in (\mathbf{0}, \bar{\mathbf{m}})$

With $\bar{p} = \beta$, farmers are indifferent where to sell the milk, and $\bar{s}$ could in anywhere between zero and $\bar{m}$, but unstable.

Lemma 4. *Consider the utility maximization problem given in* (1) *in the equilibrium when $\bar{p} = \beta$ such that $\bar{s} \in (0, \bar{m})$. Then, (1) if there is a decrease in current income, $y_t < \bar{y}$, and/or past milk production, $m_{t-1} < \bar{m}$, then $\bar{s} < s_t < s_{t+1} < \cdots$, but $\{s_t\}$ does not necessarily converge to $\bar{m}$ depending on the property of underlying utility function; (2) if there is an increase in y_t and/or m_{t-1}, then $\bar{s} > s_t > s_{t+1} > \cdots$, and $\{s_t\}$ does not necessarily converge to 0.*

Proof. Whenever there is a shift in (y_t, m_{t-1}), s_t will response in the opposite direction to maintain a zero first-order derivative (A.1). This effect will pass along into future, and is decreasing return to scale which can be seen by comparing the partial derivatives of the first-order condition (setting (A.1) equal to zero) with respect to s_t and s_{t-1}, respectively. In this sense, the new equilibrium $\bar{s}$ does not necessarily converge to zero or $\bar{m}$ due to a one-time shift in (y_t, m_{t-1}), all else equal. □

B Semi-parametric estimator and its implementation

B.1 Local linear kernel estimator

To conceptualize this estimation process, let $\alpha = (\alpha_2, \cdots, \alpha_n)'$, $D = (I_n \otimes i_T)d_n$, $d_n = (-i_{n-1}, I_{n-1})'$ and z is a vector with past milk production, m_{t-1}, and net income, y_{it}. We can then write Equation (2) in matrix form:

$$Y = D\alpha + M + X\beta + v, \tag{B.1}$$

where $Y = (y_{11}, \cdots, y_{1T}, y_{21}, \cdots, y_{nT})'$, $X = (x_{11}, \cdots, x_{1T}, x_{21}, \cdots, x_{nT})'$, $v = (v_{11}, \cdots, v_{1T}, x_{21}, \cdots, v_{nT})'$, and $M = (m(z_{11}), \cdots, m(z_{1T}), m(z_{21}), \cdots, m(z_{nT}))'$.

Using this matrix form, the estimation process proceeds as follows:

1. If α and β were known, we have a purely non-parametric regression:

$$Y - D\alpha - X\beta = M + v.$$

2. Obtain the local linear estimator for $M(z) \equiv \big(m(z), (H\dot{m}(z))'\big)'$ that includes $m(z)$:

$$M_{\alpha,\beta}(z) = S(z)(Y - D\alpha - X\beta), \qquad m_{\alpha,\beta}(z) = s(z)'(Y - D\alpha - X\beta), \tag{B.2}$$

   where $S(z)$ and $s(z)$ are the local linear pre-multipliers, explicitly defined in the appendix.

3. Apply the unfeasible estimator $m_{\alpha,\beta}(z_{it})$ for $m(z_{it})$ in (B.1) and rearrange. By partitioned regression formula, we obtain the least square parametric estimators:

$$\hat{\beta} = (X^{*\prime} M^* X^*)^{-1} X^{*\prime} M^* Y^*, \qquad \hat{\alpha} \equiv (\hat{\alpha}_2, \cdots, \hat{\alpha}_n)' = (D^{*\prime} D^*)^{-1} D^{*\prime}(Y^* - X^*\hat{\beta}). \tag{B.3}$$

   where $A^* \equiv (I_{nT} - S)A$, for $A = Y, X, D$; $S \equiv (s_{11}, \cdots, s_{1T}, s_{21}, \cdots, s_{nT})'$ and $s_{it} \equiv s(z_{it})$.

4. Plugging $\hat{\beta}$ and $\hat{\alpha}$ back to (B.2), we have the estimators for $M(z)$ and $m(z)$:

$$\hat{M}(z) = S(z)\big(Y - D\hat{\alpha} - X\hat{\beta}\big), \qquad \hat{m}(z) = s(z)'\big(Y - D\hat{\alpha} - X\hat{\beta}\big). \tag{B.4}$$

   Estimator for α_1 follows as $\hat{\alpha}_1 = -\sum_{i=2}^{n} \hat{\alpha}_i$.

Local linear kernel estimator is used throughout this paper due to its advantages over Nadaraya-Watson estimator (bias reduction, better behavior at boundary, ability to estimate derivatives, etc., see Fan, 1992, 1993). To facilitate the understanding of the estimation procedure, here we take Equation (B.2), the unfeasible local linear estimators, as an example. Denote the pseudo regressand as $y^*_{it} \equiv y_{it} - \alpha_i - x'_{it}\beta$ and put in vector form $Y^* = (y^*_{11}, \cdots, y^*_{1T}, y^*_{21}, \cdots, y^*_{nT})'$. Given $\mathrm{E}(y^*_{it}|z_{it}) = m(z_{it})$, for z_{it} of size 2×1, the unfeasible local linear estimators for $M(z) \equiv \left(m(z), (H\dot{m}(z))'\right)'$ and $m(z)$ are given as:

$$\begin{aligned} M_{\alpha,\beta}(z) &= \arg\min_{\theta \in \mathbb{R}^3} \sum_{i=1}^{n}\sum_{t=1}^{T} \left(y_{it}^* - \theta_0 - (z_{it}' - z')(\theta_1, \theta_2)'\right)^2 K\left(H^{-1}(z_{it} - z)\right) \\ &= \arg\min_{\theta \in \mathbb{R}^3} \left(Y^* - \vec{Z}(z)\theta\right)' \mathbf{K}_H(z) \left(Y^* - \vec{Z}(z)\theta\right), \end{aligned} \tag{B.5}$$

where $\vec{Z}(z) \equiv \left(Z_{11}(z), \cdots, Z_{1T}(z), Z_{21}(z), \cdots, Z_{nT}(z)\right)'$, $Z_{it}(z) \equiv \left(1, H^{-1}(z_{it} - z)'\right)'$, and $\mathbf{K}_H(z) \equiv diag\{K_H(z_{it} - z)\}_{i,t=1}^{n,T}$. $K_H(z) \equiv |H|^{-1}K(H^{-1}z)$, where $K(z)$ is a kernel function on $\mathbb{R}^2$, $H = diag(h_1, h_2)$ is matrix of bandwidths, and $|H|$ is the determinant of H.

Minimization in (B.5) gives $M_{\alpha,\beta}(z) = \left(\vec{Z}(z)'\mathbf{K}_H(z)\vec{Z}(z)\right)^{-1}\vec{Z}(z)'\mathbf{K}_H(z)Y^* \equiv S(z)Y^*$, and $m_{\alpha,\beta}(z) = s(z)'Y^*$, where $s(z)' \equiv e'S(z)$ and $e = (1,0,0)'$. Here, $S(z)$ and $s(z)'$ are the local linear estimator pre-multipliers in Equation (B.2) and (B.4).

B.2 Asymptotic properties of $\hat{\beta}$ and $\hat{M}(z)$

Asymptotic properties of $\hat{\beta}$ and $\hat{M}(z)$ are established in Su and Ullah (2006) in Theorem 3.1 and 3.2 respectively under assumptions A1-A7. For $\hat{\beta}$, let $\tilde{x}_{it} = x_{it} - \mathrm{E}(x_{it}|z_{it})$, $\vec{x}_{it} = x_{it} - \left(s(z_{it})'X\right)'$, and $\hat{v}_{it} = y_{it} - x_{it}'\hat{\beta} - \hat{m}(z_{it}) - \hat{\alpha}_i$, we have

$$\sqrt{n}(\hat{\beta} - \beta) \xrightarrow{d} \mathcal{N}\left(0, \Sigma\right), \tag{B.6}$$

where $\Sigma = \Phi^{-1}\Omega\Phi^{-1}$, $\Phi = \sum_t \mathrm{E}\left(\tilde{x}_{it}(\tilde{x}_{it} - \sum_s \tilde{x}_{is}/T)'\right)$, and $\Omega = \sum_s\sum_t \mathrm{E}\left(\tilde{x}_{it}(\tilde{x}_{is} - \sum_l \tilde{x}_{il}/T)'v_{it}v_{is}\right)$. A consistent estimator for Σ is given by $\hat{\Sigma} = \hat{\Phi}^{-1}\hat{\Omega}\hat{\Phi}^{-1}$, where $\hat{\Phi} = n^{-1}\sum_i\sum_t \vec{x}_{it}(\vec{x}_{it} - \sum_l \vec{x}_{il}/T)'$, $\hat{\Omega} = n^{-1}\sum_i\sum_t\sum_s \vec{x}_{it}(\vec{x}_{is} - \sum_l \vec{x}_{il}/T)'\hat{v}_{it}\hat{v}_{is}$.

For $\hat{M}(z)$, let $\bar{f}(z) = \sum_t^T f_t(z)$, $\tilde{v}_{it} = v_{it} - T^{-1}\sum_{s=1}^T v_{is}$, $\sigma_t^2(z) = \mathrm{E}(\tilde{v}_{it}^2|z_{it} = z)$, and $\bar{\sigma}^2(z) = \sum_{t=1}^T \sigma_t^2(z)f_t(z)$, we have

$$\sqrt{n|H|}\left(\hat{M}(z) - M(z) - Q^{-1}\begin{pmatrix} \frac{\bar{f}(z)}{2}tr(\int_{\mathbb{R}^2} uu'K(u)\mathrm{d}uH\ddot{m}(z)H) \\ 0 \end{pmatrix}\right) \xrightarrow{d} \mathcal{N}\left(0, Q^{-1}\Gamma Q^{-1}\right), \tag{B.7}$$

where $\ddot{m}(z)$ is the second order derivative matrix of $m(\cdot)$ at z,

$$Q = \bar{f}(z)\begin{pmatrix} 1 & 0' \\ 0 & \int_{\mathbb{R}^2} uu'K(u)\mathrm{d}u \end{pmatrix}, \quad \Gamma = \bar{\sigma}^2(z)\begin{pmatrix} \int_{\mathbb{R}^2} K(u)^2\mathrm{d}u & 0' \\ 0 & \int_{\mathbb{R}^2} uu'K(u)\mathrm{d}u \end{pmatrix}.$$

The asymptotic normal distribution derived in Equation (B.7) can be used to obtain pointwise confidence intervals for the non-parametric estimator $\hat{M}(\cdot)$. As it is argued in Härdle and Linton (1994), in practice, it is usual to ignore the bias term since it usually depends on higher order derivatives of the regression function, in our case, $\ddot{m}(\cdot)$. Thus we choose a smaller bandwidth than cross-validation method to make the bias relatively small. In our application, we adopt the commonly used Epanechnikov product kernel,

$K(u) \equiv \prod_{i=1}^{2} k(u_i)$, where $k(u) = 0.75(1-u^2)1(|u| \leq 1)$. Let $\mu_i \equiv \int_{\mathbb{R}} u^i k(u)\mathrm{d}u$, $\nu_i \equiv \int_{\mathbb{R}} u^i k(u)^2 \mathrm{d}u$. Then, $\int_{\mathbb{R}^2} uu'K(u)\mathrm{d}u = \begin{pmatrix} \mu_2\mu_0 & \mu_1^2 \\ \mu_1^2 & \mu_2\mu_0 \end{pmatrix} = \begin{pmatrix} 1/5 & 0 \\ 0 & 1/5 \end{pmatrix}$, and $\int_{\mathbb{R}^2} K(u)^2 \mathrm{d}u = \nu_0^2 = 3/5$.

By Equation (B.7), it is easy to obtain the element-wise asymptotic normal distribution for $\hat{m}(\cdot)$ and the slope estimator, $\hat{\dot{m}}_i(\cdot)$, for $i = 1,2$,

$$\sqrt{n|H|}\left(\hat{m}(z) - m(z) - \frac{\mu_2}{2}\sum_{i=1}^{2} h_i^2 \ddot{m}_{ii}(z)\right) \xrightarrow{d} \mathscr{N}\left(0, \frac{\nu_0^2 \bar{\sigma}^2(z)}{\bar{f}^2(z)}\right), \tag{B.8}$$

$$\sqrt{nh_i^2|H|}\left(\hat{\dot{m}}_i(z) - \dot{m}_i(z)\right) \xrightarrow{d} \mathscr{N}\left(0, \frac{\nu_0\nu_2\bar{\sigma}^2(z)}{\mu_2^2\bar{f}^2(z)}\right), \tag{B.9}$$

where $\bar{f}(z) = \sum_t^T f_t(z)$, $\bar{\sigma}^2(z) = \sum_{t=1}^T \sigma_t^2(z) f_t(z)$, $\dot{m}_i(z)$ is the i^{th} element in the the first derivative vector of $m(\cdot)$ at z, and $\ddot{m}_{ii}(z)$ is the i^{th} diagonal element in the the second derivative matrix of $m(\cdot)$ at z.

A limited number of observations is a challenge in estimation the variance function for each period. For simplicity, we assume homoscedasticity and the same joint density function of the covariates across time, i.e., $\sigma_t^2(z) = \sigma_t^2 < \infty$ and $f_t(z) = f(z)$. Then, we have $\frac{\bar{\sigma}^2(z)}{\bar{f}^2(z)} = \frac{\sum_{t=1}^T \sigma_t^2}{T^2 f(z)}$. A consistent estimator for σ_t^2 is $\hat{\sigma}_t^2 = n^{-1}\sum_{i=1}^n \hat{\tilde{v}}_{it}^2$, where $\hat{\tilde{v}}_{it} = \hat{v}_{it} - T^{-1}\sum_{s=1}^T \hat{v}_{is}$. We use the consistent Rosenblatt density estimator $\hat{f}(z)$ to approximate $f(z)$, where $\hat{f}(z) \equiv (nT|H|)^{-1}\sum_{i=1}^n \sum_{t=1}^T K\big(H^{-1}(z_{it} - z)\big)$. $K(\cdot)$ is the Epanechnikov product kernel and H is obtained using cross-validation method. Thus, based on (B.8), (B.9), and estimators for the covariances, the point-wise 95% confidence intervals of $\hat{m}(z)$ and $\hat{\dot{m}}_i(z)$ are constructed respectively as $\mathrm{CI}(z) = [\hat{m}(z) - 2s(z), \hat{m}(z) + 2s(z)]$, $\mathrm{CI}_i(z) = [\hat{\dot{m}}_i(z) - 2s_i(z), \hat{\dot{m}}_i(z) + 2s_i(z)]$, where $s(z) = \big((n\hat{h}_1\hat{h}_2 T^2 \hat{f}(z))^{-1}\nu_0^2 \sum_{t=1}^T \hat{\sigma}_t^2\big)^{1/2}$ and $s_i(z) = \big((n\hat{h}_1\hat{h}_2\hat{h}_i^2\mu_2^2 T^2 \hat{f}(z))^{-1}\nu_0\nu_2\sum_{t=1}^T \hat{\sigma}_t^2\big)^{1/2}$, for $i = 1,2$.

B.3 Bandwidth selection

In non-parametric estimation, bandwidth selection is crucial in order to obtain a good estimate. We choose bandwidths using leave-one-out cross-validation method. Specifically, given that $z = (z_1, z_2)'$ consists of two variables, let $h \equiv (h_1, h_2) = (c_1\hat{s}_{z_1}(nT)^{-1/6}, c_2\hat{s}_{z_2}(nT)^{-1/6})$, where $\hat{s}_{z_i}$ is sample deviation of z_i for $i = 1,2$. We choose h to be

$$\tilde{h} = \arg\min_{h\in\mathbf{H}} CV(h) \equiv \arg\min_{h\in\mathbf{H}} \frac{1}{nT}\sum_{i=1}^{n}\sum_{t=1}^{T}\left(y_{it} - \hat{m}^{-it}(z_{it})\right)^2, \tag{B.10}$$

where $\hat{m}^{-it}(z_{it})$ is the local linear estimator for $\mathrm{E}(y_{it}|z_{it} = z)$ obtained by deleting the observation z_{it}. Consistent with Su and Ullah (2006), $\tilde{h}$ is derived by a grid search over the mesh grid $\mathbf{H}$ of two dimensions, with each constructed by an interval $[0.1\hat{s}_{z_i}(nT)^{-1/6}, 10\hat{s}_{z_i}(nT)^{-1/6}]$ over 20 steps for $i = 1,2$. Thus, $\mathbf{H}$ consists of 400 points in total. Denote the constants that associated with $\tilde{h}$ as $(\hat{c}_1, \hat{c}_2)$. Note that there is an asymptotic bias term in $\hat{M}(z)$, as is shown in (B.7). It's more convenient to undersmooth a little bit (i.e., let $nh^6 \to 0$ as $n \to \infty$) than estimating the unknown term $\ddot{m}(z)$ in the bias. Thus, in practice we choose bandwidths $\hat{h} \equiv (\hat{c}_1\hat{s}_{z_1}(nT)^{-1/6-0.01}, \hat{c}_2\hat{s}_{z_2}(nT)^{-1/6-0.01})$.

To implement Rosenblatt density estimators, we choose cross-validation method that minimizes estimate of the integrated squared error (ISE), $\int(\hat{f}(z)-f(z))^2\mathrm{d}z$. In particular,

$$\hat{h}_d = \arg\min_h CV_d(h) \equiv \arg\min_h \left\{ \frac{1}{(nT)^2|H|}\sum_{i_1=1}^{n}\sum_{t_1=1}^{T}\sum_{i_2=1}^{n}\sum_{t_2=1}^{T}\bar{K}\left(H^{-1}(z_{i_1t_1}-z_{i_2t_2})\right) \right.$$
$$\left. -\frac{2}{nT(nT-1)|H|}\sum_{i_1=1}^{n}\sum_{t_1=1}^{T}\sum_{(i_2,t_2)\neq(i_1,t_1)}K\left(H^{-1}(z_{i_1t_1}-z_{i_2t_2})\right)\right\} \tag{B.11}$$

where $\bar{K}(\cdot)$ is the convolution function of the kernel $K(\cdot)$. For Epanechnikov product kernel, $\bar{K}(u) = \bar{k}(u_1)\bar{k}(u_2)$, where $\bar{k}(u) = \int k(x)k(x-u)\mathrm{d}x = \frac{3}{160}(2-|u|)^3(u^2+6|u|+4)1(|u|\leq 2)$. $\hat{h}_d$ is obtained using 'fminsearch' in Matlab R2016a with initial value $h_0 = (\hat{s}_{z_1},\hat{s}_{z_2})(nT)^{-1/6}$. This command uses Nelder-Mead simplex direct search algorithm developed in Lagarias et al. (1998).

C Appendix Figures and Tables

Figure 15: Fitted share of dairy income for which the farmer defers payments

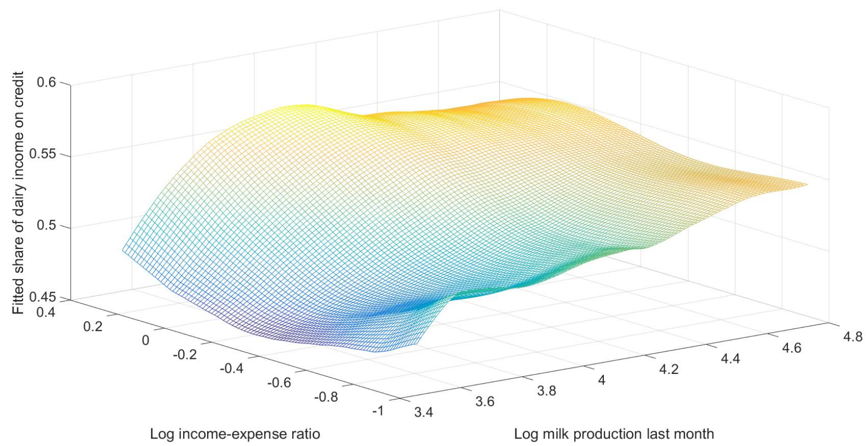

Figure 16: Fitted slopes and 95% confidence intervals for share of income deferred