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Household milk production, milk purchase and child nutrition: Panel data evidence from rural Uganda

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Abstract

The burden of low-quality diets and childhood undernutrition is widespread in rural areas in Sub-Saharan Africa, where households rely mostly on agriculture. Various empirical studies have shown the relative importance of the market, and hence food purchases, compared with farm diversification in raising dietary diversity. But are these findings applicable to all food markets? In the case of highly perishable milk, which characterises its production in rural Africa, and the low community ownership of cows, an important research question is whether milk is available in markets and whether milk purchases contribute to the nutrition of children in smallholder households. Using panel data from rural Uganda, we estimate conditional mixed-process models and find positive effects of both household milk production and milk purchases on height-for-age z-scores. We find that milk purchases and milk production are complements, and therefore a strategy combining increases in milk productivity, dairy market development and social protection programmes to increase economic access to milk markets could improve child nutrition.

Key words: milk production, milk purchases, child milk consumption, height-for-age z-scores, rural Uganda

1. Introduction

Childhood undernutrition remains a public health burden in low- and middle-income countries, (FAO/IFAD/UNICEF/WFP/WHO 2018). Poorly nourished children, specifically those below five years of age, are at higher risk of attack from infections and diseases due to impaired immunity of their systems (Bourke *et al*. 2016). Recurrence of these conditions influences stunting (low height for age) in children. Undernutrition not only undermines a child's physical growth, but also hinders their cognitive development and reduces educational attainment, as well as the earning ability of an individual in the long term (Alderman *et al*. 2006; Black *et al*. 2013). Inappropriate feeding practices and the intake of diets deficient in essential macro- and micronutrients are key underlying causes of child undernutrition in low- and middle-income countries (UNICEF 1991).

Animal-source foods (ASF) have readily available essential nutrients that may be difficult to obtain from the plant-based diets that are dominant in low-income countries. Milk is particularly important in low-resource populations, which often have limited access to other foods of animal origin (Hoddinott *et al*. 2015; Food and Agricultural Organization of the United Nations [FAO] 2013). Milk carries protein, calcium, vitamin A, vitamin B12 and riboflavin, and its consumption has been found to improve the intake of these nutrients and contribute to the daily energy requirements of young children in low-income populations (Murphy & Allen 2003; Iannotti & Lesorogol 2014). Accordingly, many studies (for example Dror & Allen 2011; Darapheak *et al*. 2013; Krasevec *et al*. 2017; Choudhury & Headey 2018; Headey *et al*. 2018) show that including milk in the diets of under-fives improves their nutritional status. Despite its nutritional importance, evidence based on demographic and health surveys (DHS) shows that milk is underprovided in the diets of young children in sub-Saharan Africa (SSA). For instance, Belay *et al*. (2022) found that the diets of 75% of children aged six to 23 months in SSA do not have milk or other dairy products. The effect of low milk consumption on the nutritional status of children under the age of five might delay countries' attainment of the Sustainable Development Goals geared toward improving young children's health and wellbeing.

In SSA, the burden of poor-quality diets and childhood undernutrition is more prevalent in rural areas, where households depend mainly on agriculture, than in urban areas (Garret & Ruel 1999; Smith *et al*. 2005; Dror & Allen 2011; Headey *et al*. 2018). Uganda is no exception when it comes to the rural-urban difference in child nutritional outcomes. The 2016 Uganda DHS shows that only 26.6% of rural children aged six to 23 months (versus 43.5% in urban areas) were given milk in a 24-hour recall period (Uganda Bureau of Statistics [UBOS] & ICF 2018). Moreover, only 28.4% of children aged six to 23 months achieved the minimum dietary diversity (MDD) in rural areas compared with 36.6% in urban areas. This corresponds to a stunting prevalence of 30% in rural areas, which is six percentage points higher than that in urban areas. Such poor dietary outcomes might be attributed to the limited physical and economic access to food markets, which characterises many rural agricultural households in SSA. In this instance, subsistence-oriented households that diversify their production are more likely to have a diversified diet by consuming own-produced foods. Based on this premise, agriculture nutrition-sensitive interventions such as cow and dairy heifer ownership that potentially address the availability of milk to a farm household have been promoted by governments and development partners in low- and middle-income countries.

The literature that evaluates these interventions is largely in agreement that there is a positive association between household cow ownership and child growth (Nicholson *et al*. 2003; Rawlins *et al*. 2014; Hoddinott *et al*. 2015; Kabunga *et al*. 2017; Choudhury & Headey 2018; Miller *et al*. 2022). The mediating effect of milk consumption in the positive association between dairy-cow ownership and linear growth of under-fives has also been examined. Fierstein *et al*. (2017), for example, found that, while non-native cow ownership was positively associated with the height for age (HAZ) of children aged nought to five years, child milk consumption assessed in the previous 24 hours was not a mediating factor in this association. Such a result could be attributed to the use of a consumption indicator that understates the continuing milk consumption of a child. Choudhury and Headey (2018), for instance, address this data limitation by using household milk production status as a proxy for child milk consumption, a mediating factor in the association between cow ownership and child linear growth. Similarly, studies by Kabunga *et al*. (2017), Choudhury and Headey (2018) and Miller *et al*.

(2022) have considered the lactation status of cows and availability of milk by differentiating between cow-owning households that produce milk and those that do not produce milk.

Our study builds upon previous work and provides further insight into the role of household milk sources in the nutrition of children under the age of five in rural areas of low-income countries using panel data collected from smallholder households in Uganda. Although various empirical studies have shown that markets have a greater influence in improving dietary diversity than agricultural production diversification (see Nandi *et al*. 2021 for a systematic review), these findings might not be applicable to all food categories. In the case of milk, consideration should be given to market imperfections peculiar to milk supply that result from a low level of dairy animal ownership in the community, and the high perishability of raw milk that characterises informal sales in developing countries (Hoddinot *et al*. 2015), leading to market shortages. Therefore, an important research question is whether rural milk purchases contribute to improvements in child nutrition. Apart from Hoddinott *et al*. (2015), who showed that the cow ownership–stunting and cow ownership–milk consumption relationships got weaker in villages where a market was present, there is a dearth of clear-cut quantitative analysis of the effect of milk markets on child nutrition in low-income countries. Previous works that shows that rural farm households get a significant proportion of their daily food from markets (Frelat *et al*. 2016; GLOPAN 2016) provide the basis for our use of household milk purchases as a proxy for both the availability of and access to milk in rural market spaces.

2. Country policy context and conceptual framework

Uganda's national development strategies address nutrition issues in a multi-sectoral framework. Achieving food and nutrition security of all households is a key objective of the agriculture sector, which also contributes to achieving SDG 2 and national socioeconomic development. To this end, the strategic planning and programming of the Uganda government in the agriculture sector has prioritised increasing farmers' access to agro-inputs, including livestock capital (National Planning Authority [NPA] 2015, 2020). Operation Wealth Creation (OWC) (Robert & Mesharch 2018) is one of the government programmes implemented to operationalise the agriculture sector's strategic plan. The OWC programme extends capital in the form of a dairy heifer to subsistence farmers, with the objective of empowering households to improve their nutrition and income security. Dairy livestock ownership has also been promoted by development partners in organisations such as Heifer International-Uganda, Send a Cow-Uganda and other USAID-funded programmes, all of which support the implementation of the agriculture sector strategies in Uganda.

Dairy production in Uganda is dominated by rural smallholder farmers, who primarily keep cows of a local breed with a low average milk yield of about four litres per day (Dairy Development Authority [DDA] 2020). While most milk is consumed on the farm, some farmers sell raw milk either from the farm or in nearby trading centres. In dry seasons, when there is a scarcity of pasture and water, consumers are faced with shortages of milk in the market. Over the years, the government has attempted to address the challenges experienced in the dairy sub-sector by, first of all, establishing a statutory body that is charged with overseeing the functioning of the dairy industry. The Dairy Development Authority (DDA) has the strategic objectives of increasing milk production and productivity, as well as improving milk marketing and consumption (DDA 2020). Accordingly, the DDA has collaborated, for instance, with the OWC and other actors to ensure beneficiaries in the OWC programme receive improved or cross-bred heifers with prospects of producing higher milk yields. Farmers also receive training in artificial insemination to increase ownership of cross-breed cows. In addition, dairy farmers have received pasture seeds and seedlings to enable fodder conservation and improve the availability of feeds in dry seasons. The authority also ensures government interventions are implemented to reduce post-harvest losses, which increase the availability of milk in the market. For instance, there are functioning rural milk collection centres with coolers in various districts, which serve as sales outlets to both final consumers and processing firms. Moreover, the government banned the use of plastics for milk storage and transportation to market outlets and implemented a programme that has provided farmers with steel milk cans. These interventions have contributed to the availability of safe and hygienic milk in local markets. At present, Uganda boasts an annual volume of 2.81 billion litres of milk produced by farmers, mainly in the central and southwestern regions (DDA 2021).

This study makes use of a simple conceptualisation of market participation by smallholders who sell a portion of their crop output and buy non-staple foods in markets. Small farmers practising agricultural diversification may keep one or two dairy cows. Consumption of milk from own production increases a household's dietary diversity (through the subsistence production pathway). However, when households experience a shortage of milk from own production, they – like non-dairy-producing households – may depend on markets to provide milk to their most vulnerable members. Market dependence may also be inevitable, since owning a dairy cow can be expensive, particularly for smallholders who struggle to find enough grazing pasture and income to acquire animal feed and extension services. Households with knowledge of the nutritional significance of milk or animal-source foods in the diet of young children would purchase milk if it was not self-produced.

Households that sell a proportion of their crop output, especially off the farm, increase both their physical and economic access to markets, where they can buy non-staples like milk (agriculture–income/market pathway). However, this depends on whether milk is available in food markets. In the rural areas of low-income countries like Uganda, milk is primarily sold raw at the farm and in nearby markets. Other informal channels, like roadside milk selling and milk hawking, are also common (Nkwasibwe *et al*. 2015). Such informal market outlets tend to bring milk closer to households, which implies that they can make daily purchases even when they are located remotely. Thus, milk purchases might be indicative of the availability of milk in markets (whether organised or informal).

Given this, we test the hypotheses that milk consumption by children aged six to 59 months and the height for age of children aged six to 23 months are influenced positively by smallholders' milk purchases.

3. Data source and description of variables

3.1 Data

The study employs three rounds of data obtained from the Feed the Future innovation lab for nutrition (NIL) surveys conducted in northern and southwestern Uganda in 2012, 2014 and 2016. NIL surveys were conducted as part of the five-year Community Connector Project (CCP) funded by USAID in Uganda. CCP was an integrated agriculture-nutrition programme implemented in 15 rural districts. The aim of the project was to alleviate poverty and malnutrition in the target districts through interventions that were in harmony with the priorities of the national Agricultural Sector Strategic Plan and the national Nutrition Action Plan. The interventions, which targeted women in the age group of 18 to 49 years, and children from birth to 59 months old, were intended to improve infant and young child feeding (IYCF) practices, water, sanitation and hygiene (WASH) practices, health-seeking behaviour, knowledge of nutrient-rich foods, dietary diversity, household food security, the adoption of agricultural technology, farm productivity, agricultural income, access to financial services, and women's participation in household decision making, among others (FHI360 2015). The CCP interventions were implemented in 15 rural districts, which had an average of nine sub-counties per district. However, only three sub-counties per district were selected to receive the interventions. In Uganda, the sub-county is the second administrative unit in a district down from the county, and is followed by the parish as the third administrative unit and the village as the lowest administrative unit. The NIL panel study report notes that all households in the CCP-beneficiary parishes benefitted either directly or indirectly from the interventions.

The panel surveys collected data from six (out of 15) districts. In 2012, baseline data were collected from 3 597 households in the districts that were to receive the CCP interventions. Out of the baseline sample of households, 3 302 and 3 196 households participated in the 2014 and 2016 surveys, respectively, creating an unbalanced panel. The surveys collected information on child and mother nutritional status from households both in project-beneficiary and non-beneficiary communities; dietary intake and health indicators; household farm production; household socio-demographics; household assets; women's household decision making; and household-community characteristics. The respondents of the surveys were the caregiver of a child in the household or a woman of reproductive age (18 to 49 years). A detailed description of the survey design is provided elsewhere (Bashaasha *et al*. 2020).

3.2 Description of variables

3.2.1 Outcome variables

Milk consumption and growth status of children aged six to 59 months were the outcome variables in this study. Milk consumption is a binary variable indicating whether cow milk was included in a child's diet in the 24 hours before the survey. We measured child growth status using a child's height-for-age z-scores (HAZ), computed from anthropometric data in reference to the WHO child growth standards (WHO 2006), and a binary indicator of child stunting. A child was considered stunted if his/her height for age was less than -2 standard deviations. Stunting as a measure of nutritional status indicates a child's prolonged nutrient deprivation.

3.2.2 Key independent variables

Our main explanatory variables are household milk purchases and household-level production of milk. Milk production is a binary variable showing whether a cow-owning household produced milk in the last 12 months. This variable takes into consideration the lactation status of the dairy animals, and therefore serves as a proxy indicator of the availability of self-produced milk to a household. Milk production is equal to one if a household produced milk in the past 12 months, and equal to zero if a household did not produce milk. Since not all farm households own a dairy cow, we expect that households that do not produce milk depend on markets to have milk in the diets of young children. We used a dummy variable of whether a caregiver purchased the milk he/she consumed in the last 24 hours before the survey as a proxy indicator of a household's access to and dependence on a milk sales outlet. We also considered a household's distance to an input/output market and imputed missing values from a household's distance to their sub-county.

3.3.3 Control variables

We controlled for household socioeconomic status and child, maternal and agricultural characteristics that might influence child milk consumption and linear growth. Child characteristics include the child's sex, birth weight, breastfeeding status, and child minimum dietary diversity (MDD) without milk. To construct the MDD, we first estimated the child dietary diversity score (i.e., the number of food groups given to a child (in the previous 24 hours) from the following seven food groups: grains, roots, tubers and plantain; legumes and nuts; dairy products (such as milk, cheese and yogurt); meat (beef and poultry) and fish; eggs; vitamin A-rich fruit and vegetables; and other fruit and vegetables (WHO 2008). We then created a dummy variable showing whether a child was given food from at least four food groups, hence achieving the MDD.

Using the principal component method we created an asset index from household agricultural and durable assets. The assets considered were land size, cash crops, sheep/goats, motorcycle, bicycle, phone and radio. Cattle was left out in the principal component analysis due to potential confounding in the main estimations. Household food per-capita expenditure, household size, household head's years of schooling, caregiver's years of schooling, and a self-reported food security status were taken into account as additional socioeconomic characteristics. In addition, we considered an indicator of a household's market participation that measures the proportion of total crop output sold out of total crop supply in the last six months before the survey. Since this indicator took into account both the physical and economic dimensions of access to a market, it has an advantage over geographical indicators of market access, such as distance or time taken to reach a food market. Household programme exposure was also taken into account to capture the potential influence of exposure to nutritional knowledge on the relevant child nutritional outcomes.

4. Empirical approach

We aimed to estimate the effect of household milk production and milk purchases on child milk consumption and HAZ. With the panel dataset at hand, we could have utilised two-way fixed-effects models. However, as mentioned in Choudhury and Headey (2018), household milk production may be endogenous, leading to biased OLS estimates. This would arise if milk production were correlated with other right-hand variables that influence child milk consumption and child growth. To address the unobserved endogeneity issue, we used Roodman's (2011) conditional mixed process (CMP) modelling technique. The CMP model can be estimated without instrumentation of the explanatory endogenous variable and can handle mixed structural equations (Alhassan *et al*. 2020). Our first system of CMP equations was estimated to understand the effect of milk production and milk purchases on 24-hour milk consumption by a child. Thus, in the first equation of the CMP model, i.e. Equation (1), MP_{it} denotes milk production and is a binary variable. For comparison with previous findings, Equation (2) was estimated as a linear model, where CON_{it} denotes whether a child in household *i* and year *t* was given milk in the 24 hours preceding the survey.

Following Choudhury and Headey (2018), who argue that household milk production is a better indicator of regular child milk consumption than 24-hour milk consumption, we used milk production in comparison with milk purchases as the main explanatory variables in our second system of CMP equations. We also focused on the six to 23 months age group, in which children's need for food nutrients is highest, and therefore poor nutrient intake in this age group increases susceptibility to stunting (Shrimpton *et al*. 2001). Accordingly, Equation (3) estimates predictors of milk production (a binary variable), while HAZ_{it} in Equation (4) is a continuous outcome variable and denotes height-for-age Z-scores. The parameters of interest, β_1 and β_3, measure whether a household's milk production and milk purchase, respectively, are associated with HAZ. With the CMP model we are also able to control for unobserved time-invariant heterogeneity among households, as well as observable and unobservable household characteristics that change over time, such as differences in food allocation to a female child and male child.

$$MP_{it} = \alpha_a + \omega_0 T_{it} + \omega_1 X_{it} + \gamma_{ai} + \gamma_t + \varepsilon_{ait} \quad (1)$$

$$CON_{it} = \alpha_b + \delta_0 T_{it} + \delta_1 MP_{it} + \delta_2 PUR_{it} + \delta_3 X_{it} + \gamma_{bi} + \gamma_t + \varepsilon_{bit} \quad (2)$$

$$MP_{it} = \alpha_c + \varphi_0 T_{it} + \varphi_1 X_{it} + \gamma_{ci} + \gamma_t + \varepsilon_{cit} \quad (3)$$

$$HAZ_{it} = \alpha_d + \beta_0 T_{it} + \beta_1 MP_{it} + \beta_2 PUR_{it} + \beta_3 X_{it} + \gamma_{di} + \gamma_t + \varepsilon_{dit} \quad (4)$$

Since we use data collected as part of the CCP, we control for the project effect on the outcome variables in all equations. Thus, T_{it} equals 1 if a household *i* was resident in a parish that benefitted from any CCP agricultural and nutritional intervention in year *t*. MP_{it} and PUR_{it} are the explanatory variables of interest in Equations (2) and (4) and represent household milk production and household milk purchases, respectively. X_{it} is a vector of control variables that include child characteristics, household socioeconomic characteristics, household food security status, and household agricultural and market participation characteristics. Since markets may serve as substitutes or as complements to own production in rural settings (Hirvonen & Hoddinott 2017; Headey *et al*. 2019), we test for the interactive association between milk production and milk purchase in relation to a child' milk consumption.

5. Results and discussion

5.1 Descriptive analysis

In this section, we describe the characteristics of children and households in the study sample. Table 1 shows that 38% of the households were resident in communities that benefitted from the CCP interventions. The prevalence of stunting among the children aged six to 59 months who were included in our analysis was 26%, while only 16% had consumed milk in the 24 hours that preceded the survey. The proportion of children who consumed milk appears to have reduced over the survey waves. The child's minimum dietary diversity was achieved by only 3% of the children aged six to 59 months. Only 7% of the households produced milk, while only 4% purchased milk. The average household size was 6.6 members. Household heads had completed an average of 6.5 years of schooling, while caregivers had completed about four years on average. Such a low average level of educational attainment points to a low level of nutrition knowledge in the study sample. Fewer than 20% of the households were food secure. The average log of annual food expenditure per capita was 12.6. Households sold about a quarter of their crop output on average. The average distance to an input/output market was 4.14 kilometres. Such a distance is quite far for a household to depend on the market for the acquisition of daily food. This suggests informal food outlets may exist closer to the households.

Table 1: Sample characteristics for households with children of 6-59 months

	N	Pooled	(1) 2012	(2) 2014	(3) 2016
Household in CCP-beneficiary parish (1/0)	7 171	0.38 (0.49)	0.37 (0.48)	0.39 (0.49)	0.38 (0.49)
Height-for-age Z-score	3 115	-1.06 (1.50)	-0.98 (1.57)	-0.92 (1.55)	-1.26 (1.37)
Stunted (1/0)	3 115	0.26 (0.44)	0.25 (0.43)	0.23 (0.42)	0.29 (0.46)
Index child consumed milk in last 24 hours (1/0)	2 740	0.16 (0.36)	0.15 (0.36)	0.20 (0.40)	0.12 (0.33)
Household produced milk (1/0)	7 171	0.08 (0.26)	0.05 (0.21)	0.07 (0.25)	0.12 (0.32)
Household purchased milk (1/0)	7 171	0.04 (0.20)	0.04 (0.20)	0.03 (0.17)	0.04 (0.21)
Share of marketed crop output	7 171	0.26 (0.23)	0.27 (0.23)	0.25 (0.24)	0.25 (0.21)
Distance to input/output market (km)	7 171	4.14 (2.36)	4.02 (1.84)	4.08 (1.84)	4.34 (3.24)
Male child (1/0)	3 115	0.50 (0.50)	0.49 (0.50)	0.55 (0.50)	0.48 (0.50)
Child's weight at birth ≥ 2.5 kg (1/0)	3 144	0.95 (0.21)	0.96 (0.20)	0.96 (0.20)	0.94 (0.23)
Child currently breastfed (1/0)	3 038	0.87 (0.34)	0.86 (0.35)	0.87 (0.33)	0.88 (0.32)
Child minimum dietary diversity (without milk) (1/0)	3 311	0.03 (0.16)	0.03 (0.17)	0.03 (0.17)	0.02 (0.14)
Caregiver/mother's years of schooling	7 171	4.01(3.07)	4.02 (3.09)	3.97 (3.10)	4.02 (3.02)
Household head's years of schooling	7 171	6.51 (3.22)	6.60 (3.27)	6.46 (3.23)	6.44 (3.16)
Household was food secure (1/0)	7 171	0.16 (0.36)	0.18 (0.38)	0.17 (0.38)	0.12 (0.33)
Household size	7 171	6.65 (2.46)	5.99 (2.52)	6.84 (2.26)	7.22 (2.36)
Log of annual food expenditure per capita	7 037	12.63 (0.63)	12.68 (0.54)	12.46 (0.71)	12.74 (0.61)

Note: Values are means, with standard deviations in parentheses

We concentrated on households that owned no more than four cows. Therefore, we ruled out very wealthy rural households in the analysis. Table 2 shows that the average number of cows owned by a household was 2.5 cows. About 33% and 10% of the households in the northern and the southwestern regions owned a cow, respectively. The cows were mainly of a local breed, which tends to have low milk yields in Uganda (Kabunga *et al*. 2017). The average annual milk yield per cow in our sample was 140 litres. Most of the milk produced was consumed by the household – 76% in the northern region and 69% in the southwestern region. There was a significant decline in the percentage of cow-owning households between 2012 and 2016, which corresponds to the significant decline in the proportion of milk-producing households in the same period. The share of milk consumed from household production also decreased significantly between 2012 and 2016. However, a significant increase in the average number of cows owned by households can be observed. There also was a decline in the percentage of cow-owning households that purchased animal feed, animal medicines/ deworming medicine, and who received veterinary services.

Table 2: Cow ownership, milk production and related activities by region

	N	Pooled	Region		Δ2012-2016[a]
			Northern n = 4 890	Southwestern n = 2 281	
Hh owns a cow (%)	7 171	26.55 (44.16)	33.89 (47.30)	10.83 (31.08)	-0.073*** (0.012)
Hh owns local cow (%)	1 904	97.11 (16.75)	99.52 (6.93)	80.97 (39.33)	0.01 (0.009)
Hh owns exotic cow (%)	1 904	0.58 (7.58)	0.18 (4.25)	3.24 (17.74)	-0.002 (0.004)
Hh owns crossbred cow (%)	1 904	2.78 (16.45)	0.42 (6.49)	18.62 (39.01)	-0.014 (0.009)
Number of cows owned by Hh	1 904	2.49 (0.70)	2.48 (0.68)	2.62 (0.86)	0.049* (0.037)
Hh produces milk (%)	7 171	7.57 (26.46)	8.77 (28.29)	5.00 (21.79)	-0.07*** (0.008)
Milk/cow/year (litres)	542	140.85 (267.56)	88.32 (151.06)	338.04 (454.79)	3.838 (27.407)
Share of milk consumed (%)	542	74.32 (31.02)	75.76 (31.18)	68.94 (29.93)	-4.558* (3.308)
Share of milk sold (%)	542	23.17 (30.89)	21.75 (31.08)	28.50 (29.70)	4.078 (3.312)
Hh purchased milk (%)	7 171	3.97 (19.53)	2.52 (15.66)	7.10 (25.69)	-0.0003 (0.006)
Hh purchased feed (%)	1 904	14.50 (35.21)	9.11 (28.79)	50.61 (50.10)	-0.033*** (0.007)
Hh provides medicines/deworming (%)	1 904	57.14 (49.50)	54.13 (49.84)	77.33 (42.00)	-0.152*** (0.013)
Hh received veterinary services (%)	1 904	52.42 (49.95)	52.08 (49.97)	54.66 (49.88)	-0.209*** (0.012)

Notes: Hh = household; values are means, with standard deviations in parentheses. [a] The column shows the difference in means between 2012 and 2016 obtained from a t-test (values are coefficients with standard errors in parenthesis); *** = $p < 0.01$, * = $p < 0.1$

Table 3: Household milk sales outlets

(%)	**Total** (n = 707)	**2012**	**2014**	**2016**	**Δ2012-2016[a]**
Share of milk sold	23.05 (31.04)	24.81 (30.60)	24.52 (32.83)	21.46 (30.20)	0.033 (0.029)
Farm gate	54.27 (49.85)	49.50 (50.12)	48.71 (50.08)	62.46 (48.50)	-0.130*** (0.045)
Nearby market	37.18 (48.36)	40.50 (49.21)	41.33 (49.33)	31.23 (46.42)	0.09** (0.044)
Distant/larger market	5.96 (23.69)	7.50 (26.41)	5.54 (22.91)	5.32 (22.47)	0.022 (0.023)
Farmers' group	2.59 (15.90)	2.50 (15.65)	4.43 (20.61)	1.00 (9.95)	0.015 (0.012)

Notes: Values are means, with standard deviations in parentheses
[a] The column shows difference in means between 2012 and 2016 obtained from a t-test (values are coefficients, with standard errors in parenthesis). ** $p < 0.05$, *** $p < 0.01$.

In Table 3 we show the outlets used by smallholders to sell their milk. Between 2012 and 2016, the proportion of dairy households that sold milk at the farm gate reduced, while the proportion that sold milk in a nearby market or village market increased significantly. This suggests an increase in the availability of milk in market spaces closer to households. The larger proportion of households selling their milk at the farm gate and in nearby markets suggests that these are the primary sources for rural households who buy milk.

5.2 Estimation results

5.2.1 Determinants of milk production

Table 4 presents the regression results from the estimation of the first CMP system of equations (Equation (1) and Equation (2)). The results in column (1) show that household size, number of crops grown, purchase of animal feed, provision of deworming or medicines to the animals, and use of veterinary services are positive influencers of a household's milk production. Our findings corroborate previous research that shows that a shortage of improved animal feed, cattle parasites and disease infestations, and a lack of extension contact are constraints to milk production among smallholder dairy farmers (Burke *et al*. 2015; Abegaz 2022).

5.2.2 Effects on child milk consumption

The results in column (2) confirm our hypothesis that milk production and milk purchase affect a child's daily milk consumption positively. Specifically, a household's milk production increases child milk consumption by 27 percentage points, while household milk purchases increase child milk consumption by 34 percentage points. In a previous comparable study, a 14 percentage points increase in child milk consumption was associated with household milk production in Bangladesh (Choudhury & Headey 2018). In Miller *et al*. (2022) the volume of milk produced by a household predicted child milk consumption in Nepal. Distance to a market, the share of marketed crop output and the log of per capita food expenditure all have a positive significant effect on child milk consumption. These three variables reflect household market accessibility and market dependence, and hence suggest that milk markets have a role in influencing child milk consumption among rural households.

Table 4: Marginal effects of household milk sources on child milk consumption (CMP regression model)

	Milk production	Milk consumption
	Probit (1)	Linear (2)
Household produced milk (0/1)		0.274*** (0.020)
Household purchased milk (0/1)		0.338*** (0.009)
Distance to input/output market		-0.007** (0.003)
Share of marketed crop output		0.104*** (0.031)
Log of per capita food expenditure		0.031** (0.013)
Middle-wealth group[a]		-0.036** (0.016)
High-wealth group[a]		-0.005 (0.019)
Child is currently breastfeeding (0/1)		-0.078*** (0.022)
Food-secure household (0/1)		0.064*** (0.021)
Household size	0.002* (0.001)	0.003 (0.003)
Caregiver's years of schooling	0.00 (0.001)	0.004 (0.003)
Household head's years of schooling	-0.001* (0.001)	0.001 (0.003)
Owns 2 cows (0/1)	0.191*** (0.012)	
Owns 3 cows (0/1)	0.284*** (0.018)	
Owns 4 cows (0/1)	0.357*** (0.028)	
Owns a bull (0/1)	0.005 (0.005)	
Number of crops grown	0.003*** (0.001)	
Purchased animal feed (0/1)	0.040*** (0.008)	
Provided medicine/deworming (0/1)	0.020*** (0.005)	
Received veterinary service (0/1)	0.014*** (0.005)	
Household in CCP-beneficiary parish (0/1)	-0.001 (0.005)	0.008 (0.014)
Constant	-3.864*** (0.179)	-0.244 (0.152)
Observations	2 963	2 963
Household fixed effects	Yes	
Year fixed effects	Yes	
/atanhrho_12	-0.108*** (0.039)	
rho_12	-0.107 (0.038)	
Log pseudo likelihood	-1 837.0349	
Prob > chi^2	0.0000	
Wald chi^2(33)	1 134.66	

Notes: Standard errors in parentheses are clustered at the household level. [a] The reference category is the low-wealth group. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.2.3 Are milk production and milk purchase complements or substitutes?

Table 5 shows that the interaction term between milk production and milk purchase is positive. This suggests that the two household milk sources are complements. Thus, households can depend on milk from markets when there is shortage in own production.

Table 5: Interaction effect (CMP regression model)

	Milk consumption Linear (1)
Household produced milk (0/1)	0.278*** (0.020)
Household purchased milk (0/1)	0.340*** (0.009)
Milk production x milk purchase	0.081*** (0.020)
Controls	Yes
Household fixed effects	Yes
Year fixed effects	Yes
Observations	2 963
/atanhrho_12	-0.109*** (0.039)
rho_12	-0.108 (0.038)
Log pseudo likelihood	-1 835.8055
Prob > chi^2	0.0000
Wald $chi^2(34)$	1 135.86

Notes: Results are marginal effects from the second stage of CMP models, with standard errors clustered at the household level in parentheses. *** $p < 0.01$

5.2.4 Effects on child growth

Columns 2 and 4 in Table 6 show the effect of milk production and milk purchase on HAZ and stunting in children aged six to 23 months, respectively. By increasing child milk consumption, milk production and milk purchases have a positive influence on HAZ and reduce stunting. The pathway of milk production has been tested previously by Choudhury and Headey (2018). Our results are consistent with the previous findings and show that a 1% increase in milk production increases HAZ by 10 percentage points and reduces stunting by 22 percentage points. On the other hand, the milk-market pathway is understudied in the literature, but our results suggest that a 1% increase in milk-market dependence leads to a five percentage point increase in HAZ and a seven percentage point decrease in stunting.

The results obtained from a two-way fixed-effects model, presented in Table A1 in the appendix, show that milk production does not affect child growth. This result is inconclusive, since the OLS model does not account for the endogeneity of milk production. This result also serves to confirm the efficiency of the CMP model in addressing the endogeneity issues in our study.

6. Conclusion and policy implications

The burden of low-quality diets and childhood undernutrition is widespread in rural areas of Sub-Saharan Africa where households depend mainly on agriculture (Garret & Ruel 1999; Smith *et al*. 2005; Dror & Allen 2011; Headey *et al*. 2018). Including milk in the diet of children under the age of five contributes to the achievement of the MDD in poor populations characterised by limited access to other ASF, and hence is essential in the fight against malnutrition in SSA. We analysed the effect of milk production and milk purchases on child nutritional status. Unlike previous studies, we utilised a panel dataset and controlled for the endogeneity of milk production in CMP models. Our results are in agreement with previous research that finds a positive association between exposure to household milk production and child growth in the age category of six to 23 months. In addition, household daily milk purchases have a positive effect on HAZ and a negative effect on stunting in children aged six to 23 months.

The results also show that household milk production and milk purchase are complements in increasing child milk consumption. These results imply that a mixed strategy, combining increases in household milk productivity and dairy market development, will increase both milk sales and the consumption of milk. Consequently, child nutritional status in both milk-producing and milk-purchasing households would improve. The determinants of milk production point to strategies that support smallholder dairy farmers to acquire feed and veterinary services. Milk-market development strategies would ensure farmers' access to milk collection centres with refrigerators to reduce post-harvest losses. On the side of the consumer, milk should be affordable. This could be achieved partly by policy tackling milk-market development to increase the availability of milk in markets. Social protection programmes would increase economic access to markets.

Our study is not without limitations. The non-quantitative indicator of child milk consumption used in this study does not show whether children consumed sufficient quantities of milk. Previous studies, for instance, show that the relationship between milk production and nutrition among small farmers is dependent on the quantities of milk produced by a household (Miller *et al*. 2022) and on the proportion consumed within the household (Jumrani & Birthal 2015). Future studies on rural Uganda could investigate explicitly whether milk is available in both formal and informal market spaces, and whether these markets are accessible to households.

Table 6: Marginal effects of household milk production and milk purchase on HAZ and stunting (CMP regression models)

	Milk production	HAZ score	Milk production	Stunting
	Probit (1)	Linear (2)	Probit (3)	Linear (4)
Household produced milk (0/1)		0.101** (0.051)		-0.217*** (0.064)
Household purchased milk (0/1)		0.055* (0.031)		-0.072** (0.028)
Distance to an input/output market		-0.002 (0.003)		0.001 (0.003)
Male child (0/1)		0.173*** (0.012)		-0.134*** (0.012)
Weight at birth ≥ 2.5 kg (0/1)		0.070*** (0.021)		-0.090*** (0.028)
Child currently breastfed (0/1)		0.032* (0.019)		-0.040** (0.020)
MDD (without milk) (0/1)		0.067 (0.043)		-0.048 (0.036)
Food-secure household (0/1)		0.033* (0.019)		-0.008 (0.018)
Household size > 7 (0/1)		0.025* (0.014)		-0.021 (0.014)
Low-wealth group		-		-
Middle-wealth group[a]		0.022 (0.015)		-0.038** (0.016)
High-wealth group[a]		0.058*** (0.016)		-0.066*** (0.017)
Caregiver's years of schooling	0.001 (0.001)	0.001 (0.002)	0.001 (0.001)	-0.002 (0.002)
Household head's years of schooling	-0.001 (0.001)	0.004*(0.002)	-0.001 (0.001)	-0.001 (0.002)
Owns 2 cows (0/1)	0.213*** (0.022)		0.218*** (0.022)	
Owns 3 cows (0/1)	0.274*** (0.030)		0.270*** (0.029)	
Owns 4 cows (0/1)	0.347*** (0.048)		0.355*** (0.048)	
Owns a bull (0/1)	-0.005 (0.008)		-0.005 (0.008)	
Number of crops grown	0.005*** (0.001)		0.005*** (0.001)	
Purchased animal feed (0/1)	0.055*** (0.014)		0.049*** (0.013)	
Provided medicine/deworming (0/1)	0.014* (0.008)		0.014* (0.007)	
Received veterinary service (0/1)	0.018** (0.008)		0.018** (0.008)	
Household size	0.002 (0.002)		0.002 (0.002)	
Household in CCP-beneficiary parish (0/1)	-0.002 (0.008)	0.017 (0.013)	-0.003 (0.008)	-0.009 (0.014)
Constant	-4.366*** (0.365)	-2.152*** (0.173)	-4.335*** (0.339)	0.582*** (0.057)
Household fixed effects	Yes		Yes	
Year fixed effects	Yes		Yes	
Observations	2 644		2 644	
/atanhrho_12	-0.197** (0.097)		0.427*** (0.121)	
rho_12	-0.194 (0.093)		0.403 (0.102)	
Log pseudo likelihood	-4 955.229		-1 724.8522	
Prob > chi^2	0.0000		0.0000	
Wald $chi^2(30)$	549.23		537.64	

Notes: Standard errors in parentheses are clustered at the household level. [a] The reference category is the low-wealth group. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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Appendix

Table A1: Household milk production and milk purchase and their associations with HAZ and stunting (fixed-effect linear models)

	HAZ score		Stunting	
	Coefficient	SE	Coefficient	SE
Household produced milk (0/1)	0.081	0.250	0.017	0.066
Household purchased milk (0/1)	0.492**	0.213	-0.141	0.088
Distance to an input/output market	-0.020	0.024	0.014*	0.008
Male child (0/1)	0.922***	0.093	-0.210***	0.028
Weight at birth ≥ 2.5 kg (0/1)	0.531**	0.211	-0.174**	0.077
Child currently breastfed (0/1)	-0.246	0.185	0.052	0.059
MDD (without milk) (0/1)	0.214	0.331	-0.053	0.090
Food-secure household (0/1)	0.333**	0.156	-0.026	0.042
Caregiver's years of schooling	0.033	0.036	-0.016	0.010
Household head's years of schooling	0.056	0.036	-0.010	0.013
Household size > 7 (0/1)	0.282*	0.152	-0.041	0.044
Household in middle-wealth group (0/1)[a]	0.140	0.116	-0.062	0.038
Household in high-wealth group (0/1)[a]	0.114	0.161	-0.055	0.048
Household in CCP-beneficiary parish (0/1)	-0.032	0.556	-0.053	0.276
Constant	-2.384***	0.438	0.648***	0.169
Number of observations	2 644		2 644	
R-squared	0.1536		0.1007	
Number of households	1 964		1 964	
Household fixed effects	Yes		Yes	
Year fixed effects	Yes		Yes	

Notes: Results are average marginal effects from fixed-effect linear models, with standard errors clustered at the household level. [a] The reference category is the low-wealth group.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$