



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Adoption and Impact of Improved Cow Breeds on Household Welfare and Child Nutrition Outcomes: Empirical Evidence from Uganda

Nassul Kabunga

Associate Research Fellow at the Development Strategy and Governance Division of
International Food Policy Research Institute (IFPRI)-Kampala Office, Uganda.

Plot 15 East Naguru Road
P.O. Box 28565, Kampala, Uganda.

Tel: +256-414-285-060
E-mail: N.Kabunga@cgiar.org

**Contributed Paper prepared for presentation at the 88th Annual Conference of the
Agricultural Economics Society, AgroParisTech, Paris, France**

9 - 11 April 2014

Copyright 2014 by Nassul Kabunga. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Acknowledgement:

We acknowledge financial support from the Nutrition Innovation Labs-Africa, a flagship collaboration managed by the School of Nutrition Science and Policy at Tufts University and funded by the United States Agency for International Development (USAID). The technical and editorial contributions of Todd Benson and the editorial assistance of Lucy Billings are appreciated.

Abstract:

There is increasing evidence that improved agricultural technologies benefit smallholder farmers in sub-Saharan Africa. This evidence is however relatively clearer for innovations in smallholder crop production systems as compared to innovations in livestock production systems. Moreover, it is unclear whether the benefits of technology adoption in livestock systems are uniform across small and relatively large farmers. This study uses a national representative sample of 906 households to rigorously assess the impact of adoption of improved dairy cow breeds on enterprise-, household-, and individual child-level nutrition outcomes in Uganda. We find that adopting improved dairy cows significantly increases milk yield, household's orientation to milk markets, and food expenditure. Consequently, adoption substantially reduces household poverty and stunting for children younger than age five. Considering heterogeneity, we find that adopting households with small farms increase milk yield, food expenditure and reduce poverty substantially while large farms increase not only own-milk consumption and commercialization but also nutrition outcomes of children younger than age five.

JEL Classification: D1, I15, O13, O33, Q12, Q18

Keywords: improved dairy cows, milk productivity, child nutrition outcomes, poverty, propensity score matching, sub-Saharan Africa, Uganda

1. Introduction

The adoption and extensive use of improved agricultural technologies is vital for poverty reduction and improved food and nutritional security in developing countries (Barrett et al., 2010). As one of the food-based strategies to increase production and consumption of specific micronutrient-dense foods, the adoption of improved agricultural technologies is considered more sustainable and culturally acceptable than supplementation or fortification (Ruel, 2001). For some poor households with opportunities to rear livestock, the adoption of improved dairy cows can potentially leverage pathways to poverty and hunger alleviation as well as reduce the prevalence of malnutrition in several ways.

First, at the farm level, adoption of improved dairy cows could potentially improve milk yield, which translates into higher production per unit area or per cow. Increased milk production will stimulate rural milk markets and the integration of smallholders into improved value chains, thus improving producer incomes, which in turn can be used to purchase other foods to satisfy household nutritional needs (Staal et al., 1997). Second, milk consumption by the poor in developing countries is heavily constrained by insufficient supply and, consequently, high cost. Moreover, other cultural factors may constrain consumption—for instance, intrahousehold food allocation patterns, may limit milk intake of the most vulnerable groups such as women and children (Gittelsohn and Vastine, 2003). While food access issues at the household (or even community) level can generally be addressed through educational and awareness interventions, the sustainable solution to low milk availability and high cost lies in improving dairy productivity at the farm level. When consumed, milk is a good source of animal-based proteins, vitamins, and other micronutrients (such as calcium and zinc) to complement plant-based foods in local diets with significantly lower micronutrient bioavailability. Consequently, the consumption of even small amounts of milk can contribute significantly to improved dietary

outcomes, especially for women and children (Henriksen et al., 2000; Black et al., 2002; Wiley, 2009). Finally, beyond nutrition and income roles, livestock serves as a buffer resource for farmers to use in responding to emergencies, such as crop failure, as well as acts as a live bank, facilitating both income distribution and savings.

Empirical evidence on the impact of improved agricultural technologies on the welfare of smallholder farmers in sub-Saharan Africa (SSA) is slowly being documented in recent literature. This is however mostly true for innovations in smallholder crop production systems as compared to livestock production systems. With specific reference to the latter, previous research demonstrates that dairy cows ownership can enhance household welfare and individual nutrition outcomes in site-specific studies: Nicholson et al (2004) found that ownership of dairy cows increased household-level intakes of dairy products as well as cash incomes in a sample of 184 households in coastal Kenya while other studies indicate a possible positive correlation between child linear growth and ownership of dairy cows by the foster households (Nicholson et al. 2003; Rawlins et al. 2014). Yet still, existing literature presupposes that the benefits of adoption accrue uniformly across small and relatively large farms, ignoring marginal benefits and costs due to scale.

In this article, we use a nationally representative sample of 907 Ugandan households with 715 children younger than age five and examine whether adoption of improved dairy cow breeds translates into better nutrition outcomes for children living in adopting households, by drawing empirical pathway linkages between milk production, consumption, marketing, household expenditure, poverty, and ultimately nutrition outcomes. We do this by first separating households with improved dairy breeds from those with local (unimproved) breeds and then controlling for multiple confounding factors. Then, we examine the effects of improved cow breeds on per-cow productivity (annual milk yield),

the household's orientation to milk markets, and individual milk consumption. We then test whether adoption translates into improved household expenditure on food and nonfood items, food availability at the household level, and broader poverty reduction indicators. On nutrition outcomes, we sieve out households with children younger than age five and analyze the impact of improved dairy cows on the linear growth of these children.

To estimate the net effects, we first isolate adoption from other confounding factors that potentially may have a simultaneous effect on the outcomes of interest, based on the assumption that improved dairy cow adoption behavior is not random. Failure to sufficiently correct for this self-selection to technology adoption could bias our results, a deficiency observed in most causal studies (for a synopsis see Webb, 2013). We employ propensity score matching (PSM) approaches that select, match, and compare dairy-producing households (or individuals) with and without improved dairy cow breeds with similar characteristics. Because technology adoption may have a differential impact on adopting households, we also assess heterogeneous impacts of adoption by scale, defined by herd size and land area. In so doing, we develop empirical evidence of how the adoption of improved dairy cattle contributes to improved welfare and nutritional status.

The rest of this article is organized as follows: Section 2 gives a brief background on improved dairy cow systems in Uganda. Section 3 describes the data sources and the empirical strategies to isolate the impact of improved dairy cow adoption. Section 4 presents the results and discussion, and conclusions are summarized in Section 5.

2. Background on Improved Dairy Cow Systems in Uganda

a) The livestock sector in Uganda

The agricultural sector in Uganda employs 66 percent of the Ugandan population and is key to poverty reduction (Ssewanyana and Okidi, 2007). The livestock census of 2008 reports the total cattle herd in Uganda to be in excess of 11 million, with 25 percent of all households owning cattle (MAAIF, 2010). The livestock sector continues to grow annually at 3 percent, with dairy production contributing about half of the total livestock gross domestic product (GDP), which in turn contributes to nearly 20 percent of the total agricultural GDP (BoU and PMA, 2009 as cited in Mbowa, Shinyekwa, & Lwanga, 2012). Dairy cows contribute to household food, are a major source of animal-based protein and minerals for the entire household, and are a dependable and stable source of cash income through the sale of mainly fluid milk and also milk byproducts to a very limited scale. Dairy cows also provide farmyard manure that is essential in the low-input smallholder integrated farming systems typical of East Africa. Moreover, dairy cows are considered some of the most important assets for Ugandan households (BoU and PMA, 2009) with potential for high asset-to-cash convertibility. Dairy production is identified as a priority sector for promotion to meet local and regional milk export market demands, owing to the favorable agroecological conditions in most parts of Uganda (Elepu, 2008; Wong and Kibirige, 2009).

b) Dairy production systems, markets and technology adoption

The majority of dairy production in Uganda takes place on small mixed farms, with a significant share of this production done through semi-intensive zero-grazing units (with cows kept in stalls and fed in-house with cut grass, very limited grain and little or no grazing). A substantial number of zero-

grazing units of one to three dairy cows are managed by women, who often have constraints to land access. A small share of milk is produced on commercial farms with relatively large herds of exotic dairy cows (Wong and Kibirige, 2009). From a regional perspective, most dairy production activities take place in Western Uganda. Central Uganda, where Kampala City is located, provides the biggest market for raw liquid milk in the country. Dairy marketing remains largely informal, with nearly 80 percent of all milk sold as unprocessed fluid milk (Dobson, 2005; Wong and Kibirige, 2009). However, the formal dairy industry has substantially grown, especially in response to the demand of urban, educated consumers for hygienic and high-quality products.

Changes in consumer preferences notwithstanding, the growing dairy sector has major implications for income growth, poverty reduction, and nutrition outcomes for dairy-producing households, as well as for actors along the value chain. Over the last two decades, Uganda's dairy sector has steadily transformed from a solely government-controlled system to a more competitive industry with private actors as major players. The Dairy Development Authority (DDA), a government agency, regulates the industry and works to increase production and consumption of milk for economic development and improved nutrition. The DDA has created an enabling business environment that has spurred increased milk production (Kjær et al., 2012). Among private actors, milk traders and processors are the most significant agents. However, farmer groups and international nongovernmental organizations such as Send a Cow, Heifer International, and Land O'Lakes, in particular, have been active in the supply of essential inputs, crossbreeding, extension services, and enhancing efforts for improved dairy technology adoption (Mbowa et al., 2012).

Among all these efforts, the introduction and dissemination of exotic dairy breeds—particularly Holstein-Friesian, Guernsey, Jersey, and Ayrshire—and crossbreeds to increase milk production is regarded as the most significant step to develop a modern and commercial dairy industry in Uganda (Garcia et al., 2008). Reforms in the dairy sector that encouraged and expanded trade in milk are credited for a generic growth in the number of milk-producing households. With increased milk trade, households undertook to improve herd productivity by adopting improved dairy cattle breeds. NGOs have been instrumental in restocking and improving dairy cow productivity through numerous donor-funded smallholder support programs. The targeting of specific groups, such as women, for adoption of improved dairy animals, as done by Send a Cow, Heifer International, and also National Agricultural Advisory Services—an ongoing government initiative for agricultural extension and technology development—has potentially improved household welfare, particularly for children in those households. Research has shown that the returns to technology adoption in terms of household welfare are higher if women have a substantial control of household resources, including new technologies introduced (e.g. Quisumbing and Pandolfelli, 2010).

c) Indications for impact

The hypothesis of this study is that the reforms in the dairy sector have provided general significant economic benefits and, more importantly, reduced poverty and malnutrition in Uganda. In spite of the higher initial investment costs for dairy cow systems, the higher milk yields obtained ensure increased on-farm per capita milk availability and consumption, increased surpluses of milk that can be marketed, and lower average milk prices for buying households. This postulation is not unusual. Observations in Uganda have shown substantial transformations in livestock husbandry practices, with dairy farms shifting away from free-range to paddocking, accompanied by reduced herd sizes of

improved breeds (Dobson, 2005; Mbowa et al., 2012). Raw milk production has shown growth since 2000, and the share of exotic crossbreeds to local cattle has increased by 7 percent between 2005 and 2009, with a remarkable 20 percent more households taking on dairy farming as a commercial venture between 2005 and 2009 (Mbowa et al., 2012). These increases in milk production seem to be the result of more farmers adopting high-yielding cow breeds than of increased herd sizes (Mbowa et al., 2012). This study investigates the impact of dairy cow adoption on milk productivity in terms of milk yield per cow after accounting for potential confounding factors.

Further, per capita milk consumption has grown from an average of about 28 liters per year in early 2000 to about 58 liters per year in 2010 (Dobson, 2005; Mbowa et al., 2012). Although this is still much lower than the international recommended milk consumption level of 200 liters per capita per year, it is higher than the average of countries in SSA, which is estimated at 30 liters per year (Gerosa and Skoet, 2012). Higher milk production and improved consumer incomes among some sections of the population are considered some of the major reasons for increased milk consumption (Dobson, 2005; Gerosa and Skoet, 2012). These potentially cause significant changes in the nutritional status of consuming households and in the income level of milk-producing households.

3. Data and Methodology

a) Data

To estimate the household- and individual-level impacts of improved dairy cow adoption, we use the Uganda National Panel Survey (UNPS) 2009/2010. This dataset was compiled by the Uganda Bureau of Statistics (UBoS) as part of a nationally representative household survey. The 2009/2010 round is

the first wave of a panel of annual household surveys initiated by the UBoS and its partners to track changes in the sampled households and individuals over time. The 2009/2010 round comprises 2,975 households that were selected from the sample of households surveyed in the 2005/2006 round of the Uganda National Household Surveys—UNHS (UBoS, 2007).

A two-stage, stratified, random-sampling design was followed to generate the UNPS sample. In the first stage, enumeration areas were randomly selected from the four geographical regions based on probability proportional to size, except for Kampala, where all enumeration areas in the 2005/2006 UNHS were selected for the 2009/2010 survey. Regional stratification is of interest in this study, as the Western region of Uganda represents the milk surplus region, while the Central region represents the biggest market for milk produced in the country (Mbowe et al., 2012). In the second stage of the sample selection for the 2009/2010 UNPS, 10 households that had been randomly selected in the 2005/2006 UNHS were re-interviewed, except in cases where the respondent could not be traced. For this paper, the sample was further reduced to include only 907 households that had dairy cow enterprises.

The UNPS 2009/2010 was conducted between September 2009 and August 2010. The enumerators made two visits six months apart to all agricultural households in the sample to better capture agricultural outcomes associated with two major cropping seasons in Uganda. The survey questionnaire captured data on household demographics, assets, income, and expenditure, among others. The questionnaire also included an agricultural module that provided data on livestock production activities among other enterprises in which the household was involved. In the livestock section, we were able to isolate households that reared dairy cows as a focus of analysis for this paper.

Moreover, the questionnaire required respondents to categorize different livestock owned as either local, crossbreeds, or exotic. Thus, we are able to categorize “improved dairy cow adopters” (referred to as *adopters*) as those households that mentioned owning at least one crossbred or exotic dairy cow; and households that reared only local indigenous dairy cows as *nonadopters*. The UNPS 2009/2010 also captured data on child anthropometry to derive linear growth. Height (in cm) and weight (in kilograms) measures of eligible children ages 0–59 months living in sampled households were obtained. We have observations on the height and weight of 745 children for analysis among the households in the UNPS sample that reared dairy cows.

b) Empirical strategies

Our major objective is to estimate the impact of improved dairy cow adoption, measured by the average treatment effect on the treated (ATT), on several outcomes of interest. ATT computes the average difference in outcomes of adopters with and without a technology:

$$ATT = E(y_{1i} - y_{0i} | D_i = 1) = E(y_{1i} | D_i = 1) - E(y_{0i} | D_i = 1) \quad (1)$$

where $E(\cdot)$ denotes an expectation operator, y_{1i} is an outcome of interest for a household or an individual living in household with improved dairy cows (adopter), y_{0i} is the outcome of the same household or individual living in the same household without improved dairy cows (nonadopter), and D_i is a treatment indicator equal to 1 (adopter) if the household adopted improved dairy cows and 0 (nonadopter) otherwise. Since we cannot observe how the outcome levels would behave without adoption, the fundamental problem we face is that of missing data on the counterfactual, that is, the outcome of adopters had they not adopted: $(y_{1i} | D_i = 0)$. Thus, with observational data, one may be inclined to simply compare outcomes between adopters and nonadopters. Yet, due to nonrandom self-selection into adoption or nonadoption, such an analysis may result in biased estimates.

The two potential sources of bias are, first, adopters may differ from nonadopters with respect to observed characteristics, such as education, age, landholding, and wealth; and second, adopters may differ with respect to unobserved characteristics, such as motivation, managerial skills, and risk preference, which may play an important role in technology adoption (Feder et al., 1985; Bandiera and Rasul, 2006; Foster and Rosenzweig, 2010; Krishnan and Patnam, 2014) as well as in heterogeneous information exposure to technology (Kabunga et al., 2012).

We use PSM to construct a suitable control group with nonadopters that are similar to improved dairy cow adopters in all relevant observed characteristics (Caliendo and Kopeinig, 2008). Empirically, this follows two stages: First, we generated propensity scores $p(x_i)$ from a probit model, which essentially indicate the probability of a household adopting improved dairy cows given observed characteristics, x_i :

$$\Pr(D_i = 1|x_i) \equiv p(x_i) \quad (2)$$

It is upon this propensity score that a control group is constructed by matching. Adopters without an appropriate match from the nonadopter category (and vice versa) were dropped from further analysis.

In the second stage, we calculated the ATT of improved dairy cow adoption on outcome variables of interest, y_i , using matched observations of adopters and nonadopters as follows:

$$ATT^{psm} = E[y_{1i}|D_i = 1, p(x_i)] - E[y_{0i}|D_i = 0, p(x_i)] \quad (3)$$

where ATT^{psm} measures the mean difference of adopters matched with nonadopters who are balanced on their propensity scores and lie within the region of common support¹.

Several methods are proposed in the literature to match similar adopters and nonadopters (Caliendo and Kopeinig, 2008). The most commonly used approaches are the nearest neighbor matching (NNM) and kernel-based matching (KBM) methods. NNM consists of matching each adopter with a nonadopter that has the closest propensity score. Thereafter, the differences of each pair of matched units can be computed, and finally the ATT is obtained as the average of all these differences. In KBM, all adopters are matched with a weighted average of all nonadopters, using weights that are inversely proportional to the distance between the propensity scores of adopters and nonadopters.

Given that the analysis conditions not on all covariates but on the propensity score, it is recommended to check covariate balancing by comparing the pseudo- R^2 s before and after matching (Sianesi, 2004). The pseudo- R^2 , which indicates how well the covariates x_i explain the adoption probability, should be fairly low after matching, since no systematic differences should appear in the distribution of covariates between both groups.

While PSM cannot control for bias due to unobservables, we test the robustness of the impact results by using different matching algorithms. Moreover, we test whether unobservables might affect our estimated results using the bounding sensitivity tests (Rosenbaum, 2002).

¹ It is important that the assumption of common support, which requires substantial overlap in covariates between adopters and nonadopters, is satisfied, so that households being compared have a common probability of both being adopter and nonadopter.

c) Derivation of outcome indicators

Our analysis considers a broad set of outcome variables that are not only farm-household relevant but also individual specific in order to understand the impact of improved dairy cow adoption from a broader perspective.

(i) Milk yield and commercialization

We use annual milk yield per cow to assess the impact on productivity and the share of milk sold to capture the effects on commercialization of production. Annual milk yield is estimated as the total milk produced in a year divided by the number of cows owned. The share of milk sold is calculated as the ratio of the quantity of milk sales to total production expressed as a percentage.

(ii) Milk consumption and number of meals

We use per capita annual milk consumption to measure the impact that dairy cows have on the nutritional security of households. Milk consumption as applied here refers only to own-produced milk that is consumed by a producing household and is calculated as the annual volume of milk reported consumed, divided by the number of resident household members. As a measure of gross household food security, we use the average reported number of meals consumed daily per household.

(iii) Income and poverty indicators

As our outcome measure for income, we use per capita monthly expenditures on food and nonfood items. We follow the same approach as Ssewanyana and Kasirye (2012) to aggregate household expenditures item by item. Given the different recall periods used in the survey to collect household expenditure data, conversion factors are applied to generate an indicator of household consumption

on the basis of a 30-day month. Home-produced food consumption is valued at local market prices for those food items.

For poverty indicators, we employ per capita expenditure (PCE) in our analysis rather than household income². The PCE was calculated by aggregating different subcomponents of expenditures but excluding nonconsumption expenditure (Ssewanyana and Kasirye, 2012). This aggregation of expenditure was normalized on an adult equivalent basis by taking into account the demographic profile of each sample household³ (Appleton, 2001). Using the national consumer price index, we accounted for intertemporal variations by converting all monetary values into 2005/2006 prices. Thereafter, per adult equivalent consumption expenditure (expressed in 2005/2006 prices) was compared to the poverty lines following a cost of basic needs approach (Ravallion and Bidani, 1994).

We follow the standard Foster-Greer-Thorbecke poverty indexes that incorporate the three most common poverty measures—poverty headcount (P_0), poverty gap (P_1), and squared poverty gap (P_2) (Foster et al., 1984), specified as:

$$P_{\alpha} = \frac{1}{N} \sum_{i=1}^m \left[\frac{z - y_i}{z} \right]^{\alpha} \quad (4)$$

where N is the number of people in the sample, z is the poverty line, y_i is PCE for the i th person, and α is the poverty aversion parameter. When $\alpha = 0$, P_{α} is simply the headcount index (P_0), or the proportion of households that are poor. When $\alpha = 1$, P_{α} is the poverty gap index (P_1), a measure of the depth of poverty defined by the mean distance to the poverty line, where the mean is formed over

² PEC reflects effective consumption of households, thus provides information on the food security status of households.

³ The adult male aged 18–30 years is the reference person to calculate per adult equivalents.

the entire population with the nonpoor counted as having a zero poverty gap. When $\alpha = 2$, P_α is a measure of severity of poverty (P_2) and reflects the degree of inequality among the poor.

The poverty line (z in Equation 4) in Uganda was developed in Appleton et al. (1999) and follows the cost of basic needs approach. The poverty line consists of a food and a nonfood component. The food poverty line—termed as the *lower bound* poverty by (Ravallion, 1998)—is constructed from the Ugandan food basket, comprising the most frequently consumed food items by households with less than median income. On the other hand, the nonfood poverty line—termed the *upper bound*—is constructed by estimating the nonfood expenditure of households whose total expenditure is greater than the poverty line. In all estimations, variations in prices of nonfood items are allowed. For this reason, Uganda has nine poverty lines, depending on whether a household is located in a rural or an urban setting, plus regional variations (Levine, 2012). In our estimations, we use the different poverty lines to estimate the respective poverty indexes noted above, as appropriate.

(iv) *Nutrition and health indicators*

In the last part of the analysis, we identify the extent of malnutrition among children ages 0–5 years in both adopter and nonadopter households based on linear growth metrics. Anthropometric z-scores, standardized for age and sex, are used: stunting, or insufficient height-for-age; being underweight, or insufficient weight-for-age; and wasting, or having insufficient weight-for-height, indicating acute malnutrition (Aslam and Kingdon, 2012). We compute and use z-scores for the conventional measures—height-for-age (HAZ), weight-for-age (WAZ), and weight-for-height (WHZ)—following

Leroy (2011)⁴. The z-scores generated are used in further analysis as dependent variable indicators to examine children’s health outcomes and to compute prevalence differentials of stunting, wasting, and underweight in adopter and nonadopter households. Children are considered malnourished if their relevant z-score is less than -2.0 .

4. Results and Discussion

a) Descriptive statistics

As explained earlier, adopters are classified as households that own at least one crossbred or exotic dairy cow in the year preceding the survey, while nonadopters are households that owned only indigenous dairy cows. The number of sampled households and their adoption status by region are reported in table 1. Twenty-one percent of all sampled households are adopters: The highest adoption rates are observed in Western Uganda (38.1 percent) followed by Central Uganda (25.8 percent), with the smallest share in Northern Uganda (2.2 percent). These observations reflect what is reported elsewhere (Mbowa et al., 2012).

Table 1: Number of Sampled Households Surveyed and their Adoption Categories by Region

	Central	Eastern	Northern	Western
Adopters	49	48	6	56
Nonadopters	141	246	270	91
Total	190	294	276	147

Source: *Author calculations based on UNPS 2009/10 dataset*

⁴ We use a STATA add-on command ZSCORE06 to convert observed height, weight, and age of a given child into a z-score relative to the 2006 World Health Organization (WHO) growth standards

Tables 2 and 3 report summary statistics for the sample households of selected outcome indicators and key observed farm and household characteristics, respectively. Appropriate sampling weights are applied so that the statistics reflect the characteristics in aggregate of all households in Uganda that are engaged in dairy production. The average annual milk yield of dairy cow systems in Uganda is estimated at 65 liters per cow, which is much lower than in neighboring Kenya, in Africa as a whole, and in Europe (Wambugu et al., 2011). The level of farm commercialization also is low: An average of 12 percent of milk produced is sold. Although the biggest share of milk is retained for household consumption, annual per capita consumption of own produced milk is far much lower than the international standard. Ugandan milk-producing households consume about 31 liters per person per year, only a quarter of that consumed by neighboring Kenyans (Wambugu et al., 2011).

Table 2 further reports that Ugandan dairy-farming households consume about 2.5 meals per day, compared with the median standard of 4 meals per day, including breakfast. Further, these households spend a monthly average of 27,507 Ugandan shillings (UGX) on food items per capita, which is slightly higher than the average national food poverty line (UGX 26,232). Although the number of daily meals a household consumes is a poor metric for food security because it does not explicitly inform us of the food quality or quantity, observing this number alongside monthly food expenditure points to the fact that an average household in our study lies on the poverty line. Their chances of falling even further, below the poverty line, are high. Additionally, dairy-producing households spend a monthly average of close to UGX 19,000 on nonfood items such as education, health, clothes, and others, which is slightly more than half the amount spent on food.

Table 2: Summary Statistics for Outcome Indicators

Variable	Description	N	Mean ^a	S.E.
Milk yield	Annual milk production per cow (liters/cow)	906	64.71	17.60
Milk sales	Share of annual milk sales (%)	907	12.30	0.87
Milk consumption	Annual per capita milk consumption (liters/person)	907	31.33	3.09
Meals	Number of meals consumed by household the previous day	902	2.52	0.02
Food expenditure	Per capita monthly expenditure on food items (UGX)	906	27,507	693.98
Nonfood expenditure	Per capita monthly expenditure on nonfood items (UGX)	863	18,927	777.50
Food poverty headcount	Share of extremely poor households (per adult equivalent monthly expenditure is below the food poverty line)	906	0.29	0.02
Food poverty gap	Measures the depth of poverty in relation to the food poverty line	906	0.13	0.01
Food poverty severity	Measures the severity of poverty; reflects the degree of inequality among the food-poor households	906	0.07	0.00
Nonfood poverty headcount	Share of poor households (per adult equivalent monthly expenditure is below the nonfood poverty line)	906	0.46	0.02
Nonfood poverty gap	Measures the depth of poverty in relation to the nonfood poverty line	906	0.24	0.01
Nonfood poverty severity	Measures the severity of poverty; reflects the degree of inequality among the non-food-poor households	906	0.14	0.01
HAZ	Stunting—Height-for-age z-scores	745	−1.44	0.07
WAZ	Underweight—Weight-for-age z-scores	742	−0.83	0.05
WHZ	Wasting—Weight-for-height z-scores	735	−0.05	0.04

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: N = number of observations; S.E. = standard errors; UGX = Ugandan shillings.

^a Population-weighted statistics are reported.

Based on the three Foster-Greer-Thorbecke measures of poverty, table 2 shows that 29 percent of dairy cattle households are extremely (food) poor, with their monthly real gross expenditures below the food poverty line, and 46 percent of sampled households are nonfood poor. These results are comparable to other studies (Levine, 2012; Ssewanyana and Kasirye, 2012). The analysis of expenditure and the poverty indexes generally indicate a high prevalence of poverty among dairy cattle households.

At the bottom of table 2, we show nutrition indicators for children ages 0–5 years. It is important to note at this point that the number of observation for the analysis of child nutrition outcomes is substantially lower than the number of household observations. This is due to two reasons: First, household sampling was random as also was the child selection for anthropometric measurements, implying that if a sampled household had no child aged 0-5 years, the section for anthropometry would be skipped. Second, during data processing, a few other observations were voluntarily omitted from the sample due to measurement error. Nonetheless, our estimations mimic the Uganda Demographic and Health Survey ⁵ (UBoS and ICF, 2012) and we are confident that the omissions do not introduce any bias.

On average, most children living in Uganda’s dairy cattle households are below the WHO reference population mean height and weight. The average HAZ is -1.44 , suggesting that sampled children are almost one-and-a-half standard deviations shorter on average than the reference population, suggesting stunting and chronic undernutrition. The average WAZ is -0.83 , implying that the weight of sampled children is on average below that of the reference population. Unlike HAZ and WAZ, which are indicators of long-term deprivation, the deviation from mean of WHZ, indicative of more recent short-term deprivation, is not as bad, although still below the WHO population reference mean.

Table 3 provides information on the characteristics of Ugandan dairy cattle households. An average household head in such households has attained some education, but less than the statutory seven years of primary education, and is about 48 years of age. Majority households are male-headed,

⁵ The Uganda Demographic and Health Survey presents the mean scores as: HAZ= -1.4 ; WAZ= -0.8 ; and WHZ= -0.0 which is comparable to our estimates.

although half of household members are female. Households are relatively large, with an average of 8 members but with some households having as many as 29 members. The dependency ratio is high, with the share of working-age household members almost half of the non-working-age members. Sample households have relatively large farm areas compared with those in other studies (Kassie et al., 2011). This is not surprising because cattle-herding systems are known to thrive on relatively large land expanses compared with field crop systems. However, half of the sampled households are small, with farms of less than 2 acres. Another way to look at scale effects for dairy cattle households is in terms of herd size. Sampled households have an average of seven heads of dairy cattle, although the majority of households (56 percent) are smallholders with one to three heads of cattle.

Table 3: Summary Statistics: Farm and Household Characteristics

Variable	Description	N	Mean ^a	S.E.
Education	Number of completed years of schooling for household head	899	5.46	0.14
Age	Age of household head (years)	906	48.38	0.50
Sex	Sex of the household head (male = 1)	907	0.77	0.01
Household size	Number of people residing in household	907	7.52	0.13
Male share	Share of males residing in household (%)	907	49.95	0.59
Dependency ratio	Share of dependents to working-age household members (%)	892	142.25	3.82
Farm size	Total landholding (acres)	876	9.82	1.00
<i>Small</i>	Below median	438	1.78	0.05
<i>Large</i>	Above median	438	16.93	1.97
Herd size	Number of cattle heads owned	907	7.00	0.71
<i>Small</i>	Below median	507	1.58	0.04
<i>Large</i>	Above median	400	13.2	1.55
Assets	Value of capital assets owned (million UGX)	907	1.13	0.12
Off-farm income	Share of households with off-farm income	907	0.98	0.01
Central	If household is located in Central region (yes = 1)	907	0.22	0.14
West	If household located in Western region (yes = 1)	907	0.18	0.01
Urban	If household is urban (yes = 1)	907	0.09	0.01

Source: Author calculations based on UNPS 2009/10 dataset

Notes: N = number of observations; S.E. = standard errors; UGX = Ugandan shillings.

^a Population-weighted statistics are reported

Average asset holdings⁶ are in excess of UGX 1 million. Ninety-eight percent of all households are involved in off-farm income activities, perhaps as a risk diversification strategy away from farming. Other literature has shown that off-farm income helps offset farm and household cash needs (Babatunde and Qaim, 2010). Twenty-two percent and 18 percent of households are resident in Central and Western Uganda, respectively. Irrespective of regional placement, cattle herding, as many other agricultural activities, is a rural phenomenon, with 91 percent of all sampled households located in rural settings. These locational variables will be included later in multivariate analyses to control for potential influences related to markets and agroecological production characteristics.

To examine differences in observed characteristics between adopters and nonadopters, we performed significance tests on the equality of means (and equality of proportions for binary variables). Table 4 shows significant differences between all enterprise-level outcome indicators for adopters and nonadopters. With improved dairy cow breeds, adopters on average obtain more than fourfold the amount of milk per cow as nonadopters. This is reported elsewhere: Dobson (2005) asserts that indigenous cows can on average yield 1–2 liters of milk, while crossbreds and Friesians yield in the range of 5–20 liters per day. Members of adopting households consume more than twice as much of own-produced milk per year as nonadopters. Moreover, adopters are more likely to be involved in milk markets than nonadopters, with adopters selling one-third of all their production, a figure that is more than thrice that of nonadopters.

⁶ Assets exclude housing units and livestock.

Table 4: Differences in Mean Enterprise-level Indicators for Adopters and Nonadopters

	Adopter (N = 159)	Nonadopter (N = 748)	Difference	t-value
Milk yield	198.07 (513.48)	45.48 (150.67)	152.60***	6.86
Milk consumption	70.73 (190.43)	23.01 (65.29)	47.71***	5.51
Milk commercialization	30.00 (35.38)	8.74 (22.22)	21.24***	9.72

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: N = Number of observations. *** indicates statistical significance at the 1% level.

Figures in parentheses are standard deviations.

Household-level comparisons for welfare indicators are presented in table 5. Adopters of improved dairy cows are seemingly better off than nonadopters in many aspects. Adopters have a significantly higher number of meals as well as higher monthly per capita food expenditure. These two indicators point to the fact that adopters are likely more food secure than nonadopters. Adopters also have higher monthly per capita nonfood expenditures, implying that adopters can access more nonfood items such as healthcare, education, and clothes, which can impact quality of life. These facts are further emphasized by the observed poverty levels. Poverty incidence in the nonadopter category is relatively higher: Extreme poverty based on the food poverty line reference point shows that only 13 percent of adopters are extremely poor, compared with 32 percent in the nonadopter category; nonfood poverty incidence is comparatively much higher in nonadopters, with a difference of 24 percent between adopters and nonadopters.

Table 5: Differences in Mean Household-level Welfare Indicators for Adopters and Nonadopters

	Adopters (N = 159)	Nonadopters (N = 747)	Difference	t-value
Meals	2.76 (0.57)	2.46 (0.64)	0.30***	5.33
Food expenditure	29,768 (17,066)	25,265 (19,163)	4,503***	2.74
Nonfood expenditure	27,956 (32,016)	15,839 (17,418)	12,117***	6.57
Food poverty headcount	0.13 (0.34)	0.32 (0.49)	-0.19***	-4.87
Food poverty gap	0.06 (0.17)	0.16 (0.25)	-0.10***	-4.73
Food poverty severity gap	0.03 (0.10)	0.09 (0.16)	-0.06***	-4.20
Nonfood poverty headcount	0.27 (0.45)	0.51 (0.50)	-0.24***	-5.52
Nonfood poverty gap	0.14 (0.24)	0.28 (0.30)	-0.14***	-5.57
Nonfood poverty severity	0.08 (0.15)	0.16 (0.21)	-0.09***	-5.19

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: N = Number of observations. *** indicates statistical significance at the 1% level.

Figures in parentheses are standard deviations.

The poverty gap and poverty severity indexes are both significantly higher among nonadopters, implying that relatively more effort would be required to improve the welfare levels of nonadopters above the respective poverty lines than would be required for adopters. Moreover, significantly higher inequalities are prevalent in nonadopters than in adopters. These results indicate that improved dairy cows may be instrumental in reducing poverty, income gaps, and inequality among the poor.

Table 6 shows mean value comparisons of nutrition and health outcome indicators for individual children ages 0–5 years living in adopter and nonadopter households. Children living in adopter households are shown to be significantly healthier than children living in nonadopter households when assessed based on HAZ (stunting) and WAZ (underweight). However, WHZ is not significantly different, meaning that both adopting and nonadopting households had suffered equally from a more

recent deprivation, if any. Again, these z-scores imply that increased milk production as a result of adopting improved dairy cows, and certainly consumption of own-produced milk, may have important effects on improving nutrition outcomes of children living in adopting households.

Table 6: Differences in Mean Individual-level Nutrition Indicators for Children Younger than Age Five in Adopter and Nonadopter Households

	Adopters (N = 120)	Nonadopters (N = 625)	Difference	t-value
HAZ	-0.93 (1.82)	-1.48 (1.86)	0.55***	2.96
WAZ	-0.51 (1.14)	-0.83 (1.26)	0.32***	2.61
WHZ	0.04 (1.36)	-0.03 (1.17)	0.07	0.58

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: HAZ = height-for-age z-scores; WAZ = weight-for-age z-scores; WHZ = weight-for-height z-scores.

*** indicates statistical significance at the 1% level. Figures in parentheses are standard deviations.

Tables 4 to 6 have presented mean value comparisons of outcome indicators between adopters and nonadopters. Yet other potentially confounding factors to the observed outcomes beyond adoption are possible. Table 7 presents differences in the characteristics of adopting and nonadopting dairy households alongside their t-values. Comparisons show that education level, household size, dependency ratio, and the share of male household members are significantly different between adopters and nonadopters. Specifically, adopters have more years of education and significantly more household members. Household size is a proxy for labor, as most rural households in Uganda depend heavily on household labor rather than hired labor. Adopters also have a bigger share of male members and a lower dependency ratio than nonadopters. Since indications show that improved dairy cows are more labor intensive (Nicholson et al., 2004), requiring adopters to spend more time and effort grazing besides complementary feeding, vaccination, and protection against pests, adopters should have not merely labor but rather skilled labor available. It is thus logical that an average adopter has attained seven years of statutory primary education. Also, traditional Ugandan societies consider cattle rearing

and management a male-domain chore. Unsurprisingly, households with more males are more likely to be adopters.

Table 7: Differences in Household Characteristics of Adopters and Nonadopters

	Adopters (N = 159)	Nonadopters (N = 747)	Difference	t-value
Education	7.31 (4.34)	5.24 (4.17)	2.07***	5.62
Age	50.09 (15.08)	48.04 (14.34)	2.06	1.63
Sex	0.79 (0.41)	0.77 (0.42)	0.02	0.51
Household size	8.42 (3.96)	7.58 (3.48)	0.84***	2.69
Male share	52.74 (16.68)	49.20 (16.79)	3.54**	2.42
Dependency ratio	118.43 (95.17)	154.75 (116.35)	-36.32***	-3.67
Farm size	20.33 (73.86)	8.47 (16.90)	11.86***	3.87
Assets ('000 UGX)	2,744 (6,085)	902 (2,947)	1,842***	5.71
Off-farm income	0.96 (0.19)	0.99 (0.11)	-0.03**	-2.31
Central	0.30 (0.46)	0.18 (0.39)	0.11***	3.26
West	0.35 (0.48)	0.12 (0.33)	0.23***	7.37
Urban	0.16 (0.37)	0.10 (0.30)	0.07**	2.49

Source: Author calculations based on UNPS 2009/10 dataset

Notes: N = Number of observations; UGX = Ugandan shillings.

*** and ** indicate statistical significance at the 1% and 5% levels, respectively.

Figures in parentheses are standard deviations.

Further, table 7 reports significant differences in farm size holdings: Adopters have more than twice as much land as their nonadopting counterparts. Significant differences are also observed with respect to value of assets owned, excluding housing and livestock. Considering land and assets as proxies for wealth, we construe that adopters are wealthier than nonadopters. Adopters are also less likely to be involved in off-farm activities, suggesting that households that decide to adopt improved dairy cows commit substantial labor to the enterprise, possibly at the expense of off-farm economic activities.

We also observe that most adopters are located in the Western and Central regions of Uganda. As earlier mentioned, the Western region represents the milk production hub for Uganda, while the Central region is the biggest milk market. Irrespective of regional placement, significantly more adopters are located in urban settings than rural. This further underscores the role of ready milk markets, potentially offered by urban dwellers, in influencing adoption of improved dairy cows.

b) Propensity score matching estimation of impact of improved dairy cow adoption

Summary statistics and tests analyzed in the previous subsection indicate that adopters of improved dairy cows are better off than nonadopters. However, a critical look at possible covariates in table 7 hints at a positive selection bias in adoption behavior, with better-off farmers more likely to adopt improved dairy cows. Moreover, the substantial variation observed in the listed covariates may also confound the impact of adoption on the outcomes of interest. To investigate and separate the net technological effect, we employ multivariate approaches that account for self-selection that may arise as a result of the observed systematic differences between adopters and nonadopters. As explained earlier, we use PSM methods to match variables that influence both treatment assignment and outcomes but are not affected by the treatment (Smith and Todd, 2005).

Based on previous studies on adoption of improved agricultural technologies in developing countries (Feder et al., 1985; Foster and Rosenzweig, 2010; Kabunga et al., 2012; Krishnan and Patnam, 2014), we carefully select variables from the available dataset that are exogenous to treatment, but likely to influence both treatment assignment and outcomes of interest. We exclude covariates that are either unrelated to the outcome or are not proper covariates (Rubin and Thomas, 1996). As a first step, we generate propensity scores for improved dairy cow adoption by employing a probit model, with a

binary dependent variable equal to 1 for adopters and 0 otherwise (Equation 2). Results of the propensity score are reported in table 8. The subjects of analysis are households and individual children living in adopter and nonadopter households, respectively. This model is specified as a first step in assessing impact for all outcomes.

Table 8: Probit Estimation of the Propensity Score

<i>Dependent variable is adoption 1/0</i>	Enterprise and household-level indicators, for example, milk yield			Individual child-level indicators, for example, HAZ		
	Coefficient	S.E.	z-value	Coefficient	S.E.	z-value
Education	0.06***	0.01	4.00	0.08***	0.02	4.17
Age	2.16E-03	4.13E-03	0.52	2.62E-03	5.36E-03	0.49
Sex	-0.30**	0.14	-2.13	-0.37*	0.20	-1.90
Household size	0.01	0.02	0.63	0.00	0.02	-0.09
Male share	4.80E-03	3.42E-03	1.40	4.49E-03	4.30E-03	1.04
Dependency ratio	-1.00E-03*	5.47E-04	-1.83	-2.15E-03***	6.79E-04	-3.16
Farm size	4.60E-03**	2.14E-03	2.15	3.76E-03***	1.36E-03	2.76
Assets (million UGX)	0.04**	0.02	2.37	0.02	0.02	0.73
Off-farm income	-1.01***	0.37	-2.77	-0.78**	0.40	-1.95
Central	0.63***	0.14	4.54	0.77***	0.15	5.12
West	0.97***	0.14	7.02	0.95***	0.17	5.56
Urban	0.02	0.18	0.11	0.13	0.22	0.61
Constant	-0.79*	0.47	-1.69	-0.76	0.53	-1.42
N	853			690		
LR χ^2 ($p > \chi^2$)	134.09(0.00)			107.39(0.00)		
Pseudo-R ²	0.17			0.17		
Log likelihood	-334.24			-261.97		

Source: Author calculations based on UNPS 2009/10 dataset

Notes: HAZ = height-for-age z-scores; SE = Standard error; UGX = Ugandan shillings; N = Number of observations; ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Figures in parentheses are standard errors..

Table 8 shows the result of the probit model specified for milk yield and height-for-age outcomes. We do not observe notable changes in coefficients of the selected covariates across all outcomes at the enterprise-, household-, or individual-level analysis. For this reason and for brevity, we use results for the height-for-age and milk yield models to represent all other outcomes.

The main objective of the propensity score modeling is to balance the observed distribution of covariates across the treated and nontreated groups and not necessarily to perfectly predict selection (Caliendo and Kopeinig, 2008; Lee, 2013). Nonetheless, it is worthwhile to mention a few things. First, the pseudo- R^2 for all the models is above 0.17, indicating a reasonably good model fit. Second, most variables included in the specification show the expected signs: Education is positive and highly significant, implying that household heads with more years of formal education are more likely to adopt improved dairy cows. Female-headed households are more likely to adopt improved dairy cows, and there is no association between adoption and the share of male household members. This has gender implications but also demonstrates the effect of recent efforts to promote zero-grazing dairy units, largely managed by women, for improved nutrition. There is a positive association between farm size and adoption, implying that the likelihood of adoption is higher for farmers with more land. Off-farm income is negatively associated with adoption, suggesting that improved dairy cow adoption requires more labor commitment. Finally, households located in Western and Central Uganda are more likely to adopt improved dairy cows than those living elsewhere. As mentioned earlier, these results are consistent with first-stage probit regressions for other outcome indicators and are also consistent with the literature on improved agricultural technology adoption in developing countries.

To consistently estimate the impact of improved dairy cow adoption, we impose the common support condition by matching adopters and nonadopters in the region of common support (Sianesi, 2004). As explained earlier, we employ two matching algorithms (NNM and KBM) with replacement to increase the quality of matches and reduce the chances of bad matches (Smith and Todd, 2005). Observations from adopters and nonadopters whose propensity scores are higher than the maximum or less than the minimum propensity score are dropped from further analysis. Figures 1 and 2 show the distribution of the propensity scores and the region of common support for adopters and

nonadopters across household- and individual child-level outcome indicators, respectively. As with the first-stage estimates, we use milk yield and height-for-age as representatives of the respective outcome levels. The figures show that there is satisfactory overlap, which shows proper matching and that the common support condition is met.

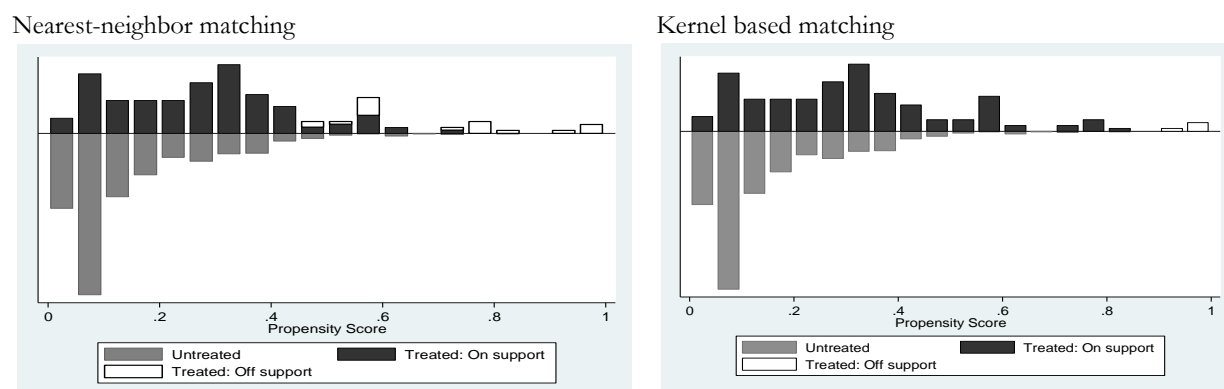


Figure 1: Propensity score distribution and common support: Impact of improved dairy cows on milk yield

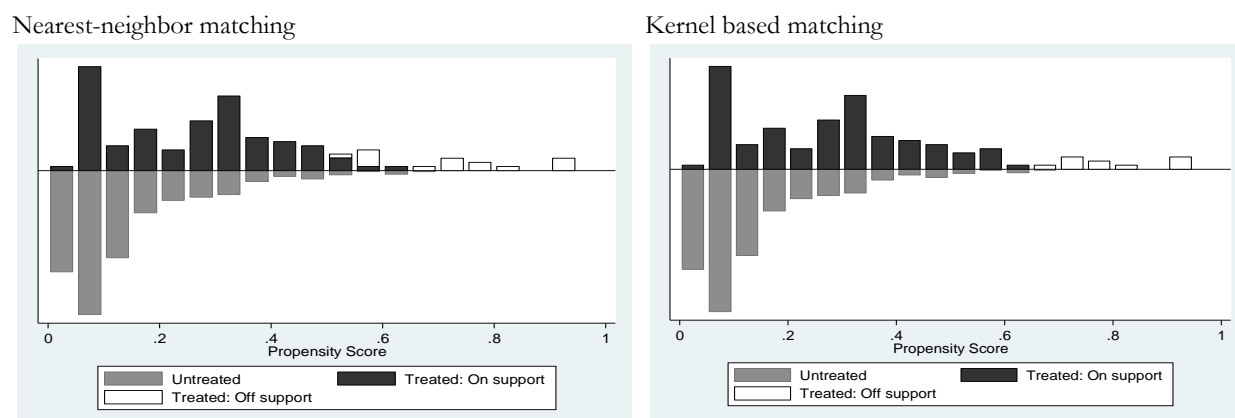


Figure 2: Propensity score distribution and common support: Impact of improved dairy cows on HAZ

Source: Author illustrations based on UNPS 2009/10 dataset

Additionally, we should remember that PSM matches adopter and nonadopter observations on a single dimension—the propensity score—that is a function of all covariates included in the model. It is therefore important that similar propensity scores emerge from similar characteristics. For this

reason, we performed balancing tests after matching. As expected, we do not have any significant differences after matching. Moreover the overall matching quality before and after propensity score estimation as exhibited by the relatively low pseudo- R^2 after matching imply no systematic differences in the distribution of covariates between adoptors and non-adopters after matching (results available on request).

After successful matching, empirical results for the net impact (ATT) of improved dairy cow adoption on the outcome indicators of interest can be calculated according to Equation 3. Tables 9 and 10 present the results based on the NNM and KBM algorithms, respectively.

At the enterprise level, results show that adoption of improved dairy cows causes a significant increase in milk yield as per the two matching algorithms. Specifically, the NNM estimates in table 9 suggest that adoption of improved dairy cows increases annual milk yields by about 170 liters per cow, while the KBM approach suggests that it could increase by about 163 liters per cow (table 10). This is the average difference in milk yield per cow between similar pairs of households that own different cow breeds and consequently belong to different adoption status. These estimates imply that improved dairy cow adoption increases milk yield by more than 200 percent. These results are not different from other observations in Uganda and the East African region: Wong & Kibirige (2009) assert that improved breeds can produce as much as 990 liters per head per year, compared with 400 liters for local breeds—a 147 percent increase in milk for improved breeds. In Kenya, a local zebu cow yields between 100 and 200 liters per year, while improved dairy cows yield in the range of 1,400 to 1,700 liters per year (Wambugu et al., 2011). Although the figures observed here are relatively lower and lag behind the genetic potential of known improved breeds, the potential to enhance milk productivity for poor African farmers through improved dairy cow adoption is irrefutable.

We also find significant effects of improved dairy cow adoption on own-milk consumption based on both the NNM and KBM algorithms. We further find positive, consistent, and highly significant ATT estimates for the share of milk sales—an indicator of commercialization of production—demonstrating the potential of improved technologies in integrating smallholders into modern markets. Unlike earlier studies, where ambiguity in the relationship between commercialization and own-food consumption has been reported (Alderman, 1994; von Braun, 1995), this study shows that the benefits of adopting improved dairy cows help in enhancing both outcomes.

At the household level, we find that adoption of improved dairy cows significantly and robustly (across both matching algorithms) increases the number of meals consumed and monthly per capita food expenditure, but not monthly nonfood PCE. The causal effect of adoption on monthly food expenditure ranges between 0.14 and 0.18, which is the average difference between monthly food expenditures of similar households, but belonging to different adoption status. Since expenditure is expressed in our model as a natural logarithm, further computations show that adopters spend 15 to 21 percent more on food than matched nonadopters do. These estimates imply that adopters are relatively better off especially in terms of food access, although not better off in terms of nonfood items such as education, health, and clothing.

Table 9: Nearest Neighbor Matching: Average Treatment Effects and Results of Sensitivity Analysis

Outcome	Mean		ATT	t-value	Observations		Critical level of hidden bias (Γ)
	Treated	Control			Treated	Control	
<i>Enterprise-level indicators</i>							
Milk yield	231.34	61.02	170.32*** (62.16)	2.74	134	700	1.40–1.50
Milk consumption	51.56	29.05	22.51* (11.99)	1.88	134	700	1.20–1.30
Milk sales	26.44	14.54	11.89*** (4.19)	2.84	134	700	1.50–1.60
<i>Household-level indicators</i>							
Meals	2.75	2.54	0.22** (0.09)	2.54	134	698	1.50–1.60
Food expenditure (log)	10.18	9.99	0.18** (0.08)	2.13	134	700	1.10–1.20
Nonfood expenditure (log)	9.60	9.47	0.14 (0.12)	1.11	131	668	—
Food poverty headcount	0.15	0.25	−0.10* (0.06)	−1.68	134	700	1.20–1.30
Food poverty gap	0.07	0.14	−0.07** (0.03)	−2.23	134	700	1.20–1.30
Food poverty severity	0.03	0.08	−0.05** (0.02)	−2.44	134	700	1.20–1.30
Nonfood poverty headcount	0.30	0.44	−0.14** (0.06)	−2.46	134	700	1.50–1.60
Nonfood poverty gap	0.15	0.23	−0.08** (0.04)	−2.00	134	700	1.20–1.30
Nonfood poverty severity	0.08	0.15	−0.07** (0.03)	−2.47	134	700	1.30–1.40
<i>Individual-child indicators</i>							
HAZ	−0.95	−1.39	0.43* (0.26)	1.70	103	572	1.25–1.30
WAZ	−0.54	−0.69	0.15 (0.16)	0.95	101	569	—
WHZ	0.02	0.04	−0.02 (0.18)	−0.08	102	564	—

Source: Author calculations based on UNPS 2009/10 dataset

Notes: ATT = Average treatment effects; HAZ = height-for-age z-scores; WAZ = weight-for-age z-scores; WHZ = weight-for-height z-scores.

** and * indicate statistical significance at the 5% and 10% levels, respectively. Figures in parentheses are standard errors.

Table 10: Kernel-Based Matching: Average Treatment Effects and Results of Sensitivity Analysis

Outcome	Mean		ATT	t-value	Observation		Critical level of hidden bias (Γ)
	Treated	Control			Treated	Control	
<i>Enterprise-level indicators</i>							
Milk yield	232.32	68.51	163.81*** (56.28)	2.91	149	700	1.20–1.30
Milk consumption	66.20	27.73	38.47** (15.82)	2.43	149	700	1.20–1.30
Milk sales	28.65	10.20	18.45*** (3.13)	5.90	149	700	1.60–1.70
<i>Household-level indicators</i>							
Meals	2.77	2.55	0.22*** (0.06)	3.67	147	698	1.80–1.90
Food expenditure (log)	10.17	10.03	0.14** (0.06)	2.55	149	700	1.40–1.50
Nonfood expenditure (log)	9.71	9.58	0.13 (0.09)	1.34	145	668	—
Food poverty headcount	0.14	0.26	−0.12*** (0.04)	−3.04	149	700	1.7–1.80
Food poverty gap	0.06	0.13	−0.07*** (0.02)	−3.39	149	700	2.70–2.80
Food poverty severity	0.03	0.08	−0.04*** (0.01)	−3.22	149	700	2.70–2.80
Nonfood poverty headcount	0.28	0.43	−0.15*** (0.05)	−3.23	149	700	1.10–1.20
Nonfood poverty gap	0.14	0.24	−0.10*** (0.03)	−3.73	149	700	1.90–2.00
Nonfood poverty severity	0.08	0.15	−0.07*** (0.02)	−3.79	149	700	2.50–2.60
<i>Individual child indicators</i>							
HAZ	−0.95	−1.44	0.49** (0.21)	2.34	108	572	1.40–1.50
WAZ	−0.55	−0.70	0.15 (0.13)	1.14	109	569	—
WHZ	0.01	0.08	−0.07 (0.14)	−0.52	107	564	—

Source: Author calculations based on UNPS 2009/10 dataset

Notes: ATT = Average treatment effects; HAZ = height-for-age z-scores; WAZ = weight-for-age z-scores; WHZ = weight-for-height z-scores.

***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Figures in parentheses are standard errors.

The effects on expenditures consequently have a positive bearing on poverty reduction. As shown in tables 9 and 10, the NNM and KBM algorithms yield significant and negative ATT's for all poverty measures. Particularly, adoption can reduce chances of households falling below the food poverty line by 10–12 percent and the nonfood poverty line by 14–15 percent. Adoption also reduces the depth and severity of poverty: Based on the food poverty line, the net effect of adoption on poverty depth is 7 percent, while the effect based on the nonfood poverty line is in the range of 8–10 percent. Moreover, adoption of improved dairy cows decreases food and nonfood poverty inequality as measured by the poverty severity indexes by 4–7 percent. These are very strong results with wider implications on poverty reduction at the national level. These results suggest that improved dairy cows should further be promoted for better poverty outcomes.

Finally, we discuss the net effects of improved dairy cow adoption on individual child nutrition indicators. The bottom sections of tables 9 and 10 show positive and consistently significant ATT estimates for HAZ but not for WAZ or WHZ, implying that improved dairy adoption reduces stunting but not underweight or wasting of children younger than age five. Our estimates show that children living in adopting households are on average taller than those living in nonadopting households for the same age and gender. Although we still observe stunted children in matched adopting and nonadopting households, the adoption of improved dairy cows reduces stunting of children in the household by an average of 0.43 to 0.49 standard deviations. These are quite large effects by any standards but are not surprising, given that milk is a nutrient-dense food. Children who consume cow's milk have been shown elsewhere to attain augmented height and bone mass gain than children who avoid it (Henriksen et al., 2000; Black et al., 2002; Wiley, 2009).

The last columns of tables 9 and 10 present results of the sensitivity analysis on hidden bias for significant adoption effects. The critical levels of gamma, Γ , at which point the causal inference of significant adoption effects may be questioned, are found within sufficient range. For instance, the value of 1.40–1.50 for milk yield (table 9) implies that if households that have the same covariates differ in their odds of adoption by a factor of 40–50 percent, the significance of the adoption effect on output may be questioned (Rosenbaum, 2002). This shows that the level of hidden bias has been substantially reduced by identifying the most important variables that affect both adoption and outcome indicators.

c) Heterogeneous Effects

In this section, we seek further understanding of the impact of adoption by scale, measured by herd and farm acreage. Accordingly, we stratify the sample into two groups: small and large farmers, as explained in table 3. For heterogeneous effects, the stratified samples are based on matched samples obtained using the NNM algorithm, and all the balancing properties are satisfied.

Table 11 shows heterogeneous effects at the enterprise level. We find that adoption of improved dairy cows significantly increases milk yield for households with both large and small farms. From the herd size perspective, however, the effect of adoption is 70 percent more on small farms, implying that productivity is higher with small herds as compared with large herds. On the other hand, farm acreage has a stronger leverage on milk yield than herd size, which makes sense—it would be difficult to hold large herds without large farm areas. On household’s own-milk consumption and commercialization, we find that households with large farms observe the biggest benefits from adoption. With specific reference to herd size, the effect on commercialization is twice as much for households with large

farms, while we also find significant effects of adoption on commercialization among households with large farm acreage. These results suggest that farm acreage is influential to adoption but may also stimulate the household's ability to achieve substantial gains from adoption.

Table 11: Heterogeneous Effects by Scale: Enterprise Level

		Scale by herd size			Scale by farm acreage		
		ATT	S.E.	t-value	ATT	S.E.	t-value
Milk yield	Large	114.65**	44.90	2.55	287.57**	123.21	2.33
	Small	195.19*	111.35	1.75	48.64*	26.70	1.82
Milk consumption	Large	69.37**	31.14	2.23	98.01***	33.33	2.94
	Small	7.49	6.348	1.18	3.45	7.44	0.46
Milk sales	Large	14.03**	6.85	2.05	27.94***	5.86	4.76
	Small	8.64**	4.14	2.09	3.32	4.84	0.69

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: ATT = average treatment effects; S.E. = standard error.

***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 12 presents the heterogeneous effects of dairy cow adoption on the number of meals consumed by the household as well as the household's expenditures on food and nonfood items. For both scale categorizations, we find large and stronger effects on meals for households with smaller farms. We also find that households with small farm acreage increase their food expenditure but not necessarily nonfood expenditures. These results demonstrate that the biggest benefits of improved dairy cow adoption on consumption (or generally household food security) accrue to small farmers.

Table 12: Heterogeneous Effects by Scale: Food and Nonfood Expenditures

		Scale by herd size			Scale by farm acreage		
		ATT	S.E.	t-value	ATT	S.E.	t-value
Meals	Large	0.16	0.10	1.61	0.13	0.09	1.40
	Small	0.29***	0.09	3.07	0.34***	0.09	3.61
Food expenditure	Large	0.11	0.09	1.15	0.08	0.10	0.85
	Small	0.18**	0.08	2.23	0.28***	0.09	3.24
Nonfood expenditure	Large	0.10	0.15	0.63	0.12	0.16	0.77
	Small	0.09	0.13	0.66	0.12	0.12	0.99

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: ATT = average treatment effects; S.E. = standard error.

*** and ** indicate statistical significance at the 1% and 5% levels, respectively.

On the broader outcome indicators of household poverty and child nutritional status, table 13 presents effects of improved dairy cow adoption among households with small and large farms. We find substantial food and nonfood poverty reduction effects of adoption on households with small farms. Poverty reduction effects for large farmers are not very precisely measured, being significant only at the 10 percent level or insignificant altogether. Conversely, however, we find bigger and significant effects of adoption on nutrition outcomes (HAZ) only among households with large farms (based on both herd size and acreage) but not those with small farms. This implies that adopting improved dairy cows may not adequately improve nutrition outcomes for children younger than age five in Ugandan households with less than median farm size.

This result is puzzling, as we would expect that significant increases observed for milk productivity, food expenditures, and poverty reduction, particularly among small farmers, are also reflected in improvements of child nutrition outcomes. Yet, this result is not unusual: A recent review of 26 Indian studies found that enhancing agricultural productivity typically improves output, income, and

consumption, but does not automatically translate into better nutrition outcomes (Gillespie et al., 2012).

Table 13: Heterogeneous Effects by Scale: Poverty and Nutrition

		Scale by herd size			Scale by farm acreage		
		ATT	S.E.	t-value	ATT	S.E.	t-value
Food poverty	Large	-0.11*	0.06	-1.89	-0.06	0.06	-1.00
	Small	-0.12*	0.07	-1.83	-0.19***	0.06	-3.06
Nonfood poverty	Large	-0.11	0.08	1.47	-0.09	0.08	1.09
	Small	-0.13*	0.07	-1.69	-0.22***	0.07	-3.04
HAZ	Large	0.97***	0.35	2.77	0.90**	0.38	2.34
	Small	0.33	0.37	0.89	0.28	0.36	0.79

Source: *Author calculations based on UNPS 2009/10 dataset*

Notes: ATT = average treatment effects; HAZ = height-for-age z-scores; S.E. = standard error.

***, ** and * indicate statistical significance at the 1%, 10% and 5% levels, respectively.

In the context of this study, some possible reasons for this lack of improvement in child nutritional outcomes are as follows: First, small farmers may be observing benefits of adoption as portrayed above, but certainly below a minimal threshold to leverage nutritional outcomes of young children resident in these households. In fact, as observed in table 12, adoption stimulates commercialization to some level but does not increase own-milk consumption for households with small farms. Additional income derived from the technological change, from product marketing, or from both may not sufficiently cause significant changes in nutrition. In fact it matters how large and how strong the linkages are between observed income changes derived from improved agrosystems and the dimension of health being considered (Hoddinott, 2012). If households do not use the additional derived income on more foods or foods of improved quality but rather on other goods that do not have a direct effect on health and nutrition, then the benefits of improved production will be minimal. In this case, it is possible that additional income derived from adoption for small farmers is used to achieve broader household food security objectives that focus on having more high-calorie foods

without paying particular attention to quality feeding needs of young children. This could be a factor of insufficient nutritional knowledge, resources, or both.

Second, in improved smallholder production systems with commercialization as a major goal, it is important to understand gender and intrahousehold allocation of benefits for nutrition (von Braun, 1995). In this case study, it is possible that women have less control of profitable enterprises, including dairy cows, to the detriment of child nutrition as also reported to occur in Kenyan milk-producing households (Meinzen-Dick et al., 2012). Third, it is also possible that the adoption of improved production systems may not be accompanied by improved food safety systems at the household level such that gains in productivity, increased nutrient density intakes, or both are canceled out by ingested toxins in the product, plus zoonotic pathogens (Spears, 2013).

Thus, while the literature links agricultural development to improved nutrition outcomes, this study shows that the underlying causes of undernutrition may go beyond direct nutrition-specific interventions to possibly include other factors such as gender and intrahousehold dynamics, education, and awareness of the contribution of high-quality foodstuffs in the health of children, as well as improvement in food safety and hygiene at the household level. For holistic and sustainable improvements in poverty and health outcomes, agricultural innovation programs should be complemented with related programs on gender empowerment, nutritional education and awareness, and food safety and hygiene.

5. Conclusions

The introduction and dissemination of improved dairy cow breeds in Uganda is arguably the most significant step taken to develop a modern and commercial dairy industry over the last two decades. In this study, we draw and evaluate empirical links between farm productivity, commercialization, poverty alleviation, and nutrition outcomes of children younger than age five. We analyze the impact of adoption of improved dairy cow breeds on three levels of outcomes: enterprise level (milk yield, own-milk consumption, and commercialization), household level (the number of meals; food and nonfood expenditure; poverty incidence, depth, and severity), and child health (child stunting and wasting). Our analysis is based on a nationally representative primary household dataset recently collected in Uganda. We employ rigorous impact assessment techniques using PSM to account for selection bias and achieve consistent estimates. We further test the robustness and sensitivity of our results using various matching algorithms as well as the consideration of heterogeneous effects of adoption based on farm acreage and herd size.

In the probit estimation of the first stage of the PSM, we find that the probability of adoption of improved cow breeds increases with education of the household head, farm size, and the sex of the household head being female. The latter is an interesting finding, as it demonstrates the effect of recent governmental and nongovernmental efforts to promote zero-grazing units, which are largely managed by women.

Controlling for heterogeneity in household- and contextual-level observables, we find a consistent increase in milk yield by more than 147 percent due to adoption of improved cow breeds. These are substantial increases in milk yield, although still lower than the genetic potential of known improved

breeds. We also find significant positive effects of adoption on own-milk consumption and milk commercialization using the share of milk sales indicator, suggesting that improved dairy cows may help farmers to increase milk intakes and to integrate into modern milk markets. At the household level, we find that adoption of improved dairy cows increases the number of meals consumed and monthly food expenditure in a significant and robust way, but not nonfood expenditure. Adopters spend 15–21 percent more on food than nonadopters, implying that adopters are relatively more food secure than nonadopters. Consequently, increased expenditures have positive impacts on poverty reduction: Adopters reduce chances of falling below the food and the nonfood poverty lines by 10–12 percent and 14–15 percent, respectively. Moreover, adopters also reduce the depth and severity of poverty in the range of 7–10 percent and 4–7 percent, respectively. These results suggest that improved dairy cows are instrumental for poverty alleviation.

Further, the study finds no significant effects of dairy cow adoption on weight-for-age but finds substantial positive effects on height-for-age indexes. Individual children younger than age five living in households that adopted improved dairy cows are on average much taller than those living in nonadopting households for the same age and gender, implying that adoption of improved dairy cows is influential in reducing stunting.

The impact findings are further differentiated by scale effects in terms of herd size and acreage. We find that adoption of improved dairy cows significantly increases milk yield for households with both large and small farms. From the herd size perspective, however, the milk yield effect of adoption is 70 percent more on small farms, implying that productivity is higher with small herds than with large herds. Yet the productivity effect is conversely bigger and stronger among households with larger acreage. Moreover, households with large farms, especially those with larger acreage, achieve higher

benefits of adoption in terms own-milk consumption and commercialization. The study further shows that households with generally small farms will likely consume more meals per day and significantly increase their food expenditure, an indication of improved household food security, due to adoption of improved dairy cows. Consequently, adoption helps small farmers to substantially reduce both food and nonfood poverty. The puzzle, however, is that improved welfare conditions (in terms of food security and poverty reduction) due to adoption do not translate into improved child nutrition outcomes for households with small farms. Rather, we find bigger and positive significant effects of adoption on stunting only in households with large farms that have also shown significant increases in milk consumption and commercialization due to adoption.

The empirical findings of this study suggest that promoting improved dairy cow breeds is likely to benefit farmers, especially smallholder farmers, to improve productivity, output, commercialization, food security, and poverty. However, large farmers, instead of the smallholders, will more likely achieve higher child nutritional benefits from improved dairy cow adoption despite their modest improvements in productivity, output, and poverty levels due to adoption. While existing literature links agricultural development to improved nutrition outcomes, we argue that the underlying causes of undernutrition may go beyond direct nutrition-specific interventions to possibly include other factors such as gender and intrahousehold dynamics, education, and awareness of the contribution of high-quality foodstuffs such as milk in the health of children, as well as improvement in food safety and hygiene at the household level. For holistic and sustainable improvements in nutrition outcomes, we recommend that agricultural development programs should be accompanied with related programs on gender empowerment, nutrition education, as well as food safety, sanitation, and hygiene.

References

- Alderman, H. "Why should it matter what commodity is the source of agricultural profits? Dairy development in India", in J.v. Braun and E. Kennedy (eds.), *Agricultural commercialization, economic development, and nutrition*. (Baltimore: John Hopkins University, 1994, pp. 239-251).
- Appleton, S. *Education, Incomes and Poverty in Uganda in the 1990s* (Nottingham, University of Nottingham, 2001).
- Appleton, S.M., T. Emwanu, J. Kagugube and J. Muwonge "Changes in Poverty in Uganda, 1992-1997", *Working Paper 99-22* (Centre for the Study of African Economies: University of Oxford, 1999).
- Aslam, M. and G.G. Kingdon "Parental Education and Child Health—Understanding the Pathways of Impact in Pakistan." *World Development*, Vol. **40**, (2012) pp. 2014-2032.
- Babatunde, R.O. and M. Qaim "Impact of off-farm income on food security and nutrition in Nigeria." *Food policy*, Vol. **35**, (2010) pp. 303-311.
- Bandiera, O. and I. Rasul "Social Networks and Technology Adoption in Northern Mozambique." *The Economic Journal*, Vol. **116**, (2006) pp. 869-902.
- Barrett, C.B., M.R. Carter and C.P. Timmer "A Century-Long Perspective on Agricultural Development." *American Journal of Agricultural Economics*, Vol. **92**, (2010) pp. 447-468.
- Black, R.E., S.M. Williams, I.E. Jones and A. Goulding "Children who avoid drinking cow milk have low dietary calcium intakes and poor bone health." *The American Journal of Clinical Nutrition*, Vol. **76**, (2002) pp. 675-680.
- BoU and PMA "Agricultural Finance Yearbook, Investment-Led Productivity Building in Agricultural Value Chains", (GTZ, Cooperation Republic of Uganda, Federal Republic of Germany: Bank of Uganda (BoU) and Plan for the Modernization of Agriculture (PMA), 2009).
- Caliendo, M. and S. Kopeinig "Some practical guidance for the implementation of propensity score matching." *Journal of economic surveys*, Vol. **22**, (2008) pp. 31-72.
- Dobson, W.D. "Dairy Industry of Uganda", *Dairy Updates No. 106* (Babcock Institute: University of Wisconsin, 2005).
- Elepu, G. "Assessment of Impacts of Changes in Dairy in East Africa: The Case of Uganda.", *Final draft submitted to the International Livestock Research Institute* (Nairobi, Kenya: ILRI, 2008).
- Feder, G., R. Just and D. Zilberman "Adoption of agricultural innovations in developing countries: A survey." *Economic Development and Cultural Change*, Vol. **33**, (1985) pp. 255-298.
- Foster, A. and M. Rosenzweig "Microeconomics of Technology Adoption." *Annual Review of Economics*, Vol. **2**, (2010) pp. 395-424.
- Foster, J., J. Greer and E. Thorbecke "A Class of Decomposable Poverty Measures." *Econometrica*, Vol. **52**, (1984) pp. 761-766.
- Garcia, O., D. Balikowa, D. Kiconco, A. Ndambi and T. Hemme "Milk Production in Uganda: Dairy Farming Economics and Development Policy Impacts", *Working Paper 09-08* (Addis Ababa, Ethiopia: IGAD Livestock Policy Initiative, 2008).
- Gerosa, S. and J. Skoet "Milk Availability: Trends in Production and Demand and Medium-Term Outlook", *Agricultural Development Economics Working Paper No.12-01* (Rome: Food and Agricultural Organization, 2012).
- Gillespie, S., J. Harris and S. Kadiyala "The Agriculture-Nutrition Disconnect in India: What Do We Know?", *Discussion Paper No. 01187* (Washington, DC: International Food Policy Research Institute (IFPRI), 2012).

- Gittelsohn, J. and A.E. Vastine "Sociocultural and Household Factors Impacting on the Selection, Allocation and Consumption of Animal Source Foods: Current Knowledge and Application." *Journal of Nutrition*, Vol. **133**, (2003) pp. 4036s–4041s.
- Henriksen, C., M. Eggesbø, R. Halvorsen and G. Botten "Nutrient intake among two-year-old children on cows' milk-restricted diets." *Acta Paediatrica*, Vol. **89**, (2000) pp. 272-278.
- Hoddinott, J. "Agriculture, health, and nutrition: Toward conceptualizing the linkages", in S. Fan and R. Pandya-Lorch (eds.), *Reshaping agriculture for nutrition and health* (Washington, DC: International Food Policy Research Institute, chapter 2, 2012, pp. 13-20).
- Kabunga, N.S., T. Dubois and M. Qaim "Heterogeneous information exposure and technology adoption: the case of tissue culture bananas in Kenya." *Agricultural Economics*, Vol. **43**, (2012) pp. 473-486.
- Kassie, M., B. Shiferaw and G. Muricho "Agricultural technology, crop income, and poverty alleviation in Uganda." *World development*, Vol. **39**, (2011) pp. 1784-1795.
- Kjær, A.M., F. Muhumuza, T. Mwebaze and M. Katusiimeh "Coalition-driven Initiatives in the Ugandan Dairy Sector: Elites, Conflict and Bargaining", *Working Paper 2012:02* (Copenhagen: Danish Institute for International Studies (DIIS), 2012).
- Krishnan, P. and M. Patnam "Neighbors and Extension Agents in Ethiopia: Who Matters More for Technology Adoption?" *American Journal of Agricultural Economics*, Vol. **96**, (2014) pp. 308-327.
- Lee, W.-S. "Propensity Score Matching and Variations on the Balancing Test." *Empirical Economics*, Vol. **44**, (2013) pp. 47-80.
- Leroy, J. "ZSCORE06: Stata module to calculate anthropometric z-scores using the 2006 WHO child growth standards." *Statistical Software Components*, (2011).
- Levine, S. "Exploring Differences in National and International Poverty Estimates: Is Uganda on Track to Halve Poverty by 2015?" *Social indicators research*, Vol. **107**, (2012) pp. 331-349.
- MAAIF *Statistical Abstract* (Entebbe, Uganda, Ministry of Agriculture, Animal Industry and Fisheries, Agricultural Planning Department., 2010).
- Mbowa, S., I. Shinyekwa and M.M. Lwanga "Dairy Sector Reform and Transformation in Uganda Since the 1990s", *EPRC Research Report* (Kampala, Uganda: Economic Policy Research Center, 2012).
- Meinzen-Dick, R., J. Behrman, P. Menon and A. Quisumbing "Gender: A key dimension linking agricultural programs to improved nutrition and health", in S. Fan and R. Pandya-Lorch (eds.), *Reshaping Agriculture for Nutrition and Health* (Washington, DC: International Food Policy Research Institute, chapter 16, 2012, pp. 135-144).
- Nicholson, C.F., L. Mwangi, S.J. Staal, and P.K. Thornton. Dairy Cow Ownership and Child Nutrition Status in Kenya. AAEA Meetings Selected Paper, 2003.
- Nicholson, C.F., P.K. Thornton and R.W. Muinga "Household-level Impacts of Dairy Cow Ownership in Coastal Kenya." *Journal of Agricultural Economics*, Vol. **55**, (2004) pp. 175-195.
- Quisumbing, A.R. and L. Pandolfelli "Promising Approaches to Address the Needs of Poor Female Farmers: Resources, Constraints, and Interventions." *World Development*, Vol. **38**, (2010) pp. 581-592.
- Ravallion, M. "Poverty Lines in Theory and Practice", *LSMS Working Paper* (Washington DC: The World Bank, 1998).
- Ravallion, M. and B. Bidani "How robust is a poverty profile?" *The World Bank Economic Review*, Vol. **8**, (1994) pp. 75-102.
- Rawlins, R., Pimkina, S., Barrett C.B., Pedersen, S. and B. Wydick "Got Milk? The Impact of Heifer International's Livestock Donation Programs in Rwanda." *Food Policy*, Vol. **44**, (2014) pp. 202–213
- Rosenbaum, P.R. *Observational studies* (New York, Springer, 2002).

- Rubin, D.B. and N. Thomas "Matching using estimated propensity scores: relating theory to practice." *Biometrics*, Vol. **52**, (1996) pp. 249-264.
- Ruel, M.T. *Can food-based strategies help reduce vitamin A and iron deficiencies?: A review of recent evidence. Food Policy Review* (Washington DC, International Food Policy Research Institute, 2001).
- Sianesi, B. "An evaluation of the Swedish system of active labor market programs in the 1990s." *Review of Economics and Statistics*, Vol. **86**, (2004) pp. 133-155.
- Smith, J. and P. Todd "Does Matching Overcome LaLonde's Critique of Nonexperimental Estimators?" *Journal of econometrics*, Vol. **125**, (2005) pp. 305-353.
- Spears, D. "How much international variation in child height can sanitation explain?", *Policy Research Working Paper, WPS 6351* (Washington, DC: World Bank, 2013).
- Ssewanyana, S.N. and I. Kasirye "Poverty and Inequality Dynamics in Uganda: Insights from the National Panel Surveys 2005/06 and 2009/10.", *EPRC Research Paper* (Kampala, Uganda: Economic Policy Research Center, 2012).
- Ssewanyana, S.N. and J.A. Okidi "Poverty estimates from Uganda National Household Survey III, 2005/2006": Economic Policy Research Centre (EPRC), 2007).
- Staal, S., C. Delgado and C. Nicholson "Smallholder dairying under transactions costs in East Africa." *World Development*, Vol. **25**, (1997) pp. 779-794.
- UBoS "Uganda National Household Survey 2005-2006: Social Economic Report", (Kampala: Uganda Bureau of Statistics (UBoS), 2007).
- UBoS and ICF "Uganda Demographic and Health Survey 2011.", (Kampala, Uganda and Calverton, Maryland: Uganda Bureau of Statistics and ICF International Inc, 2012).
- von Braun, J. "Agricultural commercialization: impacts on income and nutrition and implications for policy." *Food policy*, Vol. **20**, (1995) pp. 187-202.
- Wambugu, S., L. Kirimi and J. Opiyo "Productivity Trends and Performance of Dairy Farming in Kenya", (Nairobi, Kenya: Tegemeo Institute of Agricultural Policy & Development, 2011).
- Webb, P. "Impact Pathways from Agricultural Research to Improved Nutrition and Health: Literature Analysis and Research Priorities": Food and Agricultural Organization of the United Nations (FAO) and World Health Organization (WHO), 2013).
- Wiley, A.S. "Consumption of milk, but not other dairy products, is associated with height among US preschool children in NHANES 1999-2002." *Annals of Human Biology*, Vol. **36**, (2009) pp. 125-138.
- Wong, M. and M. Kibirige "South South Exchange: Sharing of Knowledge and Innovations, The Case of the Dairy Sector in India, Uganda and Tanzania.", *Working Paper 52074* (Washington, DC: World Bank, 2009).