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Agricultural Transformation, Technology Adoption and Inclusion of Small Farmers: The Case of Dairy in East Africa

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Agricultural Transformation, Technology Adoption and Inclusion of Small Farmers: The Case of Dairy in East Africa

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Abstract

Based on unique primary surveys, we study dairy transformation processes in East Africa, specifically in Ethiopia and Uganda. Evidence on transformation and differential paths followed in doing so in these countries is often limited due to a lack of data. We note significant changes in the dairy sector over the last decade - with more adoption of cross-bred cows and higher milk yields - seemingly driven by rapid changes in local demand (Ethiopia and Uganda) and export markets (Uganda). However, while small farmers were included in that transformation in Uganda, they were not in Ethiopia. This was seemingly driven by better and cheaper accessibility for cross-bred cows that small farmers can better bear in Uganda.

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1. Introduction

In the last two decades sub-Saharan Africa (SSA) has seen a dramatic economic transformation (Jayne et al., 2018). One driver of this has been the population growth. According to the World Bank, the population of SSA has almost doubled since the year 2000 to more than one billion people and it is expected to double again by 2050. Along with population growth, urbanization and incomes have also been on the rise. The diets of urban populations have moved away from traditional staples and toward more high value products (Popkin, 1998; Pingali, 2007). This includes a massive expansion of food markets both in volume and product diversification (Reardon et al., 2015). To meet the growing and changing demand, the agri-food systems have transformed as well.¹

The transformation of the agricultural sector in SSA in recent decades has played a key role in its development. The growth in output, diversification and value has been enormous. SSA averaged annual agricultural value added growth rates of more than four percent between 2000 and 2016 Jayne et al. (2018). However, this growth has mostly been by way of expansion and not increased productivity. To increase productivity there must be technology adoption. There is a vast literature on technology adoption in developing countries with topics ranging from risk (Duflo et al., 2011; Hurley, 2010; Just and Zilberman, 1983) to social learning (Conley and Udry, 2001; Foster and Rosenzweig, 1995; Lambrecht et al., 2014) to the quality of the technology (Bold et al., 2015).

The barriers to technology (such as cost, risk, or lack of knowledge) can lead to certain groups, mainly small or female farmers, to be excluded from adoption. For farmers in some of the poorest areas the modern technology adoption has been limited (Sheahan and Barrett, 2014; Evenson and Gollin, 2003). Aside from low technology adoption, smallholder farmers face limited access to credit and high transaction costs (Barrett, 2008; Escobal and Cavero, 2012; FAO, 2017). Given that 80% of the food in sub-Saharan Africa is produced by smallholder farmers (FAO, 2017), these farmers need to be included in the transformation of the sector.

Reardon et al. (2009) concludes from a range of studies that there are mixed patterns of inclusion depending on the context of the sector (whether small farmers dominate or not) and country. The authors also report positive effects from the inclusion of small

farmers in modern value chains and one key to this inclusion is government policy. Other studies have shown that supporting smallholders with resources such as training and access to technology are effective methods to include these farmers in the sector’s transformation (Amare et al., 2019; Briones, 2015; Escobal and Caverro, 2012). The appropriate policies need to be implemented to ensure the most remote, rural, or small farmers also have this market access (IFAD, 2016).

In this study, we focus on the agriculture sub-sector of dairy. Globally, the dairy sector is growing quickly due to increasing demand. The high income elasticity of animal source foods like dairy combined with urbanization and increased incomes are some reasons for this demand increase (Colen et al., 2018; Delgado, 2003). For those in developing countries, the development of dairy sectors comes with large opportunities for economic growth and agricultural transformation (Gulati et al., 2007; Ngigi, 2004; Cunningham, 2009). It is also a agriculture sector with regular income (daily yields instead of seasonal) and high nutritional benefits. As this sector grows, governments need to support the smallholders. For example, India is the largest producer of milk in the world with majority of those farmers being smallholders. Kumar et al. (2011) concluded that the modern dairy value chain is growing and found evidence in India between two states that shows that this growth and change has been inclusive across farm size.

Dairy is rapidly growing in Africa. East Africa leads the way with 68% of the continent’s production (Bingi and Tondel, 2015). East Africa had a ten time increase in intra-regional dairy trade between 2002-2003 and 2010-2015 (Abdulsamad and Gereffi, 2016). Some of the challenges faced by dairy farmers in sub-Saharan Africa include low productivity, low adoption of technology, and lack of affordable feed (Makoni et al., 2014). A main driver to improve productivity in the dairy sector is the use of cross-bred breeds which leads to improved yields (Mwanga et al., 2019). The use of technology such as adoption of cross-bred cows requires capital to acquire the technology and farm management knowledge in order to use it efficiently Abdulai and Huffman (2005).

In this paper we study the cases of Ethiopia and Uganda. The dairy sector accounts for 40% and 50% of agricultural GDP in Ethiopia and Uganda respectively (Bingi and Tondel, 2015). We study the transformation that has occurred in the dairy sector in each country and compare if this change has been inclusive across farm sizes. These

kind of comparisons are often uncommon due to lack of data. This paper contributes to the growing literature on the transformation of the dairy sector in developing countries. Others who have used primary data include Squicciarini et al. (2017) and Janssen and Swinnen (2017) from India, Minten et al. (2018) and Vandercasteelen et al. (2019) from Ethiopia and Van Campenhout et al. (2021) from Uganda. We find significant changes in the dairy sector over the last decade. Both countries have evidence of more adoption of cross-bred cows more participation in the value chain than a decade ago.² While small farmers are included in that transformation in Uganda, they were not in Ethiopia. This was seemingly driven by better and cheaper accessibility for cross-bred cows that small farmers can afford in Uganda.

The rest of this paper is structured as follows. Section 2 explains the data collection process and introduces our sample. In Section 3 the context of the agricultural transformation seen in both countries is explained and Section 4 provides the evidence from the dairy sector. Section 5 provides evidence of the transformation at farm level and studies the inclusiveness of different farm sizes with this transformation. In Section 6 we explore possible explanations for the differential effects on inclusion. Finally, Section 7 offers a discussion of the main results and concludes with some policy recommendations.

2. Data

We use primary data from both countries for this study. Each country used a similar method of stacked surveys to collect data along the dairy value chain. In Ethiopia, data was collected in January and February 2018 from two dairy production zones around Addis Ababa, the Ethiopian capital city. Data collection in Uganda took place in September 2018 in the central milk shed, which is a mostly domestic milk value chain with majority of the milk going to the Ugandan capital city, Kampala.

In both countries, a similar household survey was implemented among a large number of farmers in predominantly rural and sub-urban areas. The selected farmers in both countries were interviewed on a host of farm and household characteristics and more generally, the management of their dairy cows. This means we have extensive data on herd size, yields, and adoption of technology.

In Uganda, 1,200 farmers were interviewed using a two stage random sampling strategy. First, villages were selected with a probability proportional to village size. In each selected village, we then consulted village household lists to randomly select farmers. The number of households selected within each village was again proportional to the total number of households residing in the village.

In Ethiopia, a sample of 955 dairy farmers was targeted. A three-step sampling procedure was followed whereby both woredas (comprising several villages) and villages themselves were selected to have sufficient variation in remoteness to Addis Ababa. Within the selected villages, farmers were chosen randomly from a census of all households with cows. In an effort to also include the bigger farms in the survey area, farms with more than 25 cows was targeted, resulting in an extra 13 observations. We also collected community level information from focus groups in each kebele.

Table 1: Descriptive statistics

	Unit	Uganda	Ethiopia
Household Size	number	7.3	6.0
Female-headed household	%	9	8
Age of Head	years	49.1	48.8
Head Completed Primary	%	30	41
Grazing Land Owned	hectares	18.3	0.6

Source: Authors' calculations

Table 1 provides some descriptives of the farmers from each country. The main differences between the farmers are that the Ethiopian farmers are slightly more educated and the farmers in Uganda own much more land.

3. Context for Transformation

Multiple factors in both countries have led to the transformations in the dairy value chains in Uganda and Ethiopia. Three important drivers that we discuss are income growth, urbanization, and the policy reforms within the dairy sector.

Income growth and urbanization are interlinked drivers of transformation in the agricultural sector. Figure 1 presents the GDP per capita and urbanization rate for each

country since 2000. The GDP per capita in both countries has been steadily increasing over time and while Uganda has normally been higher than Ethiopia, the countries are almost equal as of 2018. Similarly, the urbanization rates in each country have followed a similar pattern with Uganda urbanizing slightly faster. Both income growth and urbanization lead to changes in diet (Popkin, 1999). This shift includes more consumption of animal protein (including dairy), oils, and fats (Drewnowski and Popkin, 1997; Kearney, 2010). Studies have also shown the high income elasticity of dairy which creates an increasing demand for dairy products within these countries (Colen et al., 2018; Delgado, 2003). The growing income and urbanized populations suggest that the demand for dairy products will continue to increase in both Uganda and Ethiopia.

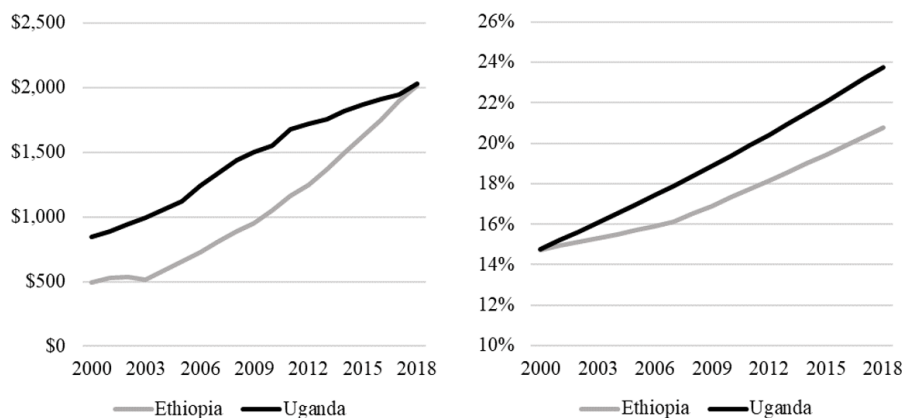


Figure 1: GDP per Capita (PPP) Urban Population (%) by Country

Source: World Bank Development Indicators

Lastly, the institutional support through policy reform in each country is a key driver for the transformation of a sector. Uganda's dairy sector began changing in the early 2000's.³ In 2006, the once centralized, government owned, monopolistic processing sector in Uganda was privatized. Since then, more has been invested into the sector including the building of more cooling and bulking centers. With this sector growth, then foreign processing companies built plants in order to produce dairy exports. In the last decade, the value of dairy exports in Uganda increased from zero to 130 million USD in 2017 according to the Dairy Development Authority. Ugandan processors are not yet producing at full capacity and continue to invest more into the dairy sector to increase productivity. They are building more milk collection centers (MCCs), which are also cooling centers, in villages

and some companies are testing quality based payment to incentive farmers to maintain quality standards.

In Ethiopia, there has not been much policy reform with respect to the dairy sector which has hindered its growth. Ethiopia is still a net importer of dairy products even with the recent growth in the sector. Between 2005 and 2015, the total milk production grew by 41% (Bachewe et al., 2018) but the value of dairy products imported also grew from 6 million USD to 18 million USD (Bachewe et al., 2017). Ethiopia faces high import tariffs which only increases the already high price for these products in the country. As demand for products continues to grow, the sector needs to also grow.

Both countries have experienced a similar transformation in terms of urbanization and income growth. However, with regard to the dairy sector reform, Uganda has been more pro-active in their dairy sector development than Ethiopia.

4. Evidence of Transformation throughout the Value Chain

We now focus on the different levels of the value chain and how they have been transformed by the drivers we discussed. Both Uganda and Ethiopia have seen an increase in dairy consumption over recent years, which is not surprising with the increased GDP per capita and the increase in urban population over time. Comprehensive data on consumption is hard to find and our survey did not collect consumption data. Therefore we utilize other sources to study the consumption trends in both countries. Nationally representative data from the last two decades have found an increase in the consumption of dairy products in both countries with the rate of increase being higher in wealthier and urban areas.⁴ This is not a surprise given the high income elasticity of the product, shown in Ethiopia by Abegaz et al. (2018). Both populations consume dairy in a variety of forms. Aside from liquid milk, dairy is also consumed as butter or ghee. In Uganda bongo (a fermented dairy drink) is also common and in Ethiopia, powdered milk is popular given its long shelf life.

The increase in consumption has led to changes in the midstream as well. There is demand for transporting the milk from farm up the chain and the number of dairy traders has grown with the sector. In Uganda, the traders operate alone as they are usually collecting milk on a bicycle or motorcycle (which limits the amount they can collect). The

traders collect directly at the farm. The midstream in Uganda also includes the MCCs, where many traders take their product. These are bulking and cooling centers that have become an important part of the value chain in Uganda.

The midstream in Ethiopia looks quite different than that in Uganda. The traders in Ethiopia trade much larger quantities of milk, most utilizing trucks to collect. Due to this, the traders usually pick up milk at specified locations. The farmers must take their milk to these locations, often by foot. The traders operate more as a business with multiple employees. However, there is no cooling in the midstream in Ethiopia. These traders face issues of lower quality milk and spoilage. Ethiopian traders are more comparable to the MCCs in Uganda than the traders.

The transformation has also been significant for the producers upstream. Table 2 presents the changes over time for the farmers in our sample, specifically the size and breed of their herd as well as their participation in the value chain. The farmers were asked these questions in relation to their situation at the time of the survey and as well as ten years prior. We note that recall questions can be prone to measurement error (de Nicola and Giné, 2014; De Weerd et al., 2014). These recall questions are only used descriptively to demonstrate the transformation within our sample. We do not use these data in our regression analyses.

We find that Ugandan farmers have shifted towards smaller dairy herds. Ten years prior to the survey, the farmers had an average of 28.6 cows, compared to the average of 14.9 cows owned at the time of the survey. This shift is from a reduction in the number of local cows they own which decreased on average by 17.9 cows since the ten years before the survey. They increased the average number of cross-bred cows owned by 4.2. The herd size for Ethiopian farmers surveyed has minimally changed from 3.4 cows ten years before the survey to 3.8 cows at the time of the survey. Farmers reduced their number of local cows by 0.6 on average as compared to ten years before the survey and increased the average number of cross-bred cows, on average, from 1.1 to 2.2.

The average share of the herd that is cross-bred is similar across the two countries when we compare the full samples from both. The share of cross-bred cows in Uganda is, on average, 43% and in Ethiopia, the share of cross-bred cows is 40%, on average. We find that this has increased more in Uganda where ten years before the survey, the

farmers share of cross-bred cows in their herd was only 9%, on average. In Ethiopia, ten years before the survey, farmers had an average of 27% of their herd cross-bred. Given the difference in herd sizes, with Ugandan farmers averaging three times as many cows than Ethiopian farmers, and the large increase in the share of cross-bred cows, our data indicate that the use of cross-bred cows in Uganda has dramatically increased more than in Ethiopia.

Table 2: Dairy Farm Changes Over Time

	Time Period	Uganda					Ethiopia				
		mean	sd	min	max	count	mean	sd	min	max	count
Total Cows Owned	time of survey	14.9	18.4	1	193	1,252	3.8	6.6	1	111	957
	10 years earlier	28.6	22.1	0	108	903	3.4	3.0	0	25	922
Local Cows Owned	time of survey	8.6	14.9	0	190	1,252	1.6	1.7	0	20	957
	10 years earlier	26.5	21.3	0	79	911	2.2	2.1	0	13	922
Cross-bred Cows Owned	time of survey	6.3	9.0	0	49	1,252	2.2	6.7	0	111	957
	10 years earlier	2.1	6.4	0	49	972	1.2	2.7	0	25	922
Share of Cross-bred	time of survey	43%				1,252	40%				957
	10 years earlier	9%				901	27%				911
Sold Milk (Y/N)	time of survey	100%				1,252	36%				956
	10 years earlier	65%				978	30%				910

Source: Authors' calculations

Lastly, in Table 2 we see that the share of farmers who sell milk has increased over time in both countries. In Uganda, where we specifically sampled farmers who were selling milk at the time of the survey, only 65% of them were selling milk 10 years before the survey. In Ethiopia, the share of the sample who sells milk increased from 30% to 36% within the same time-frame, however farmers who sell milk were not specifically sampled.

The evidence from Table 2 suggests that in Uganda, dairy farmers have decreased their herd size while increasing the use of cross-bred cows and their participation in the value chain. In Ethiopia, there has been minimal change in the herd size or share of farmers who sell milk but a slight increase in the use of cross-bred cows. Comparing these results between the two countries, this descriptive evidence is the first indication that the

use of cross-bred cows may be more accessible for farmers in Uganda than in Ethiopia.

The transformation of the dairy sector in each country followed similar paths at the consumption level. We see some differences in the transformation at the midstream level with Uganda's use of cooling technology allows more remote farmers to participate. However, the midstream in both countries have mechanisms in place that allow farmers to participate in the value chain and sell their milk. In the upstream level at the farms, the countries appear to differ the most. In the next section, we further study the adoption of cross-bred cows at the farm level.

5. Inclusion of Small Farmers

We have shown thus far that Uganda has seen a greater change in the use of cross-bred cows than Ethiopia since the 10 years before the survey data was collected. We want to explore these changes at different farm sizes as related literature has noted that small farmers are often excluded in agricultural transformations Reardon et al. (2009). We noted in Section 3 that the Ugandan government has been more proactive in transforming their dairy sector than Ethiopia and we will see how this relations to small farmers and their adoption of cross-bred cows.

The definitions of small, medium, and large farms varies by country and sometimes even by region. Herrero et al. (2010) define smallholder farmers as those with less than 2 hectares of land, who grow several crops and possibly have 1-2 cows. In Uganda, there are many different dairy production systems, seven have been outlined by Garcia et al. (2008). The production systems are split between intensive and extensive systems and are dependent on the amount of land owned as well as the number of animals. Given that the dairy sector has transformed since these different systems were outlined, we use the work of Garcia et al. (2008) as a guideline to help us define the farm sizes within our sample.⁵ Therefore in Uganda, we identify those with up to 5 cows as smallholder farms, those with 6-29 cows as medium size farms and farms with 30 or more cows as large farms.

In Ethiopia, the definitions of each size of farm differs from Uganda. The method of sampling used in the data collection in Ethiopia helps define the different farm sizes. As some large farms were targeted, these with more than 25 cows are clearly the large farms.

Other papers such as Minten et al. (2018), have used the more traditional definition of smallholder farmer as having 1-2 cows which leaves those farmers with 3-24 cows as medium farmers.⁶

5.1. Descriptives

Table 3 presents the summary of the share of cross-bred cows and the average daily yield by both breeds of cow by farm size. In Table 2 we reported that from our sample, the average share of cross-bred cows between the countries did not differ greatly at 43% for Uganda and 40% for Ethiopia. We now see a different pattern in Table 3 when we differentiate by farm size. In Uganda, there is not a lot of variation. Farmers average between 40 and 45% of their herd being cross-bred for all farm sizes. In Ethiopia, the small farms average 30% of cross-bred cows, the medium sized farms have 49% and the large farms have 97% cross-bred cows. We find similar results when using the continuous measure of total cows owned by each farmer, this can be seen in Figure A.1 in the Appendix.

The minimal difference in the share of cross-bred cows across farm sizes in Uganda suggests that the availability and price of this technology is similar for all farmers. In Ethiopia, the share of cross-bred cows increases drastically with farm size which indicates there are more barriers to this technology for the smaller farmers. It may be argued that more remote farmers may have less access to technology. We do find that more remote farmers in Ethiopia have a lower share of their herd improved, as seen in Figure A.2 in the Appendix. However, the more remote farmers are not necessarily smaller, as seen in Figure A.3 in the Appendix.

In Table 3 we also compare average yield by both local and cross-bred cows over the farm sizes. The yield is affected by a range of factors besides the breed of the cow including hygienic and feeding practices. These are often addressed analyzed when studying technology adoption in the dairy sector (Janssen and Swinnen, 2017; Burkitbayeva et al., 2020). However, the production systems of our two samples differ which affects their feeding and hygiene practices and makes comparison difficult.⁷ For the purpose of this paper, comparing yields is a more comparable variable that is a result of feeding and hygienic practices.

The average yields by cow breed, presented in Table 3, provide insight on the inclusion

Table 3: Cross-bred Adoption and Yields

	unit	Small Farms	Medium Farms	Large Farms	Correlation Coefficient
Share of cross-bred					
Uganda	%	40	45	44	0.07**
Ethiopia	%	30	49	97	0.25***
Yield					
<i>Local Cows</i>					
Uganda	l/cow/day	3.1 (1.8)	2.8 (2.1)	3.0 (2.8)	-0.13***
Ethiopia	l/cow/day	1.7 (4.3)	1.6 (1.3)	6.0 (5.6)	0.09**
<i>Cross-bred Cows</i>					
Uganda	l/cow/day	5.4 (3.6)	5.8 (5.3)	5.6 (3.5)	0.04
Ethiopia	l/cow/day	6.1 (4.2)	7.2 (4.5)	16.4 (8.1)	0.19***

Source: Authors' calculations. Standard deviations are in parentheses. We use Spearman's rank correlation to assess the association between the size of the farm and each of the variables presented. We report the coefficient size with ***, **, * that indicate two-sided significance levels at 1, 5, and 10 %, respectively.

of small farmers in each country. Local Ugandan cows have an average yield of 2.8 to 3.1 liters per day. We calculate the Spearman's rank correlation to test if the farm size is correlated to the mean yield per day per cow. The reason to test for this is because larger farms may have better practices or resources which make their cows more productive than small farms. This can provide descriptive evidence of whether or not the small farms have been included in the sector transformation. For the local cows in Uganda, we find a negative relationship with a coefficient of -0.13 significant at the 1% level. This indicates that larger farms in Uganda have lower yields from their local cows. However, when the mean yields are compared, the size of this effect is small. In Ethiopia, the local cows of small and medium farms have similar yields at 1.7 and 1.6 liters per cow per day each respectively. The local cows on large Ethiopian farms are much more productive, averaging 6.0 liters per cow per day. The Spearman's rank correlation test indicates a positive coefficient of 0.09 with a significance at the 5% level. This confirms that larger farms have more productive local cows than smaller farms. This indicates that the large farmers in Ethiopia may have better practices than the small and medium farmers.

In Uganda, cross-bred cows have an average yield of 5.4 to 5.8 liters per cow per day. The Spearman's rank correlation test fails to reject the null hypothesis therefore finding no correlation between the farm size the the yield of cross-bred cows. This suggests that Ugandan farmers may have access to similar practices or resources. In Ethiopia, we find

that the average yield per cross-bred cow per day ranges from 6.1 to 16.4. The Spearman’s rank correlation test, with a high coefficient of 0.19 significant at the 1% level, confirms that this increases with farm size. Now that we have evidence of this descriptively, we move on to regression analysis in the next section where we can control for other characteristics and see if these patterns hold.

5.2. Adoption Regression

In Table 4 we use a Tobit model to measure the correlation between cross-bred breed adoption and characteristics of the farmer. The dependent variable is the share of the farmer’s herd that is cross-bred. The right hand side includes household characteristics, herd size, and distance to the city. Although this model does not address various endogeneity issues such as self-selection, it can provide valuable correlations.

In addition to the farm size categories, we also include specifications that use a continuous measure of the number of cows owned. This helps us test the correlation from both non-linear and linear effects. We use household characteristics and remoteness as independent variables. For each specification we run one with only the farm size and another including household characteristics. In Ethiopia, these household characteristics were not collected for the large size farms. Additionally, for Ethiopia we include specifications with a binary indicator if the household sells milk. As mentioned previously, in Uganda only households who sell milk were sampled while this was not the case in Ethiopia. It could be argued that those selling milk would have better access to cross-bred cows and while sales of milk are not the focus of this paper, we include this variable to see if the pattern holds.

In Table 4, Models 1 to 4 present the results for Ugandan farmers and Models 5 to 10 present the results for Ethiopian farmers. In Model 1, we find that a medium farm in Uganda does have a significantly higher share of cross-bred cows than a small farm but once we include the household characteristics in Model 2, this results disappears. In Model 4, we find that for each additional cow a farmer owns, there is a significant negative effect on the share of the herd being cross-bred, however this effect is very small at 0.3 percent. In sum, in Uganda the farm size does not significantly influence the share of cross-bred cows a farmer has in their herd. The age of the household head and land area owned do

Table 4: Factors Associated With Share of Cross-bred Cows

	Uganda					Ethiopia				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Medium Farm	0.122** (0.060)	0.064 (0.060)			0.715*** (0.206)	0.736*** (0.253)	0.288* (0.155)			
Large Farm	0.102 (0.088)	-0.068 (0.097)			2.935*** (0.623)					
Total Cows			-0.000 (0.001)	-0.003** (0.001)			0.073*** (0.024)	0.218*** (0.051)	0.072** (0.028)	
Female Head		-0.045 (0.071)		-0.048 (0.073)		-0.099 (0.386)	0.011 (0.275)		-0.084 (0.395)	0.005 (0.279)
HH Members		0.004 (0.011)		0.005 (0.010)		-0.120** (0.055)	-0.050* (0.030)		-0.133** (0.052)	-0.054* (0.029)
Head Age		-0.007** (0.003)		-0.007** (0.003)		-0.005 (0.005)	-0.001 (0.004)		-0.008 (0.006)	-0.002 (0.004)
Land Owned (Acres)		0.002*** (0.000)		0.002*** (0.000)		0.032 (0.035)	0.018 (0.023)		0.037 (0.034)	0.021 (0.022)
Head Completed Primary		0.017 (0.071)		0.019 (0.072)		0.243 (0.237)	-0.037 (0.115)		0.178 (0.231)	-0.054 (0.115)
Distance to Nearest Town (hrs.)		-0.027 (0.068)		-0.024 (0.072)		-0.489** (0.204)	-0.151 (0.107)		-0.472** (0.201)	-0.149 (0.108)
Sells Milk							2.259*** (0.295)			2.231*** (0.294)
Pseudo R^2	0.003	0.018	0.000	0.018	0.110	0.075	0.294	0.107	0.084	0.294
Observations	1252	973	1252	973	957	872	872	957	872	872

significantly influence the share of cross-bred cows, each with a magnitude of less than 1 percent.

In Ethiopia, the results in Model 5 show that the share of cross-bred cows on a medium sized farm is 71.5 percent higher than small farms and the share on large farms is almost 300 percent higher than small farms. Once we control for the household characteristics in Model 6, we find a similar result for medium sized farms. We also find that households with more people are correlated with a lower share of cross-bred cows. Also, more remote farms also have a smaller share of cross-bred cows. In Model 7, we include the binary indicator for whether the household sells milk. This is highly correlated with the share of cross-bred cows on the farm but we still find a significant result that medium sized farms have a larger share of cross-bred cows than small farms. In Models 8 and 9, when we measure farm size with the continuous measure for total cows owned, we find similar results that larger farms are correlated with a higher share of cross-bred cows. In Model 10,

when we include the indicator for selling milk, we again find this is an important correlate of share of cross-bred cows and that additional cows are positively correlated with this as well. Overall, in Ethiopia we find evidence that larger farms do have a statistically significant larger share of cross-bred cows in their herd.

In sum, we find a correlation between the farm size and the adoption rate of cross-bred cows in Ethiopia but not in Uganda. We acknowledge there may be endogeneity issues and we are not claiming causality. In the next section, we study the average yield by breed of cow. While small farmers in Ethiopia have a smaller share of cross-bred cows than larger farms, the average yield from the improved cows they do have may be the same as medium and large farmers.

5.3. Yield Regression

Now that we have studied what characteristics are related to adopting cross-bred cows, we want to explore how this correlates with productivity. In Table 5 the dependent variable is the average daily yield for local and cross-bred cows as reported by the farmers. Our cross-sectional data does not allow us to make causal claims but we want to demonstrate the important correlation between cross-bred cow adoption and productivity. Each farmer reports the average yield for each breed of cow (or only one breed if they do not have both). We include an indicator variable for the breed of the cow to capture the average yield difference, local cows are the reference group. Also included are some farm characteristics that might be associated with productivity. The land size of the farm may indicate the farm's wealth or capture unobservant related to their farm management as larger farms need more management and proper care is needed for cross-bred cows to reach their full productivity. We include indicators for the two farm practices we mentioned in the descriptives, cleaning the udders before milking and whether the farmers mostly graze feed their cows. We expect that cleaning udders will be positively associated with yields and that farmers who mostly graze feed will be negatively associated with yields.⁸ In the specifications for Ethiopia, we include if the farmers sell their milk. This may also be related to unobserved behaviors or knowledge that would increase yields.

For both countries, we use the recent average daily yields. The results for Uganda indicate that cross-bred cows produce, on average, over two liters more per day than local

cows. The farm size or distance from the capital do not have any significant correlation with the productivity. We do find that cleaning the udders before milking results in a significant correlation of a higher a yield, about half a liter.

Table 5: Average Yield (l/cow/day)

	Uganda				Ethiopia			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cross-bred Cow	2.156*** (0.146)	2.212*** (0.147)	2.155*** (0.145)	2.209*** (0.147)	4.579*** (0.270)	2.453*** (0.250)	4.491*** (0.284)	2.410*** (0.255)
Medium Farm	-0.287 (0.237)	-0.153 (0.255)			0.232 (0.223)	-0.066 (0.207)		
Large Farm	-0.097 (0.278)	0.027 (0.298)			8.933*** (2.108)			
Total Cows			-0.002 (0.003)	-0.002 (0.003)			0.151** (0.059)	0.084* (0.043)
Land Area (Ha)		0.001 (0.003)		0.003 (0.003)		-0.282*** (0.089)		-0.313*** (0.095)
Udders Cleaned before Milking		0.483*** (0.174)		0.475*** (0.173)		0.445* (0.253)		0.441* (0.254)
Feed: Graze Cows		-0.248 (0.243)		-0.276 (0.232)		-0.631** (0.254)		-0.608** (0.244)
Time to Capital (hrs)	-0.127 (0.089)	-0.116 (0.091)	-0.145 (0.089)	-0.129 (0.091)				
Log of Transport Cost to Addis (birr/person)					-0.724*** (0.189)	-0.507*** (0.162)	-0.693*** (0.190)	-0.516*** (0.164)
Sells Milk						3.013*** (0.286)		2.953*** (0.287)
Constant	3.490*** (0.323)	3.355*** (0.359)	3.352*** (0.276)	3.324*** (0.330)	4.310*** (0.560)	2.536*** (0.772)	3.920*** (0.566)	2.498*** (0.779)
R^2	0.178	0.188	0.176	0.188	0.365	0.373	0.359	0.374
Observations	1077	1040	1077	1040	1063	972	1063	972

Note. All models are OLS with fixed effects at the subcounty (Uganda) or kebele (Ethiopia) level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

In Ethiopia, we find that cross-bred cows produce, on average, two to four more liters than local cows. In Model 5, we find that medium farms do not have a significantly different yield while large farms average almost nine more liters per cow per day than small farms. We also control for the distance to the city as measured by the cost of transport.⁹ We find that more remote farmers in Ethiopia is significant and negatively associated with yield. When we include farm characteristics in Model 6, again medium farms do not have have significantly different yields than small farms. We find a negative association with yields for farms with more area, farms who mostly graze feed and more remote farms. We also find a positive association of cleaning udders before milking and those who sell milk

with their yield. In Models 7 and 8, when we use the continuous measure of farm size, we find similar results. We find that larger farms are associated with higher yields.

Overall, we find that farm size is associated with both the adoption of cross-bred cows and productivity in Ethiopia but not in Uganda with larger farms having a higher adoption rate and higher yields per cow. Our correlation results suggest that in Uganda, farmers have similar access to this technology while in Ethiopia there are more constraints for small farmers. The exclusion of small farmers from this technology and its benefits are a barrier to Ethiopia's dairy sector growth.

6. Reasons for Differential Effects on Inclusion

We explore potential reasons for these diverging effects on the inclusion of small farmers in the dairy sector within the adoption of cross-bred cows. The cost and availability of this technology may differ by country. We study the availability of artificial insemination (AI) services and the prices of cross-bred cows.

6.1. Availability of AI

The difference in the cost and availability of AI services could be an explanation of the difference in smallholder inclusion between the two countries and the recent transformations they have both recently experienced. The use of AI services improves the production and genetic makeup of cattle and it has been widely used in developed countries (Kaaya et al., 2005). The uptake of this technology has remained low in African countries (Mwanga et al., 2019).

Mugisha et al. (2014) find that the main determinants of AI use in Uganda are the availability of the services, whether the farmer keeps records of his cows and the availability of milk markets. The authors do not find an effect of farmer education and age in the likelihood of adoption. In their study, the authors note that AI services cost about 11 USD per attempt, compared to 2.30 USD for bull services.¹⁰ Both Mwanga et al. (2019) and Mugisha et al. (2014) find that Ugandan farmers use bull services more often than AI. However, Mugisha et al. (2014) finds that a greater share of farmers in their sample report a preference for AI than those who use AI. This indicates that Ugandan farmers

face barriers to access the services.

In Ethiopia, determinants of AI include availability of extension agents, access to credit and income from milk sales (Tefera, 2014). Makoni et al. (2014) estimate the cost of an insemination in Ethiopia around 26 USD per attempt, more than double the price reported in Uganda. Constraints to these services include a shortage of liquid nitrogen (Makoni et al., 2014) and distance to the service provider (Mwanga et al., 2019). These are interlinked because without the ability to keep the sample cool, distance will have an impact on the quality and therefore the likelihood of success. The government of Ethiopia had created multiple liquid nitrogen plants, however they are often out of order. Zijlstra et al. (2015) note that the public AI group, the National Artificial Insemination Center (NAIC) is highly inefficient. Some of the issues facing the NAIC include different price between technicians, low availability of technicians and importing problems of the semen. The Addis Livestock Production and Productivity Improvement Service (ALPPIS) is the only private AI service and can not meet all the need within the country yet Makoni et al. (2014).

In both countries, farmers face limited access to these services. One common determinant of those who use AI in both countries is that farmers who are in the value chain are more likely to use AI (Mugisha et al., 2014; Tefera, 2014). The cost of AI services faced by farmers also influences the adoption rate. Often these services must still be paid even if unsuccessful, which is not the case for bull services (Mwanga et al., 2019). Given the recent growth of the dairy sector in Uganda as their use of cooling technology in the middle, the use of AI has potential to grow.

We rely on the farmer survey from Ethiopia to study the correlations of AI use and farm size. The data from Uganda do not allow us to compare the countries on this technology uptake. However, since our evidence thus far has indicated that small holders seem to be more excluded in Ethiopia than Uganda, we feel this is an important analysis to include. Within our sample in Ethiopia, 33% of farmers use AI services.¹¹ The three main reasons reported about why the farmers in our sample do not use these services are because the farmers report being unaware of these services, the farmers are unable to find AI inseminators, and the AI inseminators are too far away. Of the farmers in our sample who do not use AI services, only 23% of them report using a cross-bred bull (either their

own or a neighbor's) to breed. The other farms use local bulls. Within our sample, the use of AI increases with farm size. We find that 25% of small farms use AI, 41% of medium sized farms and 92% of large farms. To confirm this correlation, we present the results of a linear probability model in Table 6.

Table 6: Use of AI Service in Ethiopia

	Use AI Services			
	(1)	(2)	(3)	(4)
Medium Farm	0.032 (0.039)	0.041 (0.042)		
Large Farm	0.205*** (0.075)			
Total Cows			0.005*** (0.002)	0.018*** (0.007)
Distance to AI Services (Hrs)	-0.057*** (0.019)	-0.055*** (0.019)	-0.058*** (0.019)	-0.055*** (0.019)
Sells Milk	0.507*** (0.061)	0.486*** (0.062)	0.503*** (0.063)	0.473*** (0.064)
Female Head		0.066 (0.051)		0.069 (0.052)
HH Members		0.005 (0.009)		0.003 (0.009)
Head Age		0.001 (0.001)		0.000 (0.001)
Land Owned (Acres)		-0.007 (0.007)		-0.007 (0.007)
Head Completed Primary		0.065** (0.032)		0.060* (0.031)
Constant	0.354*** (0.068)	0.340*** (0.100)	0.358*** (0.058)	0.358*** (0.100)
R^2	0.390	0.355	0.392	0.360
Observations	771	697	771	697

Note. All models are OLS with clustered standard errors at the kebele level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

In Models 1 and 2, we measure the farm size by category and in Models 3 and 4 we measure farm size by the continuous measure of total number of cows. All models control for the walking distance (in hours) to the nearest AI service center (self-reported by the farmer) and if the farmer reports selling milk as the literature has found that farmers with access to milk markets are more likely to use AI services. In Model 1, we find that large farms are positively associated with a higher rate of AI adoption than small farms. Distance to the services has a negative correlation with the adoption rate and as expected,

selling milk has a positive correlation of using AI. Model 2 finds similar results when we control for farmer characteristics although we do not have estimates for the large farms. The results also indicate that the education of the household head is correlated with the adoption AI. Models 3 and 4 also find similar correlations, that while distance and selling milk are associated to adoption rates, we still find a positive correlation with farm size.

Overall, from the literature on the use of AI in both countries and our survey data from Ethiopia, we can make some conclusions about this technology. From the literature, it appears that both countries face low adoption of AI. A couple of reasons for the low adoption rate are cost and lack of availability. The cost of these services is much higher in Ethiopia, which creates a financial constraint for small farmers. The lower price in Uganda indicates that small farmers would be able to afford this technology. In terms of availability, Uganda has an advantage from the infrastructure of their value chain. The number of MCCs continue to grow in Uganda, even in remote villages, and these centers are equipped with coolers for the milk. The effort needed to equip them with cooling for AI services is lower than in Ethiopia, where cooling centers in villages do not exist. Given the lower cost of these services and the infrastructure in place, it follows that adoption of AI services by small farmers would increase more easily in Uganda than in Ethiopia.

6.2. Price of Improved Cows

Another method to own a cross-bred animal is through purchase instead of breeding. We rely on our farmer survey data from both countries to study the prices for dairy cows at the time of the survey.

Table 7 presents the mean prices for both local and cross-bred cattle. Panel A presents the mean prices by country and cattle type and Panel B presents mean cow prices by farm size in each country. In Panel A, we find that local cattle are more expensive in Uganda than in Ethiopia. A local cow in Uganda costs about 910 USD and in Ethiopia a local cow is about 630 USD. The cross-bred cows are much more expensive in Ethiopia than Uganda. In Uganda, a cross-bred cow costs, on average, 1,227 USD and in Ethiopia this is around 2,680 USD. The relative difference in price between local breeds and cross-bred cows is much smaller in Uganda across cows, heifers and calves. In Uganda, cross-bred cattle cost between 30-40% more than local breed, where in Ethiopia the cross-bred cattle

cost, on average, more than 4 times the price than local breeds (except for cross-bred calves which are only 3 times the price more than local calves).

Table 7: Cattle Prices (USD, PPP)

Panel A	Prices by Type of Animal			
	Uganda		Ethiopia	
	Mean	count	Mean	count
<u>Local</u>				
Cows	910 (227)	970	630 (215)	667
Heifers	638 (172)	774	402 (197)	409
Calves	245 (86)	790	132 (84)	543
<u>Cross-bred</u>				
Cows	1227 (330)	861	2680 (1431)	667
Heifers	831 (268)	661	1739 (1310)	338
Calves	337 (119)	706	434 (398)	401
<hr/>				
Panel B	Price of Cow by Farm Size			
Farm Size	Small	Medium	Large	Corr. Coef.
<hr/>				
<u>Local Cows</u>				
Uganda	890 (230)	915 (218)	929 (246)	0.07**
Ethiopia	625 (197)	632 (229)	1090 (509)	0.87
<u>Cross-bred Cows</u>				
Uganda	1220 (351)	1214 (316)	1282 (345)	0.06*
Ethiopia	2275 (1340)	2835 (1402)	4658 (851)	0.25***

Source: Authors' calculations. Mean price reported in USD PPP terms. Standard deviations are in parentheses.

In Table 7 Panel B, we present the mean price for cows by farm size. We find that the mean price for local cows in Uganda slightly increases with farm size. We use the Spearman's rank correlation test and it resulted in a significant coefficient of 0.07. However, the magnitude of this is quite small as the difference between the mean price reported by small and larger farmers is about 40 USD. In Ethiopia, the prices are smaller for local cows and we do not find a significant difference for the price of local cows by farm size. The large average price of these cows for large farms is a result of only three observations. The Spearman's rank correlation test is insignificant for this correlation. For the price of cross-bred cows in Uganda, we find that large farms report a slightly higher price for cross-bred cows than small farms. The magnitude of this correlation coefficient

is small at 0.06 and is only significant at the 10% level. The difference in price between small and large farms is about 60 USD. In Ethiopia, we find a strong positive correlation between the average price of an cross-bred cow and the farm size which ranges from 2,275 USD for small farms to 4,658 USD for large farms. The correlation coefficient is 0.25 and significant at the 1% level. These results suggest that larger farms pay twice the price for cross-bred cows than the prices paid small farmers.

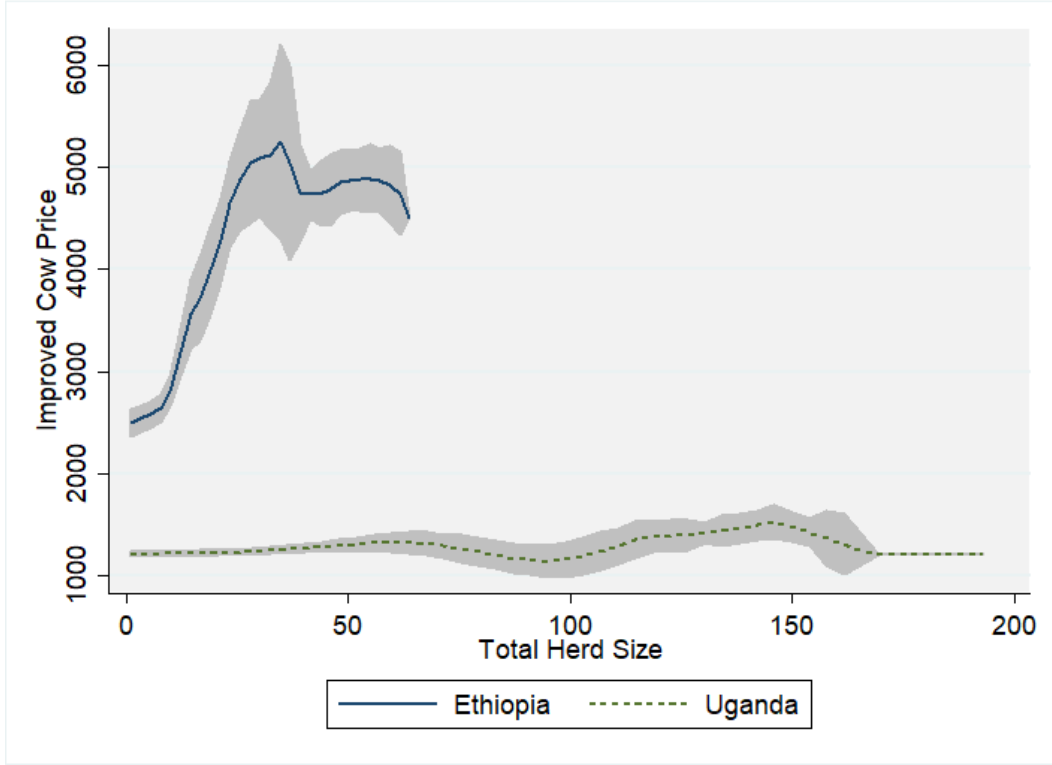
We want to confirm this association using the continuous measure of total cows owned by a farm. In Figure 2, we present the gradient for the price of cross-bred cows over the total number of cows owned by farmers in each country. Ugandan farmers report a similar price for cross-bred cows irrespective of their herd size. The farmers with more than 100 cows, we do see a slight increase which is what the correlation from Table 7 concluded. For Ethiopian farmers we see a steep increase in prices between farmers with a few cows to those with 50 cows. We find that large farms in Ethiopia are paying more for cross-bred cows than smaller farms.¹² This is counter intuitive and would suggest an upward sloping demand function for cross-bred cows in Ethiopia. One explanation is that the quality of an cross-bred cow varies. Zijlstra et al. (2015) note that the share of cross-bred blood in cross-bred cows in Ethiopia can range between 60% and 90%. We further study this correlation in a multi-variable regression analysis in Tables 8 and 9.

We model the price of cows, as reported by the farmers, as a function of their breed, the farm size and distance to the nearest town.¹³ Their breed indicates the average price difference between local and cross-bred cows, the farm size will inform us if there are price differences between farm sizes and the distance indicates of remoteness plays a role.¹⁴ Each farmer may report up to two prices in this analysis, one for each breed. Although some farmers do not have each breed and therefore may only have one responses. Local cows are the reference group.

Table 8 presents the results for Uganda. We find that cross-bred cows are consistently more expensive than local cows by at least 300 USD. We find that farm size and remoteness have no significant correlation with the price of cows, local or cross-bred.

Table 9 presents the results for Ethiopia. We also include an indicator if the farmer sells milk because farmers in the value chain may have a higher demand for cross-bred cows and could be more connected to breeders with higher quality cows. We utilize the

Figure 2: Mean Price of Cross-Bred Cows by Total Herd Size



community survey from Ethiopia to have an indicator for whether or not cross-bred cows are available in their kebele. This variable takes the value of 1 if the focus group of kebele leaders and dairy producers reported that cross-bred cows were available in their village and 0 if they reported cross-bred cows were not available. This variable can help shed light on if the farmers face a supply problem as we would expect prices to be lower if cross-bred cows are more available.

In Model 1, we find that cross-bred cows cost more than local cows across all farm sizes. The results also suggest that large farms report local cows costing more than small farms, but this is most likely an artifact of the data. As reported earlier, only three large farms reported prices for local cows. Next, we find that the price of cross-bred cows reported from medium and large farms are significantly higher than the prices reported from small farms. In Model 2, we include variables for the distance to the nearest town, whether the farm sells milk and if cross-bred cows are available in their village. Once again we find that cross-bred cows cost more than local cows and that cross-bred cows

Table 8: Cow Prices: Uganda (USD, PPP)

	(1)	(2)	(3)	(4)
Cross-bred Cow	372.949*** (47.093)	370.512*** (49.295)	302.068*** (16.294)	298.037*** (17.430)
Medium Farm	15.882 (22.782)	11.384 (23.330)		
Large Farm	42.511 (27.971)	38.930 (28.885)		
Cross-bred Cow \times Medium Farm	-76.295 (48.948)	-81.063 (51.449)		
Cross-bred Cow \times Large Farm	-21.013 (54.008)	-18.440 (56.512)		
Time to Nearest Town (Hrs)		18.890* (10.632)		19.877* (10.701)
Total Cows			0.263 (0.466)	0.173 (0.471)
Cross-bred Cow \times Total Cows			0.880 (0.651)	0.842 (0.662)
Constant	890.904*** (21.160)	863.940*** (27.497)	905.827*** (9.912)	874.960*** (19.518)
R^2	0.248	0.241	0.244	0.235
Observations	1831	1642	1831	1642

Note. All models are OLS with clustered standard errors at the household level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

on large farms cost more than these cows on small farms. Farmers who are more remote report slightly lower prices. We also find that farmers who sell milk report higher prices for cross-bred cows but not for local cows. Interestingly, in the kebele's where cross-bred cows are available, the price of local cows is slightly less but this has no correlation with the price of cross-bred cows. Models 3 and 4 find similar results using the continuous measure of farm size. Selling milk is highly correlated with the cross-bred cow prices with a large coefficient, but still the higher price for cows reported by larger farms holds.¹⁵

In terms of the availability of cross-bred cows, we have found that AI is not well organized or widely used in either country. Farmers must pay for bull services or purchase cross-bred cows to improve their herd. From our survey data, we find that the prices for cross-bred cows are much higher in Ethiopia than in Uganda. Additionally, the prices vary much more by farm size for the Ethiopian farmers while in Uganda, the price of

Table 9: Cow Prices: Ethiopia (USD, PPP)

	(1)	(2)	(3)	(4)
Cross-bred Cow	1554.680*** (103.210)	680.073*** (98.879)	1686.448*** (84.211)	606.004*** (98.632)
Medium Farm	-8.642 (19.061)	3.345 (17.922)		
Large Farm	413.946** (208.038)			
Cross-bred Cow \times Medium Farm	452.551*** (129.795)	363.366*** (124.018)		
Cross-bred Cow \times Large Farm	1815.516*** (374.681)			
Time to Nearest Town (Hrs)		-81.570*** (22.110)		-80.928*** (21.815)
Sells Milk		54.575 (38.468)		55.852 (39.038)
Cross-bred Cow \times Sells Milk=1		1323.449*** (115.963)		1287.343*** (115.953)
Cross-bred Avail. Kebele		-68.088** (30.900)		-69.995** (30.496)
Cross-bred Cow \times Cross-bred Avail. Kebele		-21.433 (139.058)		-105.034 (137.176)
Total Cows			4.313 (2.901)	-0.012 (5.139)
Cross-bred Cow \times Total Cows			34.931*** (11.057)	93.822*** (21.826)
Constant	1469.753*** (133.136)	946.437*** (232.280)	1489.719*** (133.686)	1031.374*** (229.303)
R^2	0.611	0.638	0.607	0.645
Observations	1129	1035	1129	1035

Note. All models are OLS with clustered standard errors at the household level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

an cross-bred cow is fairly consistent. Given the correlation of price with farm size, we assume that this is an indicator of the quality of the cross-bred cow the large Ethiopian farms purchase. This type of pattern reinforces the exclusion of smallholder farmers from the dairy sector. Cross-bred cows are a large expense for small and medium farmers in Ethiopia but the quality of their technology is not equal to the large farmers. With lower quality technology than other farmers and high prices for that technology, the farmers in Ethiopia face more challenges to enter the dairy value chain.

7. Conclusion

Using primary data from two countries, we study the inclusion of technology adoption over farm size. Both Uganda and Ethiopia have seen an expansion in the dairy sector from producers to consumers. With incomes increasing along with the urban populations, consumption has been increasing over the last decades in both countries, especially in the urban areas. This increased domestic demand (along with the export market growth in Uganda) has affected practices in the sector and the value chains in both countries.

First, we compared these changes both over time within country. Over time, the farmers in our sample from Uganda have decreased the number of cows they own and increased their share of cross-bred cows from 9 percent ten years before the survey to 43 percent at the time of the survey. In Ethiopia, the average herd size has not changed since the ten years before the survey. The farmers have also increased the share of their herds that are cross-bred from 27 percent to 40 percent. While the Ugandan sampling aimed to include farmers who sold milk, we found that only 65 percent were selling milk ten years before the survey. In Ethiopia, the share of farmers who sell milk only increased by 6 percent since the ten years before the survey.

Second, we compared the technology adoption of cross-bred cows between the countries and the farm sizes. We found the use of cross-bred cows to be much more equal across different farm sizes in Uganda. In Ethiopia, the largest farms are almost entirely cross-bred cows with the small and medium farmers averaging less than half their herd being an cross-bred breed. The productivity of cross-bred cows is also correlated with larger farm sizes in Ethiopia and not Uganda. This suggested that farm size may not only be associated with the likelihood to adopt this technology but also with how to use it most efficiently.

Lastly, we explored some explanations as to why this divergence in inclusion took place. We concluded that the two reasons for these different effects of inclusion are the lack of AI availability and the high cost of both cross-bred cows in Ethiopia. While local breeds are more expensive in Uganda than Ethiopia, the price difference between local and cross-bred cows is much lower in Uganda. cross-bred cows in Ethiopia are over twice the price of those in Uganda. The larger farms in Ethiopia are able to afford the cost of

an cross-bred cow or may have access to the private AI service. This high cost limits the small and medium farms to how many cross-bred cows they can purchase.

In sum, we provided evidence of small farmers being included in transformation within the dairy sector in Uganda. While in Ethiopia we found that the large farms have substantially grown in the last decade while the small and medium farmers are left behind. This seems to be driven by better and cheaper accessibility for cross-bred cows that small farmers can better bear in Uganda.

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Appendix

A. Additional Tables and Figures

Table A.1: Farm Size Distribution

Uganda			
	Small	Medium	Large
	1 - 5 cows	6 - 29 cows	30+ cows
	33%	57%	10%
Ethiopia			
	Small	Medium	Large
	1 - 2 cows	3 - 25 cows	25+ cows
	51%	47%	2%

Source: Authors' calculations

Figure A.1: Share of Cross-Bred Cows by Total Number of Cows

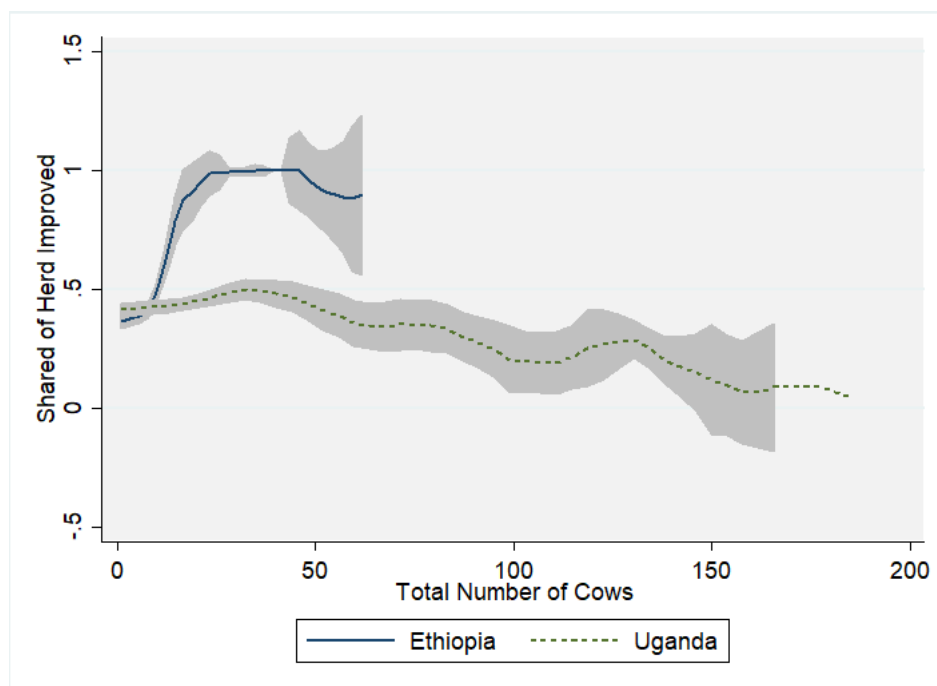


Figure A.2: Share of Cross-Bred Cows by Distance

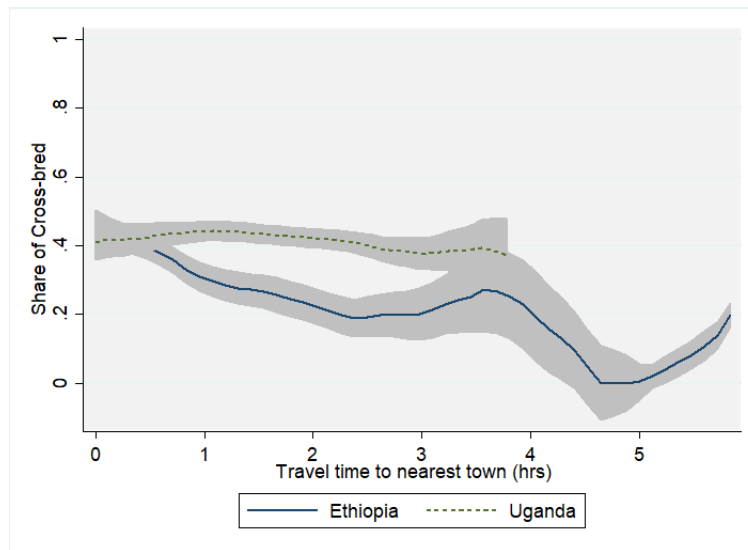


Figure A.3: Total Number of Cows Owned by Distance

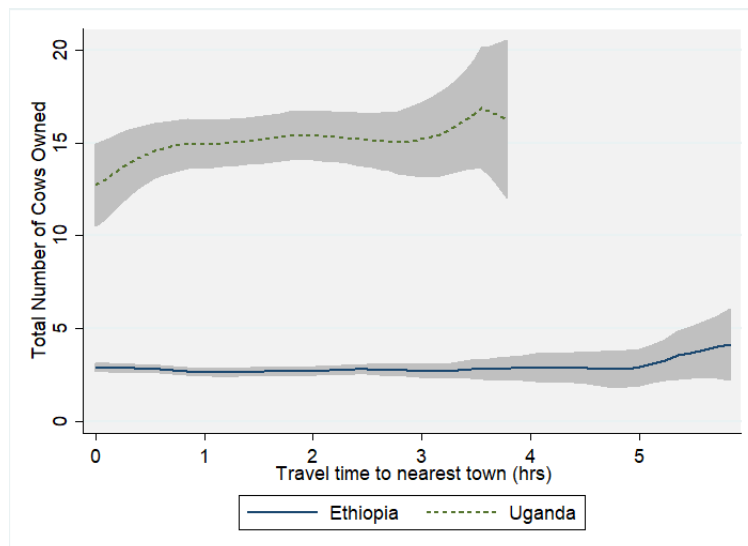
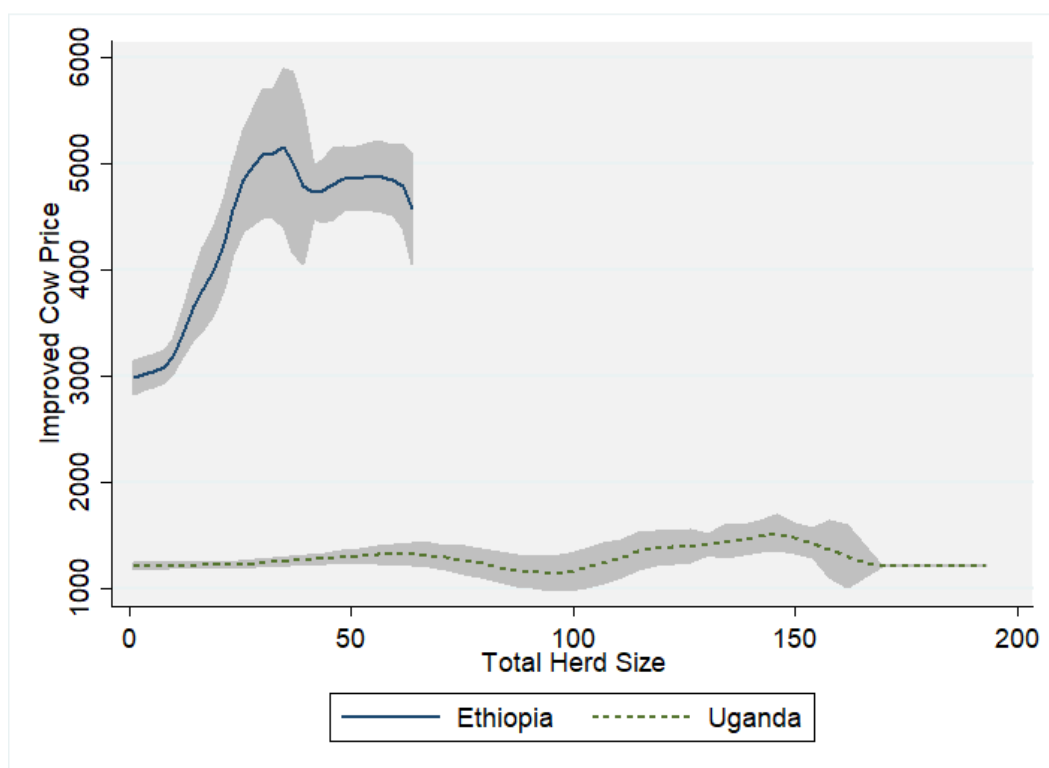


Figure A.4: Mean Price of Cross-Bred Cows by Total Herd Size



Note. This is the sub-sample of Ethiopian farmers who sell milk.

Table A.2: Other Adoption Practices

	unit	Small Farms	Medium Farms	Large Farms
Free grazing				
Uganda	%	65	88	89
Ethiopia	%	40	26	8
Clean udders before milking				
Uganda	%	50	27	22
Ethiopia	%	31	48	100

Source: Authors' calculations.

Table A.3: Calf Prices: Uganda (USD, PPP)

	(1)	(2)	(3)	(4)
Cross-bred Calf	91.973*** (14.163)	90.913*** (14.922)	86.712*** (6.234)	84.582*** (6.581)
Medium Farm	14.909* (8.742)	12.781 (9.132)		
Large Farm	35.664*** (10.894)	35.128*** (11.513)		
Cross-bred Calf \times Medium Farm	-3.927 (15.185)	-5.117 (16.037)		
Cross-bred Calf \times Large Farm	7.794 (17.356)	11.138 (18.525)		
Time to Nearest Town (Hrs)		6.409 (4.265)		6.621 (4.285)
Total Cows			0.166 (0.175)	0.174 (0.183)
Cross-bred Calf \times Total Cows			0.295 (0.250)	0.355 (0.263)
Constant	227.774*** (7.939)	219.495*** (10.499)	242.289*** (3.947)	231.873*** (7.935)
R^2	0.178	0.178	0.169	0.169
Observations	1494	1334	1494	1334

Note. All models are OLS with clustered standard errors at the household level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

Table A.4: Calf Prices: Ethiopia (USD, PPP)

	(1)	(2)	(3)	(4)	(5)	(6)
Cross-bred Calf	211.350*** (27.306)	161.190*** (26.146)	214.699*** (22.408)	154.115*** (30.975)	116.057* (66.224)	33.503 (37.723)
Medium Farm	9.282 (7.432)	-0.154 (8.283)				
Large Farm	48.825*** (15.717)					
Cross-bred Calf \times Medium Farm	76.746** (36.059)	44.761 (37.124)				
Cross-bred Calf \times Large Farm	634.228*** (156.918)					
Time to Nearest Town (Hrs)		-7.007 (5.914)		-6.814 (5.933)		-5.472 (5.915)
Sells Milk		105.571*** (24.248)		101.338*** (24.487)		88.732*** (25.706)
Total Cows			2.108 (1.434)	2.836 (3.679)	2.189 (1.430)	3.534 (3.599)
Cross-bred Calf \times Total Cows			10.802*** (3.155)	9.343 (7.390)	10.760*** (3.220)	8.283 (7.363)
Cross-bred Avail. Kebele					-3.708 (9.323)	-13.877 (10.216)
Cross-bred Calf \times Cross-bred Avail. Kebele					108.320 (72.514)	146.518*** (36.239)
Constant	246.074*** (52.225)	106.165** (50.484)	248.475*** (51.506)	105.164** (49.483)	243.110*** (52.792)	109.214** (49.667)
R^2	0.320	0.261	0.328	0.265	0.331	0.273
Observations	942	867	942	867	942	867

Note. All models are OLS with clustered standard errors at the household level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

Table A.5: Heifer Prices: Uganda (USD, PPP)

	(1)	(2)	(3)	(4)
Cross-bred Heifer	173.053*** (42.266)	149.309*** (40.620)	175.475*** (14.412)	169.837*** (14.989)
Medium Farm	7.564 (22.294)	6.245 (22.308)		
Large Farm	34.864 (25.001)	32.505 (25.508)		
Cross-bred Heifer \times Medium Farm	10.444 (43.984)	30.245 (42.652)		
Cross-bred Heifer \times Large Farm	7.363 (46.885)	22.125 (46.052)		
Time to Nearest Town (Hrs)		2.851 (9.224)		2.708 (9.221)
Total Cows			0.467 (0.334)	0.462 (0.344)
Cross-bred Heifer \times Total Cows			0.386 (0.557)	0.328 (0.570)
Constant	625.226*** (21.056)	618.693*** (25.334)	630.003*** (8.376)	622.312*** (16.719)
R^2	0.148	0.142	0.148	0.142
Observations	1433	1278	1433	1278

Note. All models are OLS with clustered standard errors at the household level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.

Table A.6: Heifer Prices: Ethiopia (USD, PPP)

	(1)	(2)	(3)	(4)	(5)	(6)
Cross-bred Heifer	873.155*** (105.777)	650.889*** (97.585)	901.928*** (83.307)	450.075*** (93.334)	452.878** (189.906)	113.584 (124.860)
Medium Farm	-54.576** (22.861)	-68.617*** (26.045)				
Large Farm	565.111*** (46.220)					
Cross-bred Heifer \times Medium Farm	307.847** (130.130)	165.026 (131.137)				
Cross-bred Heifer \times Large Farm	1773.060*** (371.978)					
Time to Nearest Town (Hrs)		-41.639* (21.892)		-44.456** (22.129)		-43.766* (22.817)
Sells Milk		470.039*** (78.220)		460.002*** (78.094)		441.568*** (78.102)
Total Cows			2.965 (5.940)	-19.186** (8.753)	3.978 (5.672)	-17.334** (8.547)
Cross-bred Heifer \times Total Cows			38.775*** (11.483)	83.895*** (22.100)	37.861*** (11.778)	79.837*** (21.956)
Cross-bred Avail. Kebele					-96.640** (38.861)	-119.680*** (35.874)
Cross-bred Heifer \times Cross-bred Avail. Kebele					519.298*** (195.559)	429.578*** (115.150)
Constant	1414.466*** (173.416)	724.070** (314.966)	1382.420*** (176.738)	848.558*** (304.869)	1412.813*** (182.458)	896.967*** (305.684)
R^2	0.501	0.401	0.502	0.417	0.507	0.423
Observations	747	671	747	671	747	671

Note. All models are OLS with clustered standard errors at the household level. ***, **, * indicate two-sided significance levels at 1, 5, and 10%, respectively.