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Interdependencies and sequential patterns in adoption of dairy technologies in Ethiopia

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In this paper adoption of dairy technologies in the Ethiopian highlands was examine using seemingly unrelated multivariate probit model which encompasses the effects of interdependencies of multiple technologies and unobserved heterogeneity in a unified framework. Model estimates show that household's likelihood of adopting dairy technologies is jointly determined by the observed household characteristics as well as unobserved household level and contextual factors. Empirical results show strong evidence of interdependencies in adoption decisions of dairy technologies, largely accounted by omitted variables. Among explanatory variables, while household income is positively associated with adoption of crossbred dairy cows, the size of livestock holdings is negatively associated with adoption of crossbred dairy cows. Overall, the results of this study suggest that the challenge to foster large scale uptake of technologies and productivity growth in the dairy sector goes beyond addressing household-level factors and requires a better understanding of unobserved heterogeneity among farmers and contextual factors.

Key words: Dairy, technology adoption, seemingly unrelated multivariate probit, heterogeneity.

INTRODUCTION

The demand for milk products is increasing in Ethiopia in response to increasing population, urbanization and rising income (Delgado, 2003). However, the supply of dairy products currently could not keep pace with the growing demand (Francesconi et al., 2010). The dairy sector in Ethiopia is primarily traditional and informal and milk production is largely dominated by smallholder farmers. Smallholder dairy production is characterized by poor genetic potential of dairy cattle herds, inadequate feed resources as well as poor quality and high cost of commercial feeds, low technological input use and low productivity of dairy cattle (Ayele et al., 2012; Ran et al., 2013). In the Ethiopian highlands, where this study was conducted, the average milk yield per cow per day is 2.31 L for indigenous cows and about 10 L for improved dairy cows. To fill the supply shortfall, Ethiopia has been importing large quantities of milk powder for many years (Ahmed et al., 2004; Francesconi and Heerink, 2011).

As experience and past research show, agricultural productivity gains are positively associated with adoption of improved agricultural technologies (Holden and Westberg, 2016; Quisumbing et al., 2015; Tilman et al., 2011; Udry and Conley, 2010). Improved technologies in feeding, animal genetics and breeding, animal health,

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animal husbandry practices, product handling and marketing have the potential to improve the livelihoods of smallholders through higher yields, improved nutrition and income generation. Several technologies that can boost the productivity of dairy cattle have been promoted in Ethiopia since the 1960s. For example, crossing exotic breeds of dairy cows with indigenous breeds through artificial insemination is a promising option that can provide rapid productivity gains (Duncan et al., 2013; Marshall, 2014). Several organizations have promoted planted fodder crops and multipurpose trees, pasture improvement and management, feed conservation technologies, and use of agro-industrial by-products in Ethiopia (Owen et al., 2012; Ran et al., 2013). A number of animal healthcare technologies such as vaccination and drugs to treat against parasites and bacterial infections have also been promoted (Mariner et al., 2012; Musaba, 2010). Considerable attention has also been given to producer cooperatives as a mean of enhancing farmers' access to agricultural input and output markets in Ethiopia (Francesconi et al., 2010). Despite a long-standing awareness that adoption of these dairy technologies could increase the productivity of dairy cattle, adoption has remained very low (Ayele et al., 2012; Duncan et al., 2013; Ran et al., 2013). Understanding the adoption process and the factors that facilitate or impede adoption of the technologies can assist in designing strategies that facilitate adoption of technologies and boost productivity of the dairy sector in the country.

A review of dairy technology adoption studies in Africa shows that single logit or probit models were often used to analyse technology adoption (Abadie and Imbens, 2006; Abdulai and Huffman, 2005; Burke et al., 2015; Franzel et al., 2001; Gebremedhin et al., 2003). Moreover, most empirical adoption studies focus on identifying specific factors affecting adoption of individual components within a package while treating their adoption as independent of other components. Yet individual components can be intricately related in a number of ways. For example, a farmer first buys a crossbred dairy cow and then participates in dairy cooperatives to sell high volumes of milk obtained from crossbred cow. Single discrete choice models fail to capture the effect of interrelationships inherent among interrelated technologies. Hence, independently defined logit or probit models used to examine adoption decision of a single technology component could lead to biased and inconsistent parameters because the same omitted variables may influence adoption decision for all the interrelated components. The possibility that the decision to adopt a particular component may be conditional on the adoption of another complementary component is often ignored. In case of interrelated technologies there is a need to understand how barriers to adoption relate to one another and whether some factors matter more than others. Thus an unobserved attributes that affect adoption of multiple technologies calls for the joint modelling of these behavioural dimensions.

Moreover, most adoption studies typically make *a priori* assumption that the effects of unobserved factors do not vary across farm households. Such studies conceal important unobserved heterogeneity effects in farmers' technology adoption decisions. Household-specific unobserved factors (e.g., technical ability, farmers' motivation, attitudes to risk and networking ability) could potentially be correlated with other observable characteristics of households and can affect their adoption decisions. However, household-specific unobserved factors like farmers' motivation and attitudes towards risk related to the explanatory variables considered in the empirical analysis may induce heterogeneous effects across households. Methodologically, prevalence of such sources of heterogeneity naturally calls for a flexible empirical model that allows for various forms of heterogeneities across farm households. This study builds an empirical model that accounts for two related concepts in technology adoption processes: Input complementarity and unobserved heterogeneity in the technology adoption decisions.

In this paper seemingly unrelated recursive multivariate probit model was employed to estimate adoption decisions by farmers facing multiple technologies that can be adopted in various combinations (Roodman, 2009). The seemingly unrelated recursive multivariate probit model encompasses the effects of interdependencies of multiple technologies and unobserved heterogeneity in a unified framework. Moreover, seemingly unrelated recursive multivariate probit model can test for the presence of hidden complementarities. Hence, the contribution of this paper is twofold. First, it tests the presence of interdependencies and sequential patterns in adoption of dairy technologies by looking at the correlation and covariance in the error terms of multiple dairy technology adoption decisions. Second, it discerns the sources of correlation and covariance in the error terms, with a particular emphasis on the role of omitted (unobserved) variables on adoption. Thus, our comprehensive specification provides interesting insights that would otherwise be impossible to extract from the existing univariate studies while also facilitating causal inference on alternative policy interventions.

MATERIALS AND METHODS

Theoretical framework

Our guiding premise in exploring the determinants of household technology adoption is grounded in the standard model of the agricultural household (De Janvry et al., 1991; Singh et al., 1986). Theoretically, the decision to adopt dairy technologies is considered under the general framework of utility maximization. It is assumed that farmers are expected to choose or adopt the technology that gives the largest expected discounted net return, or utility. However, the general framework of utility maximization models deal with situations where only one alternative is chosen from a set of mutually exclusive alternatives. Such models assume that the alternatives are perfectly substitutable for each other. The general utility maximization framework particularly faces a challenge when adoption decision involves complementarities between sequential choices. When complementarities drive technology adoption, the basic identification logic requires that the likelihood of choosing B depends on whether A is chosen, or whether the individual has chosen A in the past. To estimate complementarities in utility maximization framework, the general utility models need to be extended. Bhat et al. (2015) suggest multiple discrete choices models that allow us to model these interrelations. Multiple discrete choices accommodate rich substitution structures and complementarity effects in the technology adoption patterns.

The marginal utility of technology adoption with respect to technology k can be expressed as follows:

$$\frac{\partial U(x)}{\partial x_k} = \left(\frac{x_k}{\gamma_k}+1\right)^{\alpha_k-1}\left\{\varphi_k + \sum_{m=1}^{k}\theta_{km}\frac{\gamma_m}{\alpha_m}\left[\left(\frac{x_m}{\gamma_m}+1\right)^{\alpha_m}-1\right]\right\}$$

Where $\frac{\partial U(x)}{\partial x_k}$ is marginal utility with respect to the adoption of a vector of technologies, x_k ($x_k \geq 0$ for all k), and φ_k, γ_k and α_k are parameters associated with technology k.

In the above expression, the second term in the parenthesis indicates adoption of other complementary technologies. The formulation is not additively separable, but one in which the marginal utility of adopting one technology dependent on the adoption of other technologies.

In this paper technology adoption was considered as a choice of four dairy technology combinations: Crossbred dairy cow, artificial insemination (AI), improved forages and participation in dairy cooperatives. This study assumes a casual and sequential relationship between adoption decisions of improved forages, use of AI services, use of crossbred dairy cows and dairy cooperative membership. A farmer chooses a dairy technology combination that maximises utility subject to household demographic characteristics, household resource endowments and other determinants.

Econometric model

The adoption decisions of improved forages, use of AI services, use of crossbred dairy cows and dairy cooperative membership may be jointly determined and reciprocal in the context of the study area. Given that establishing improved forages is a relatively cheapest technology and the basis to begin a commercial dairy enterprise, adoption of improved forages was considered as y_1. Next, it was assume AI service to be y_2 on the ground that a farmer who planted improved forages wants to feed it to high yielding dairy animals. The cheapest means to get crossbred dairy cows is crossing local cows with exotic dairy breeds using AI service. Hence y_1 enters as a binary endogenous variable in the adoption equation for y_2. Next, crossbred dairy cows were considered to be y_3 as the previous technology adoption decisions most likely result in having crossbred dairy cows. Hence y_1 and y_2 was included as binary endogenous variables in the adoption equation y_3. As the idea of dairy cooperative membership comes after having surplus marketable milk from crossbred dairy cow, dairy cooperative membership seems to be the last intervention (y_4) to be adopted by farmers. This leads to the inclusion of y_3 in the adoption equation for y_4.

Ultimately the recursive system of equations would look like the following:

$$y_1^* = x_i{}'\beta_i + \varepsilon_1$$
$$y_2^* = x_i{}'\beta_i + \sigma_1 y_1 + \varepsilon_2$$
$$y_3^* = x_i{}'\beta_i + \sigma_1 y_1 + \sigma_2 y_2 + \varepsilon_3$$
$$y_4^* = x_i{}'\beta_i + \sigma_3 y_3 + \varepsilon_4$$

The error covariance matrix of the above recursive system of equations is complex, but the error covariance matrix was intuitively demonstrated using a bivariate probit example. The error covariance matrix for bivariate probit equations is given as:

$$\varepsilon = (\varepsilon_1, \varepsilon_2)' \sim N(0, \Sigma)$$

$$\Sigma = \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}$$

Where β_i is a matrix of coefficients, $y_1{}^* \ldots y_4{}^*$ and $\varepsilon_1 .. \varepsilon_4$ are random vectors and x_i is a vector of predetermined random variables. The error terms ($\varepsilon_1 .. \varepsilon_4$) represent both system-level unobservables and choice-specific unobservables (Bhat, 2008; Bhat et al., 2015). The correlation coefficient between the disturbances measures the indirect effect of y_1 on y_2 after the influence of the endogenous variable y_1 is accounted for in the first equation. For example, if ε_1 is uncorrelated with ε_2, so is y_1 with y_2. The σ_i measures endogeneity of y_1 in the y_2^* equation and so on. Hence, σ_i tests if unobservables have an effect on adoption of the technologies. The key null hypothesis maintains that the error terms $\varepsilon_1 .. \varepsilon_4$ are not correlated: $\sigma_i = 0$. If the null hypothesis is not rejected, the equations may be estimated separately by a binary probit model.

The parameters in system of equations can be consistently estimated equation by equation, but simultaneous estimation that takes into account the full covariance structure is more efficient. Hence, a seemingly unrelated multivariate probit estimation technique was employed, which simultaneously models the influence of explanatory variables on adoption of each of the different dairy technologies, while allowing the unobserved and unmeasured factors (error terms) to be freely correlated (Dorfman, 1996; Roodman, 2009; Wooldridge, 2010). The recursive model assumes a sequence in adoption decisions. In a seemingly unrelated recursive regressions (SUR) setup, the dependent variables are generated by processes that are independent except for correlated errors or endogenous variables that influence one another (Roodman, 2009).

Data and description of variables

Sampling scheme and data

The data used for this study were collected from 669 randomly selected sample households in seven districts in Ethiopia during June to July, 2013. The survey was conducted by the International Livestock Research Institute (ILRI) and the International Water Management Institute (IWMI) as part of the larger Nile Basin Development Challenge (NBDC) research project implemented in Ethiopia during 2010 to 2013. The research was carried out in the Blue Nile Basin in the Ethiopian highlands. The seven districts were selected based on the representativeness of the mixed crop-livestock farming system and suitability to dairy farming (Merrey, 2013; Sharma et al., 2012). A multistage sampling procedure was employed to select villages from each district and households from each village. First, one village was selected from each of the seven districts: Jeldu, Guder, Shambu and Diga districts from Oromia regional state, and Farta, Gondar Zuria and Fogera districts from Amhara regional state. Second, based on proportionate random sampling, 90 to 120 farm households were selected from the list of farm households in each village. The data were collected using a paper-based structured questionnaire through interviews with the household head or in his/her absence, the most senior household member available. Trained enumerators with experience in conducting surveys in the farming system collected the data. The variables of interest included information on household demographic characteristics, household farm resources and household assets, the inventory of crop and livestock production activities, use of modern livestock technologies, dairy production and marketing practices, household participation in dairy cooperatives, household access to credit and extension services, the distance a household resides from input and output markets and household sources of income and expenditure. The questions on monthly expenditure, which is used for measuring household cash income, were based on the template for the categories of goods and services in the Ethiopia Rural Household Survey questionnaire (Dercon and Hoddinott, 2004). The total monthly expenditure was computed by aggregating all expense categories (e.g. expenses for food items, clothes, school fees, weddings, funerals, loan repayment, membership fees to local organizations, church donations, etc.). In addition to the quantitative household survey, focus group and key informant interviews were conducted to triangulate with the information obtained through household survey.

Dairy technology adoption indicators

As mentioned previously, several technologies, including improved breeds of dairy cows and improved forages, have been promoted in Ethiopia to enhance the productivity of dairy cattle since the 1960s (Ahmed et al., 2004; Staal et al., 1997). Important technologies in dairy development included in the analysis are described subsequently. These are the technologies that are referred to in the conceptual model previously and will be used as dependent variables in the empirical analysis.

Crossbred dairy cows (1 = yes; 0 = no): The beginning of modern dairying in Ethiopia dates back to early 1950s when Ethiopia received the first batch of dairy cattle from the United Nations Relief and Rehabilitation Administration (Staal and Shapiro, 1996). Initial efforts on dairy development were based on the introduction of high yielding cattle in the highlands (Ketema, 2000). Various government programs and several projects have distributed crossbred dairy cattle (Ahmed et al., 2004; Staal, 1995). Hence, ownership of crossbred dairy cows is considered an important indicator of dairy technology adoption.

Artificial insemination (AI) (1 = yes; 0 = no): Reproductive technologies play an important role in genetic improvement programs. Generally, animal breeding programs aim to increase dairy productivity through breeding and selection implemented by using AI and bull services. The use of AI enables the production of a very large number of off springs from a single elite sire (Philipsson, 2000; van Arendonk, 2011). Artificial insemination has been widely promoted by the Ethiopian government as an effective technique for dissemination of genetic gain to producers at a relatively low cost. Thus the use of AI by individual farmers can be considered as an indicator of dairy technology use.

Improved forages (1 = yes; 0 = no): General scarcity of feeds and poor quality of feeds are the major constraints to livestock production in mixed crop-livestock farming systems (Ayele et al., 2012). To alleviate the shortage of livestock feed, improved forage technologies such as planted fodder crops, multipurpose trees, pasture improvement and management, feed conservation technologies and the use of agro-industrial by-products have been promoted (Lenné and Wood, 2004; Thomas and Sumberg, 1995). Therefore, the use of cultivated fodder such as elephant grass, oats-vetch, forage legumes and multipurpose trees by small households is considered as adoption of improved forage technologies in this study.

Dairy cooperatives (1 = yes; 0 = no): Milk marketing is a major problem in rural areas due to distance and poor infrastructure. Dairy cooperatives overcome marketing constraints in rural areas. Dairy cooperatives play a role in collecting and bulking, transporting and selling milk on behalf of the members. Therefore, farmers' involvement in dairy cooperatives and selling their milk to cooperatives is considered as important indicator of dairy intervention.

Description of explanatory variables and working hypotheses

Several factors may help explain why farmers fail to invest in potentially profitable agricultural technologies. The technology adoption literature suggest that factors associated with market failures such as inefficiencies in input and product markets, imperfect land, labour, credit and insurance markets and information inefficiencies are important determinants of low technology adoption. Based on our conceptual model and existing literature, explanatory variables included in the analysis and their hypothesized effects on adoption of dairy technologies are described as follows (Table 1).

Age (years): Young household heads are more likely to apply new technologies because younger household heads are less risk averse than older household heads (He et al., 2007; Sidibé, 2005). Thus it was expected that younger household heads will be more likely to adopt a dairy technology package.

Gender (1 = male; 0 = female): Women play a significant role in dairy production in Ethiopia. In Ethiopia, most of the activities in dairy production such as cattle feeding, barn cleaning, calf rearing, milk handling and marketing are performed by women (Tangka et al., 1999; Yisehak, 2008). Therefore, the gender of household head being male could be negatively associated with the adoption of a dairy technology package. This variable is defined as a binary indicator with value 1 for males and 0 for females.

Education (years): Education level is expected to have a positive influence on adoption of dairy technologies because of the assumed link between education and knowledge and the ability to read technical materials (Knowler and Bradshaw, 2007).

Family labour (in adult equivalent): Family labour is the major source of labour for farm activities. Households with a large active labour workforce have the capacity to relax the labour constraints required for a labour intensive dairy enterprise (Shiferaw and Holden, 1998). Therefore, availability of a larger active labour workforce is expected to affect the decision of adopting dairy technologies positively.

Size of land holdings (ha): In Ethiopia, smallholder dairy production is commonly practiced by farmers with limited land holdings close to towns and urban centres (Staal et al., 2002). Farmers close to towns and urban centres have limited land and this forces them to utilize small plots of land for intensive fodder production and rely on intensive dairy for their livelihoods making them more likely to adopt improved diary technologies. With the decrease in the availability of grazing land, farmers tend to sell excess animals and keep few productive animals that may speed up intensification (Carswell, 1997). Therefore, farm size is hypothesized to have a negative association with improved dairy interventions.

Livestock ownership (in TLU): The high population to land ratio results in scarcity of land and diminishes grazing land, making it difficult to maintain large number of livestock holdings. As a result farmers are expected to reduce the number of low yielding animals and keep fewer productive animals suitable for production of marketable outputs such as milk (Moll et al., 2007). Therefore,

Table 1. Definition of variables.

Variable	Short description
Adoption indicators	
Crossbred dairy cow	Ownership of crossbred dairy cows (cross or exotic) (1 = yes; 0 = no)
Improved forages	Use improved forages (1 = yes; 0 = no)
AI service	Use AI service (1 = yes; 0 = no)
Dairy cooperatives	Participation in dairy cooperatives (1 = yes; 0 = no)
Household characteristics variable	
Age	Age of household head (years)
Gender	Gender of household head (1 = male; 0 = female)
Education	Education level of household head (years of schooling)
Family labour	Family size in adult equivalent (AEU)
Dependency ratio	The ratio of the combined youth population (0 to 14 years) and senior population (65 or older) to the working-age population (15 to 64 years)
Household wealth variables and farm characteristics	
Land holding	Land holdings per adult equivalent
Livestock holding	Total number of livestock owned (in TLU)
Total household expenditure	Household expenditure per month per adult equivalent ('000 USD)
Institutional and access related variables	
Ownership of mobile telephone	(1= if household owns a mobile telephone)
Distance to farmers training centre	Distance to extension office(in walking minutes)
Distance to market	Distance to nearest market centre (in walking minutes)

adoption of improved dairy cow technologies is expected to be negatively associated with large livestock herds (Upton, 2000).

Total household expenditure per month per adult equivalent ('000 USD): An increase in household income translates directly into higher expenditure on food and non-food items (Ahmed et al., 2000). Because of under-reporting income and measurement errors, expenditure data are typically considered more reliable than income data in rural areas of developing countries (Bezu et al., 2012). Therefore, the total monthly expenditure of sample households was considered as a good proxy for household income. Increased income eases the liquidity constraint needed for new technology investments. Total household expenditure is expected to be positively associated with adoption of dairy technologies. Potentially, adoption of dairy technologies could influence total household income and vice versa.

Ownership of mobile telephone: Having information on new technologies is crucial in technology adoption in general and dairy farming is an information intensive enterprise (Aker, 2011; Pannell et al., 2006). Mobile phone offers an opportunity for novel interventions that have the power to integrate rural agricultural markets and increase competition. A mobile telephone allows for linking with input providers, as well as buyers. It is, therefore, expected that farmers who own a mobile telephone are more likely to adopt dairy technologies.

Distance to extension office (in walking minutes): Farmers living closer to an extension office are expected to be more likely to know and meet an extension agent frequently. Frequent meetings with extension agents promote knowledge about new technologies and services. Therefore, it was expected that is distance to the nearest farmers' training centre to have a negative influence on the adoption of dairy technologies.

Distance to the nearest market (in walking minutes): Households should be integrated with input and output markets to reap benefits from dairy technologies. Indicators of physical access to infrastructure are good proxies for institutional conditions that also shape market access conditions (Kruseman et al., 2006; Omamo, 1998). It was expected that farmers located in remote areas with poorer transportation infrastructure will suffer from less favourable input-output price ratios, fewer local trading opportunities, and less competitive local marketing conditions. Therefore, it was expected that long distance to the nearest market centre to have a negative influence on the adoption of dairy technologies.

RESULTS

Descriptive statistics

Before proceeding with the econometric estimation, the basic features of the data were first presented in descriptive statistics (Table 2).

The differences between adopters and non-adopters of improved dairy technologies in access to farm resources are presented in Table 2. In Ethiopia, adopters of improved dairy cows had a higher number of family members in working age group (15-64 years of aged), low number of dependants (aged under 15 and over 65 years). Adopters also had better access to mobile telephone than non-adopters. Adopters of AI services

Table 2. Mean differences in key farm resources between adopters and non-adopters of improved dairy technologies.

Variable	Mean differences of explanatory variables between adopters and non-adopters of technologies			
	Improved cows	AI services	Improved forages	Dairy cooperatives
Age of household head (years)	5.16	3.28	0.54	-10.33**
Gender of household head (1=Male)	0.023	-0.01	0.15***	0.16
Marital status of household head (1=married)	0.03	0.00	0.09	0.06
Education level of household head (years)	-0.11	0.16	-0.36	-1.42**
Number of family members in working age group	1.60***	1.73***	0.50*	-0.81
Dependency ratio	-0.32**	-0.31	-0.02	0.08
Total land holding (ha)	-0.53	-0.05	-0.55	-0.74
Total livestock holding (TLU[1])	0.54	1.91*	0.03	1.56
Household expenditure ('000 USD)	0.36***	0.38***	62.92***	0.15
Oxen holding (TLU)	0.42	0.46	0.06	0.79
Access to mobile telephone (1=yes)	0.37***	0.38***	0.22***	0.15
Distance to nearest market (walking minutes)	-0.79	-3.45*	2.67**	-6.34**
Distance to extension office (walking minutes)	-1.33	21.95***	7.08***	-1.36
N	658	658	658	657

*** p<0.01, ** p<0.05, * p<0.1; [1]TLU = Tropical livestock unit using a conversion factor of a mature animal weighing 250 kg.

Table 3. Pair-wise correlations between selected dairy technologies in Ethiopia (P-values in parentheses).

	Crossbred cows	AI service	Improved forages	Dairy cooperatives
Crossbred cows	1			
AI service	0.59(0.00)***	1		
Improved forages	0.11(0.01)***	0.13(0.00)***	1	
Dairy cooperatives	0.05(0.17)	0.03(0.45)	-0.01(0.77)	1

had a higher number of family members in working age group, better access to mobile telephone, and reside far away from the nearest market centre and farmer training centre than non-adopters. Adopters of improved forages were mainly male headed, had higher access to mobile telephone and reside close to the nearest market centre and farmer training centre than non-adopters. Adopters of dairy cooperatives had relatively younger households with higher education levels and reside close to the nearest market centre than non-adopters. Contrary to expectations, there was no difference between adopters and non-adopters of improved dairy technologies in the size of land, livestock and oxen holdings. Adopters and non-adopters of improved dairy technologies were indistinguishable in terms of access to extension services. Generally, farmers who adopted many of the dairy technologies had relatively higher number family labour and better access to mobile telephone than non-adopters in Ethiopia.

Tetrachoric correlations between the four adoption variables are presented in Table 3. Binary correlation coefficients are positive and statistically significant between crossbred dairy cows and AI service, crossbred dairy cow and improved forages, and AI services and improved forages. A dairy cooperative was not correlated with any of the technologies considered. One explanation for this could be that adequate numbers of dairy farmers are not selling their milk through dairy cooperatives.

Estimation results of factors affecting adoption of dairy technologies

The Wald chi square test strongly rejected independence of multiple dairy technology adoption decisions at 1% level [χ^2 (43) =245.63, Prob > χ^2= 0.00], indicating the validity of estimating the four adoption equations jointly using SUR model.

Model estimation results are presented in Table 4. The estimated coefficients of some of the explanatory variables of dairy technologies adoption decision are consistent with the initial hypothesis. While the size of livestock holdings is negatively associated with adoption of crossbred dairy cows; household income is positively associated with adoption of crossbred dairy cows (Table 4). The probability of adopting improved forages, AI

Table 4. Estimation results of seemingly unrelated multivariate probit model

Explanatory variable	Improved forages	AI services	Crossbred dairy cow	Dairy coop
Improved forages		0.04(0.03)	0.03(0.04)	
AI services			0.69(1.00)	
Crossbred dairy cow				0.05(0.03)
Age (years)	0. 10(0.10)	0. 05(0.48)	0. 44(0.44)	-0. 16(0.15)
Gender (1=male)	0.88(0.19)***	-0.19(0.21)	-0.07(0.13)	0.13(0.06)**
Education (year)	0. 07(0.69)	-0. 57(0.58)	0. 11(0.53)	-0.96(0.44)**
Family labour(adult equivalent)	0.31(0.74)	0. 60(0.58)	0.23(0.60)	-0.30(0.22)
Total cropped area (ha)	-0.14(0.07)**	-0.03(0.26)	0.28(0.34)	-0.13(0.14)
Livestock holdings (TLU)	0.38(0.30)	0.22(0.17)	-0.10(0.14)	0. 12(0.13)
Household expenditure (‘000 USD)	0. 42(0.18)**	0. 29(0.14)**	0. 33(0.13)***	0. 10(0.20)
Ownership of mobile telephone	0.47(0.32)	0.13(0.17)	0.34(0.20)*	0.03(1.45)
Distance to extension office	0. 25(0.21)	-0. 21(0.13)*	0.01(0.10)	-0. 14(0.06)**
Distance to nearest market	-0. 40(0.45)	-0. 38(0.18)**	0. 01(0.27)	-0. 13(0.08)*
Constant	-0.99(0.64)	0.39(0.43)	-0.38(0.39)	0.74(0.32)**
$\sigma_{\varepsilon u}$	-1.36(0.07)***	-1.92(0.14)***	-1.83(0.13)***	-2.23(0.21)***
Observations	403	403	403	403

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

services and crossbred dairy cow is positively associated with household income. As expected, distance to the nearest market and distance to farmer’s training centre are negatively associated with adoption of most dairy technologies.

DISCUSSION

The results show that adoption levels of crossbred dairy cows, artificial insemination and dairy cooperatives is very low. The relatively higher adoption level of improved forages could be due to the multipurpose nature of fodder plants. For example, the relatively higher adoption level of multipurpose trees may not be necessarily associated to feeding improved dairy cows. In Ethiopia, multipurpose trees were introduced for soil conservation and for use as animal feed (Ran et al., 2013). The result suggest that linking improved forages with land and water conservation promotion activities could provide incentives to households to adopt improved forages.

Rejection of the null hypothesis of independence of the disturbance terms in SUR regression suggest that omitted variables play a critical role in adoption decision of dairy technologies. It can be seen that the sigma terms (σ) are significant in all the four equations, which confirm the importance of these omitted (unobserved) factors. This was further confirmed by the positive and significant association between adoption equations, which suggest that omitted variables may influence adoption decision for the inter-related technologies. The significant effects of unobserved factors on adoption of crossbred dairy cows, AI services, improved forages and dairy cooperatives suggest that adopters are systematically different from those who do not adopt these technologies on a number of unobserved variables such as technical ability, farmers' motivation, attitudes to risk and networking ability, etc. The negative and significant effect of omitted variables on adoption decision of crossbred dairy cows, improved forages and dairy cooperatives suggest that adoption of these technologies is subject to downward biases due to unobserved individual heterogeneity and contextual factors. This result suggests that the root causes of low technology adoption lie outside technical boundaries, particularly in institutional and policy spheres. Low technology adoption is inherently a structural problem in the way smallholder farmers can get access to resources and inputs and output markets and in how civil services are organized. This result is consistent with the observation of some researchers argue that macro-economic institutions and policies explain more of the variation in adoption of technology by smallholders than the biophysical, farm and household socioeconomic characteristics do (Birner and Resnick, 2010; Dillon and Barrett, 2014; Sheahan and Barrett, 2014). Practical implications for policy makers and practitioners are that we have to start changing institutions and legal frameworks to usher in large scale technology adoption.

The estimation results confirm some of the hypotheses about the included explanatory variables. The results on the asset endowments of adopters and non-adopters suggest that the level of income and livestock asset are the key factors which set apart adopters from non-adopter of crossbred dairy cows. The negative association between cross-bred dairy cows and livestock holdings is broadly consistent with the hypothesis that shortage of land causes farmers to intensify agricultural production by using a yield-enhancing technology such as cross-bred cows. A related finding is the statistically significant negative effect of land holding on adoption of improved forages, indicating that farmers with little land are more inclined to adopt improved forages. These findings correspond with the drivers of agricultural intensification that the fall in the availability of key factors of production such as land may speed up intensification (Carswell, 1997). As grazing area diminishes, excess animals are sold and the few remaining productive animals are kept by the farmers (Moll et al., 2007). As availability of key resources fall, farmers tend to shift towards intensive dairy farming that produce valuable outputs using the limited available resources such as land. There seems to be a reinforcing feedback between investments in dairy technologies and household wealth.

The estimation results show that many of the theoretically-motivated explanatory variables were not related to adoption of dairy technology components. By comparison, omitted (unobserved) variables appear to play a critical role in adoption of the dairy technologies considered in this study. But it is important to note that the tests implemented in this paper do not allow us to identify precisely which omitted variables are responsible for the low technology adoption. On top of the factors included in the regression model that influence adoption of the technologies, there is overlap in the set of unobservable variables that could play a role in adoption of these technologies. Some researchers have argued that individual household heterogeneity (e.g., technical ability, farmers' motivation, attitudes to risk and networking ability, etc.), inefficiencies in input and output markets and underlying institutional and policy constraints play a critical role in technology adoption decision (Birner and Resnick, 2010; Dillon and Barrett, 2014; Sheahan and Barrett, 2014). The focus group discussants and key informants identified three categories of farmers based on their crossbred dairy cow technology adoption behaviour. First, there seems to be a small group of farmers who have the information, the resources, positive attitude and access to improved crossbred dairy cow technologies. Although a small group, these farmers mostly adopted the technologies. The second category of farmers have the information, the resources, positive attitude and want crossbred dairy cow technologies but they cannot have them because there is no supply of crossbred dairy cows. The third categories of farmers (the majority) have heard about improved crossbred dairy cow technologies but they do not adopt because keeping crossbred dairy cows is expensive for them. The farmers pointed out that limited access to farm resources and complementary services such as veterinary and artificial insemination, milk transport and marketing makes dairy unprofitable. Particularly, shortage of domestic supplies of key technologies was mentioned as the major reasons for low adoption levels across all categories of farmers. Historically, most of these technological inputs and services have been supplied by the government or donor sponsored projects. Government ranches have been supplying in-calf crossbred heifers to smallholder farmers until the end of 1990s. The collapse of government ranches coupled with lacklustre private sector involvement in crossbred dairy heifers production resulted in a critical shortage of crossbred dairy heifers in the country. The expectation that removing government-run ranches would open opportunities for the private sector to take over these functions has not been fully realized. The Ethiopian ministry of agriculture has not been able to coordinate AI services effectively (Tegegne et al., 2010). Therefore, inaccessibility of technologies could be one of the reasons for low adoption of dairy cow technologies even where farmers are willing to use them.

CONCLUSION AND POLICY IMPLICATIONS

This paper uses cross-sectional household survey data to investigate the factors that influence farmers' adoption decisions various improved dairy technologies using seemingly unrelated multivariate probit model. The estimates obtained from the seemingly multivariate probit regression model suggest that the household's likelihood of adopting dairy technologies is jointly determined by the observed household-level characteristics as well as unobserved household and contextual factors. The results show that household income is positively associated with adoption of dairy development interventions in rural Ethiopia. The omitted (unobserved) variables such as individual household heterogeneity, inefficiencies in input and output markets and underlying institutional and policy constraints appear to play critical in technology adoption decision than explanatory variables commonly included in adoption models. Failure to take account of unobserved heterogeneity among smallholders in technology adoption behaviour could lead not only to biased results but also to inefficient policy targeting. Based on these observations, dairy development programs in Ethiopia seems to have a better chance of success if they target farmers who have better resource endowments and connected to better-functioning input and output markets rather than blanket technology scale up strategies to the majority of smallholder farmers. Furthermore, development program designers and policy makers need to pursue strategies that address inefficiencies in dairy value chains and underlying institutional and policy constraints to induce large-scale adoption of dairy technologies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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