Joint Adoption Patterns of Dairy Production Technologies in SNNP and Amhara National Regional States of Ethiopia

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ABSTRACT

Increased use of improved dairy technology packages could bring improvements in dairy productivity, production, household income and poverty alleviation. In spite of this, the adoption of such technologies has remained low in Ethiopia. However, empirical evidence on factors influencing joint adoption of dairy technologies remains unclear. Determinants of joint adoption of dairy production technologies were investigated using primary data collected from a sample of 1242 dairy farmers in six selected zones of SNNP and Amara National Regional States. A multivariate probit model (MVP) was used to analyze the data. The results of the study revealed that adoption rates of crossbred dairy cows and improved forages were 21 and 29%, respectively. It was also noted that 21 and 50% of the households have adopted improved concentrates and veterinary services, respectively. The findings have also figured out that only 2% of the households have adopted all four technologies of crossbred cows, concentrates, improved forages and health services as a package. Instead, adopting only two technologies was commonly experienced by 57% of the households. The MVP model results showed the existence of correlation in the adoption decision of crossbred cows, concentrates, improved forage and veterinary services. The results also revealed that farmers' adoption of technologies varied significantly and explanatory variables had heterogeneous effects on the adoption of various technologies. Ceteris paribus, the study results further revealed that education, age, family size, training, membership in a dairy cooperative, off-farm participation, dairy income, perception, gender, access to credit, extension, experience in the use of improved crop varieties and farm size had a positive and significant effect on the choice decisions of adopting dairy technologies. From the study, it can be recommended that the adoption of dairy technology packages needs to be strongly promoted through effective extension services. Apart from this, the farmers need to be advised to adopt packages of technologies to ensure maximum benefits. Establishing crossbred heifer rearing ranches and commercializing feed resources in the regions could also largely enhance the adoption of dairy technologies.

Keywords: Dairy technologies, determinants, multivariate probit model, adoption

INTRODUCTION

Ethiopia has the largest livestock inventory compared to other African countries because of diverse and favorable agroecology for livestock and dairying (Yilma *et al.*, 2011; Tegegne *et al*., 2013). The Ethiopian Central Statistical Agency (CSA) estimated the cattle population to be 60.39 million and the dairy population (dry, pregnant and milking cows) to be more than 19 million (CSA, 2018). However, the dairy subsector in the country is underdeveloped and characterized mainly by traditional subsistent smallholder production systems with a few emerging commercial dairying in urban and peri-urban areas (Kebebe *et al.*, 2017).

The dairy production system in Ethiopia is categorized into three: (1) lowland pastoral and agro-pastoral grazing system, which is the major but the most neglected dairying system; (2) highland crop-livestock mixed farming system, and (3) urban and peri-urban system (Gizaw *et al*., 2016; Mihret *et al*., 2017). Smallholder dairy production constitutes 98 percent of milk production (Mihret *et al.*, 2017) where 3.32 billion liters of milk were produced in Ethiopia in 2017 (CSA, 2018).

However, the domestic production of dairy products was far lower than the demand, because Ethiopia is increasingly importing dairy products in terms of whole dried, skimmed dried and whole condensed to fill the gaps (Bachewe *et al.,* 2017; FAOSTAT, 2019).

Currently, the rising demand for animal source foods, in general, and dairy products such as milk and butter, in particular, is due to an ever-increasing population, urbanization and better-off (Minten *et al.,* 2020). This may offer smallholder farms to sustainably engage in dairy production as a pathway out of poverty and food insecurity (Yitayih *et al.*,2016; Kebebe *et al.,* 2017) and new employment opportunity (SNV, 2008; Mihret *et al.,* 2017). Despite its huge economic contributions and opportunities for development, the productivity of the dairy sub-sector remains low in Ethiopia. This resulted in the growing shortage of dairy products and increased expenditure of hard currency by the country in importing dairy products.

A growing body of empirical evidence suggests that shortage of cross-bred cows, feeds, grazing land, farm land, poor and inadequate veterinary services and inefficiency of artificial insemination and synchronization activities are contributing to the low productivity and performance of the dairy sub-sector (Ahmed *et al*., 2004; Kebebe *et al*., 2015; Gizaw *et al*., 2016; Diro *et al.,* 2019). With the support of development partners, the government of Ethiopia has been developing and introducing several dairy production technologies for decades ago to solve the aforementioned constraints to increase dairy productivity and household income and reduce poverty. More specifically, crossbred cows, high quality feeds (concentrates and improved forages), and veterinary services were introduced to improve the performance of the dairy sub-sector since the early 1960s. Despite the efforts by the government in the dairy sub-sector, the adoption level of dairy cattle technologies has remained low (Tesfaye *et al*., 2016; Kebebe *et al*., 2017). Apart from this, Kebebe *et al*. (2017) have also reported about less than 10% adoption rate of dairy technologies among the sample households in Ethiopia. Tesfaye *et al.* (2016) have also reported adoption rates of 28% for crossbred cows and 10% for improved forage in selected zones of Oromia Region.

The adoption of dairy technologies is affected by several interlinked factors. Farmers' decision to adopt dairy technologies is influenced by a lack of comprehensive policies, an unorganized crossbreeding system, poor institutions, extension services, and socioeconomic processes (Gebremedhin *et al*., 2003; Ahmed *et al*., 2004; Lemma *et al*., 2010; Berhanu and Poulton, 2014; Kebebe *et al*., 2015; Guadu and Abebaw, 2016). Smallholder farmers' decision to adopt dairy technologies is influenced by household demographics including age, education, family size (Basunathe *et al*., 2010; Tesfaye *et al.,* 2016; Martinez-Garcia *et al*., 2016; Yitayih *et al*., 2016), farm characteristics including farm and herd size; institutions including access to extension and credit services and infrastructures including access to roads, health centers and markets (Tesfaye *et al.,* 2016; Yitayih *et al*., 2016; Kebebe *et al*., 2017). For example, family size of the household was found to influence farmers' decision to adopt dairy technologies (Abdulai *et al*., 2008; Tesfaye *et al*., 2016; Kebebe *et al*., 2017). Education of the household head was also found to influence the decision to adopt dairy technologies (Abdulai *et al*., 2008; Fita *et al*., 2012). The age of the household head was also found to influence farmers' decision to adopt dairy technologies (Abdulai *et al*. 2008; Kebebe *et al.,* 2017). It was also reported that access to extension, training and credit services influence the decision to adopt dairy technologies (Fita *et al*., 2012; Yitayih *et al*., 2016; Tadese, 2020). Likewise, farm size was found to influence farmers' decisions to adopt dairy technologies (Rahelizatovo and Gillespie, 2004).

Nonetheless, most of the above prior studies focused on single dairy technology adoption despite the fact that farmers use a bundle of dairy technologies which often compute for capital and labor. They employed single logit and probit models to discrete choice; focused on single dairy technologies such as crossbred cow, artificial insemination, forage, or health service, independently;

and also relied on a small sample that may dearth adequate variability. Considering a single technology in the adoption analysis often ignores the interdependence and endogeneity of dairy package technologies and choice decisions (Deribe and Tesfaye, 2016). Failure to recognize interdependence of dairy technology choice decisions by smallholder farmers in examining resource allocation constraints results in biased and inefficient estimates. The exception of a study by Deribe and Tesfaye (2017) investigated the determinants of dairy technologies using a multivariate probit model, and the results showed a significant correlation between technologies. However, Deribe and Tesfaye (2017) used a small sample with limited area coverage and failed to consider veterinary service as a dairy technology.

This study, therefore, differs from these existing studies in three. First, our analysis considers four important dairy technology packages including crossbred cows, concentrate feeds, improved forage and health service. Second, the study relies on a large sample (1242 dairy households) and area coverage. Three, the study uses a multivariate probit model to figure out the interdependence between the adoption decisions of dairy technology packages. Therefore, this study attempts to investigate the joint adoption of dairy technologies and factors influencing adoption decisions.

METHODOLOGY

The Study Areas

The study was conducted in Southern Nations, Nationalities and People's (SNNP) and Amhara National Regional States with cattle populations of 11.8 and 16.1 million, respectively (CSA. 2015). A total of six zones (three from each of the regions) were selected in their representativeness of dairy production practices. From SNNP, Sidama, Welayita and Guraghe zones from SNNP while Awi, West Gojam and South Gondar zones from Amhara Region were included in the study.

Data Collection Procedures

Multi-stage sampling procedure was used to select sample zones, *woredas*[1] and *kebeles*[2] to collect the required data. While three zones were selected from each of the regions, two woredas were also selected from each of the study zones based on their representativeness in dairy production practices. Two *kebeles* were in turn selected from each of the target *woredas* based on their representativeness in dairy production. In the last stage, households were selected randomly from the identified sampling frame. To collect quantitative data, a per-tested structured questionnaire was developed and loaded on CSPro software. Data was collected using Computer Assisted Personal Interview (CAPI) by well-trained enumerators. The whole data collection process was monitored by a supervisor to ensure data quality.

Sampling Frame and Sample Size Determination

The sampling frame for this study was the population of Households who owned dairy cows either zebu or crossbred. The complete list of dairy households from where samples were drawn was obtained from records of kebele level Office of Agriculture. Sample households were drawn from the established dairy holders. Out of this sampling frame, the sample households were selected randomly using a systematic probabilistic sampling technique. To determine representative sample size, the sample size determination formula by Cochran (1977) was used:

$$N_s = \frac{Z^2 * pq}{e^2} \quad (1)$$

[1] Woreda is the third administrative division of Ethiopia
[2] Kebele is the lowest administrative unit of Ethiopia

Where N_s is the required sample size, Z is the confidence level of 99% (Z=2.58), p is the estimated proportion of an attribute of interest to be responded by the population (p=50%), q= 1-p and e = 0.037 (level of precision). Thus, using the statistical values of p =0.5, q = 0.5, and e= 0.037, the Cochran formula yields a total of 1242 sample dairy households (Table 1).

Table 1. Distribution of sample households by study regions and zones

Regions	*Zones*	*Male*	*Female*	*Overall*
SNNP	Sidama	136	64	200
	Welaita	144	56	200
	Guraghe	162	38	200
Amhara	Awi	117	72	189
	West Gojam	124	107	231
	South Gondar	140	82	222
Overall total		823	419	1242

Analytical Framework

According to classical economics, farmers are presumed to be utility maximizers (McFadden, 1974). Hence, the decision to adopt dairy technologies is made when the expected utility or net profit from adopting the technology is significantly better than would be the case without the technology (Greene, 2008). The basic assumption is the decision-maker (dairy households in this case) have perfect information to make adoption decisions. However, farm households have limited information and cognitive ability to make decisions to adopt technologies, bounded rationality of Simon (2000). The utility is often a latent variable (directly unobserved), whereas farmers' technology choice is observed. To place this utility theory in analytical form, suppose, that U_j and U_k represent a farmer's expected utility for alternative choices j and k, respectively; presume also that $\mathbf{X}_i$ and $\mathbf{X}_k$ are vectors of explanatory variables that influence the expected utility of alternative technologies j and k. Following Greene (2008) the random utility model could be specified as:

$$U_{ij}^{*} = \beta_j X_{ij} + \nu_{ij} \text{ and } U_{ik}^{*} = \beta_j X_{ik} + \nu_{ik} \quad (2)$$

Where β_j and β_k are parameters to be estimated and ν_i and ν_k are unobserved vector of error terms presumed to be independently and identically distributed, that is, ν_j and ν_k = MVN (0, **Ω**). It follows that the expected utility for the ith farmer from alternative j is greater than the utility from option k shown as:

$$U_{ij}^{*}\ (\beta_j X_{ij} + \nu_{ij}) > U_{ik}^{*}\ (\beta_j X_{ik} + \nu_{ik})\ , j \neq k \quad (3)$$

Assuming that D is the decision to adopt technology j where D takes the value of 1 if adopted and 0 otherwise, the probability that a dairy farmer will adopt improved dairy technologies of the jth alternative conditional on explanatory variables (X) can be presented as:

$$P_i = \prod_{j=1}^{J} \{D_{ji} P_{ji} - (1 - D_{ji})(1 - P_{ji}\} \quad (4)$$

This can also be expressed as follows:

$$P(D = 1|X) = P\left(u_{ij}^{*} > 0\right)$$
$$= P\left(\beta_j X_{ij} + \nu_{ij} > 0|X\right)$$
$$= P(\beta^{*} X_i + \nu^{*} > 0|X) = F(\beta^{*} X_i, \rho)$$

With F(.) is the cumulative distribution function of ν^* evaluated at $\beta^* X_i$ and the particular parameter values of $\beta_1^*, \dots, \beta_J^*$ that maximize the J individual function.

Empirical Estimation

The simultaneous adoption of dairy technologies defers between farmers due to their unique characteristics, social and economic factors. Investigation of farmers' technology adoption decision behavior requires the use of a multivariate modeling framework to take the multiple technologies and possibilities of simultaneity of the decision-making process into account. As a result, this study adopts multivariate probit (MVP) econometric method which simultaneously models the influence of the set of explanatory variables on each of the dairy technologies by allowing error terms to be systematically correlated (Belderbos *et al.*, 2004; Deribe and Tesfaye, 2017). These correlations may either be positive (showing complementarities) or negative (substitutabilities) between dairy technology types. In this study for MVP estimation, the choice of improved dairy technologies corresponds to a binary choice (1=yes/0=no) equation. Thus, a household uses M different dairy technologies and M equations each describing a latent dependent variable that corresponds to the observed binary outcome for each dairy technology that is required to be estimated simultaneously (equation 6).

A system of simultaneous multivariate probit model was built for dairy technologies following Cappellari and Jenkins (2003) which is depicted as:

$$D_{im}^* = \beta_j X_{im} + \varepsilon_{im} \quad (6)$$

$$D_{im} = \begin{cases} 1 \; if \; D_{im}^* > 0 \; and \\ 0 \quad otherwise \end{cases} \quad \text{(j= B, C, F, V)}$$

Where $\boldsymbol{\varepsilon}_m$ = (ε_{iB}, ε_{iC}, ε_{iF}, ε_{iV}) is a vector of error terms assumed to exhibit a multivariate normal distribution of mean 0 and symmetric variance-covariance matrix **Ω,** and independently and identically distributed across i (i=1,…,N) but correlated across m (m=1,…,M, J≠M) for any i, on the leading diagonal and correlations $\rho_{ij} = \rho_{ji}$ as off-diagonal elements; B, C, F and V denote crossbred dairy cows, concentrates, improved forage and veterinary services, respectively. The correlation matrix of the error terms in the four equations is depicted as:

$$\Omega = \begin{pmatrix} 1 & \rho BC & \rho BF & \rho BV \\ \boldsymbol{\rho CB} & 1 & \rho CF & \rho CV \\ \boldsymbol{\rho FB} & \boldsymbol{\rho FC} & 1 & \rho FV \\ \boldsymbol{\rho VB} & \boldsymbol{\rho VC} & \boldsymbol{\rho VF} & 1 \end{pmatrix} + (-) \quad (7)$$

The hypothesis that this study follows is that the off-diagonal correlation coefficients are non-zero while all the cross-equation correlation coefficients are equal to zero. This hypothesis is often validated with a Wald test used to test the null hypothesis (H_0) of no correlation across equations, that is, off-diagonal coefficients are all zero (Hausman, 1978). If H_0 is rejected, it proposes that MVP models are suitable to estimate the probability of joint dairy technology adoption.

Definition of Variables and Hypotheses

Dependent variables

The study identified four dairy technologies as a dependent variable namely crossbred dairy cows, concentrate feeds, improved forage, and veterinary services (Table 1). The term crossbred dairy cow in this study refers to the improved dairy cow of any blood level of indigenous zebu crossed with either Holstein Friesians or Jersey breeds. It is modeled as a dummy variable that takes the value of one if a household adopts at least one crossbreed cow, or zero otherwise. Concentrate feed refers to the use of purchased industrial by-products such as oilseed cakes, wheat bran, molasses, a multi-nutrient block (MNB), and homemade grain by-products. This variable is modeled as a dummy variable that takes the value of one if a household adopts at least one of the concentrate feed types, or zero otherwise. Improved forage refers to the use of high-quality forage including oat vetch, elephant grass, pigeon pea, alfalfa, fodder beet, desmodium, desho grass, sesbania, and tree lucerne. The variable takes the value of one if a household adopts at least one of the improved forages mentioned above, or zero otherwise. Veterinary service refers to the use of improved health care to cure sick animals (dairy cattle). This variable is modeled as a dummy variable that takes one if a household took his/her sick dairy cattle to the nearest vet clinic and got the service, or zero otherwise.

Independent variables

Based on the literature review, the independent variables considered in modeling the adoption of dairy technology packages include sex, age, education, family size, training on improved breed management and health, credit, membership to dairy cooperative, off-farm participation, experience of improved crop varieties adoption, visits of commercial dairy farm, extension contact, perception of feed shortage, income from dairying and own land size.

Sex of the respondent is a proxy variable for resource endowments of the household to represent gender. This variable is modeled as a dummy variable and takes the value of one if the household head is male, or zero otherwise. Male farmers had more access to resources and information about technologies than their counterparts. Thus, sex of household head is expected to affect the probability of adopting dairy technologies. Age of the household head is a continuous variable measured in years. It is a proxy variable for farm experience and expected to influence the probability of adopting dairy technologies. Educational level of the household head is also a continuous variable measured in completed years. More years of education is believed to be associated with the ability to gather and utilize new information. It is hypothesized that a household with more years of education positively influences the probability of adopting dairy technologies regardless of their quality. Family size also refers to the number of family members within the economic working age groups (15-64 years). It is believed to have a profound influence on the adoption of dairy technologies as dairying is a labor-intensive activity. Accordingly, a household with a large family size is expected to influence the probability of adopting dairy technologies.

Training on improved dairy breed management such as heat detection in cows, synchronization, artificial insemination, and record keeping are expected to influence dairy adoption and performance. It is modeled as a dummy variable and takes the value of one if a household took training in one of these topics, or zero otherwise. Thus, it is hypothesized that training on breed management influences the probability of adopting dairy technologies. Training is a dummy variable that takes the value of one if a household has taken training on improved health management practices, or zero otherwise. This variable is also expected to influence the probability of adopting dairy technologies. Credit access is modeled as a dummy variable that takes the value of one if a household got credit in relation to dairying, or zero otherwise. Credit relaxes the liquidity constraints of the household to invest in dairy technologies. This variable is also expected to influence the probability of adopting dairy technologies. Membership in dairy cooperatives reflects farmers' intensity of interactions with other more experienced farmers, helping them to learn new dairy technologies. It is a dummy variable that takes one if one of the household members has participated in dairy cooperatives, or zero otherwise. Thus, this variable is expected to influence the probability of adopting dairy technologies.

Off-farm refers to the activity in which a household participated outside of his/her farm to earn supplementary income. It is modeled as a dummy variable that takes one if one of the household members participated in at least one off-farm activity, or zero otherwise. Income from off-farm activities in turn provides capital to finance dairy technologies. Thus, it is expected to influence the probability of adopting of dairy technologies. Experience refers to the number of years a household adopted improved crop varieties. It is a continuous variable and is expected to influence the probability of adopting dairy technologies. Visit refers to an official visit to commercial dairy farms in order to share or gain knowledge about improved dairy management. This variable is also expected to influence the probability of adopting dairy technologies. It is modeled as a dummy variable taking one if the farmer has participated in visits, or zero otherwise. Extension contact refers to the interaction made between extension personnel and farmer in relation to dairy production. It is a continuous variable measured in the number of frequencies of contacts made per month. It is expected to influence the probability of adopting dairy technologies.

Perception refers to the understating of farmers about feed shortage as a problem for dairying. This is a dummy variable and takes a value of one if a household has perceived feed shortage as a problem, or zero otherwise. It is expected to influence the probability of adopting dairy technologies. Income refers to the income earned annually from sale of dairy products (milk, butter and cow dung). It is a continuous variable measured in Birr and is expected to influence the probability of adopting dairy technologies. Land holding refers to the land owned by a household. It is a continuous variable measured in hectares. Land is important for investment in dairy production and hence expected to influence the probability of adopting dairy technologies. Detailed description and posited relationship with the outcome variables of these factors is presented in Table 2.

Table 2. Summary of definition and hypotheses of variables

Variable	*Description and values*	*Posited relationship*
Dependent variables		
D1 (crossbred dairy cows)	1= if the household had crossbred dairy cows, 0 otherwise	
D2 (Concentrates)	1= if the household used concentrates, 0 otherwise	
D3 (Improved forages)	1= if the household used improved forages, 0 otherwise	
D4 (Veterinary service)	1= if the household used veterinary service, 0 otherwise	
Independent variables		
Sex	1= if the household head is male, 0 otherwise	+/-
Age	Age of the household head in years	+/-
Education	Education level of the household head in completed years	+
Family size	Number of family members within working age groups (15-64)	+
Training on improved dairy	1= if the household took training, 0 otherwise	+
Training on health	1= if the household took training on improved health management practices, 0 otherwise	+
Credit	1= if the household ever got credit to strengthen his/her dairying, 0 otherwise	+
Membership	1= if one of the household members was a member of dairy cooperatives, 0 otherwise	+
Off-farm	1= if one of the household members participated in off-farm activities, 0 otherwise	+/-
Experience	Number of years a household adopted improved crop varieties	+/-
Visit	1= if the household visited a dairy farm for experience sharing, 0 otherwise	+
Extension	The frequency of extension visits performed per month in relation to dairying	+
Perception	1= if the household perceived feed shortage is a problem, 0 otherwise	-
Income	Income (revenue) from sale of dairy products Birr/year	+
Land holding	The size of land owned by the household in ha	+

RESULTS AND DISCUSSION

Results of Descriptive Analysis

Summary statistics of the 15 independent and four dependent variables used in the MVP model are presented in Table 3. The average age of farmers was 41 years with an average of 1.7 years of schooling and family size in the active working age group of three. It was also noted that 17.6 and 18% of the sample households took training on breeding and improved health management, respectively. The findings also indicate that 12, 2.2, 19, and 5% of the sample households, respectively, received credit for dairying, had membership in a dairy cooperative, participated in various off-farm activities, and visited the nearby commercial dairy farms for experience sharing. Averagely, dairy farmers in the study areas had 8.2 years of experience in adopting improved crop varieties, and the average contact days spent with the extension agent were low at 0.29 in a month. The proportion of dairy farmers who perceived feed shortage as a critical problem for dairying was 32%, and the average annual income (revenue) earned from the sale of milk, butter and cow dung was estimated at 703 Birr.

Table 3. Results of descriptive statistics

Variable	*Mean*	*Std.Dev.*	*Min.*	*Max.*
Dependent variables				
D1 (crossbred dairy cows)	0.21	0.40	0	1
D2 (Concentrates)	0.21	0.41	0	1
D3 (Improved forages)	0.29	0.45	0	1
D4 (Veterinary service)	0.50	0.50	0	1
Independent variables				
Sex	0.66	0.47	0	1
Age	41.5	13.85	18	80
Education	1.7	2.8	0	13
Family size	3	2	1	9
Training on improved dairy	0.17	0.38	0	1
Training on health	0.18	0.38	0	1
Credit	0.12	0.32	0	1
Membership	0.02	0.15	0	1
Off-farm	0.19	0.39	0	1
Experience	8.2	6.37	0	27
Visit	0.05	0.22	0	1
Extension	0.29	0.65	0	6
Perception	0.32	0.46	0	1
Income	703	2824	0	50000
Land holding	1.07	0.89	0	12

The average land holding of the household was low standing at 1.07 hectares. The variables, such as income from dairy products and land holding, were transformed into logarithms for MVP model estimation. In the study areas, 21% of the sample households in SNNP and Amhara regions have adopted crossbred cows. It was also observed that the same proportion of households (21%) have adopted concentrate feeding. The proportion of households who adopted improved forages was 29%. Apart from this, 50% of the households have experienced using improved veterinary services. Other studies, such as the ones by Tesfaye *et al.* (2016) have also reported 28% adoption rate of crossbred cows in Oromia region, while Deribe and Tesfaye (2017) and Kebebe *et al* (2017), respectively, reported 20 and 21%

adoption rate of improved forages. Kebebe *et al* (2017) and Tesfaye *et al.* (2016), respectively, have also reported 72 and 94% adoption rates of improved health services.

Dairy technology adoption patterns

In this study, adoption involves three interrelated decisions at the micro-level. First, farm households decide to choose packages of dairy technologies to adopt, and then they decide on the combination of the technologies and finally decide on how much resources to allocate to each combination of the dairy technologies.

Table 4 presents the actual and possible combinations of the four dairy technologies. It is expected to have six, four, and one combination (possible combinations indicated in the denominator) of two, three, and four dairy technologies, respectively. Subsequently, the results revealed that six, four, and one combination (actual combination indicated in the numerator) of two, three, and four dairy technologies, respectively, used by smallholder farmers with different proportion. Complementary technology bundles here are composed of at least two technologies. Most (57%) of the sample farmers used two dairy technologies while only 2% of the sample households used four dairy technology bundles. Complementary packages most typically included 2-4 adopted dairy technologies indicating that all the possible combinations of technologies were adopted. As the number of bundled dairy technologies increases, they are most likely to be complementary with one another, although subsets of these technologies are substitutes when seen disjointedly.

Table 4. Complementary dairy technology bundles (N=1242)

Number in bundles (n)	*Observed outcomes of technology combinations/possible combinations of technologies*	*Percent*
2 dairy technologies	6/6	57
3 dairy technologies	4/4	16.4
4 dairy technologies	1/1	2

Table 5 presents the probability distribution of the joint adoption probabilities of crossbred cows, concentrates, improved forages and veterinary services. The adoption of none of the technologies is ignored as there was no household who did not adopt at least one dairy technology. The results revealed eleven combinations of adopted dairy technologies. It was recognized that 2% of the sample households adopted all four technologies while 11.8% of the sample households jointly adopted two dairy technologies (crossbred cows and veterinary service). The findings also indicate that 11.7% the households jointly adopted concentrates and improved forages. The results showed that the unconditional probability of adopting some dairy technologies was higher than the joint probabilities. For instance, the unconditional probability of adopting veterinary service was 49.7% while the probability of adopting crossbred and veterinary service (joint probability) was 11.8%, implying health service is important for all the sick dairy cattle (cows, calves, heifers, bulls and oxen).

Table 5. Probability distribution for joint & individual adoption of dairy technologies

Technologies (B, C, F, V)	*Frequency*	*Percent*
1, 1, 1, 1	26	2.1
1, 1, 1, 0	61	4.9
1, 1, 0, 1	46	3.7
1, 0, 1, 1	45	3.7
0, 1, 1, 1	52	4.2
1, 1, 0, 0	95	7.7
1, 0, 1, 0	114	9.2
1, 0, 0, 1	146	11.8
0, 1, 1, 0	145	11.7
0, 1, 0, 1	95	7.7
0, 0, 1, 1	113	9.1
1, 0, 0, 0	255	20.5
0, 1, 0, 0	259	20.9
0, 0, 1, 0	359	28.9
0, 0, 0, 1	617	49.7

Note: B= crossbred cows, C= concentrates, F= improved forage, V= veterinary service; 1=adopt, 0=no adopt

The conditional probability of adopting four dairy technologies of interest is presented in Table 6. The conditional probabilities are computed from Table 5. The conditional probability of adopting dairy technologies of one or more combinations is generally higher suggesting the existence of possible interdependence (synergy) across the four dairy technologies. For instance, the probability of adopting crossbred cows increased from 21 to 37, 45 and 57% conditional on the adoption of concentrates, improved forage and veterinary services, respectively. The likelihood of adopting crossbred cows also increased from 21 to 24% conditional on adopting improved forage and concentrate. The result is in conformity to the significance test of correlations of the disturbance terms in MVP model (Table 7).

Table 6. Conditional probabilities for the adoption of four dairy technologies in the study area

Conditions	*Technologies*			
	Crossbred (B)	Concentrates (C)	Improved forage (F)	Veterinary service (V)
P ($\boldsymbol{D_j^M}$=1)	0.205	0.209	0.289	0.497
P ($\boldsymbol{D_j^M}$=1|B=1)	1.00	0.367	0.318	0. 237
P ($\boldsymbol{D_j^M}$=1|C=1)	0.373	1.00	0.404	0.154
P ($\boldsymbol{D_j^M}$=1|F=1)	0.447	0.56	1	0.183
P ($\boldsymbol{D_j^M}$=1|V=1)	0.572	0.367	0.315	1.00
P ($\boldsymbol{D_j^M}$=1|B=1, C=1)	1.00	1.00	0.17	0.074
P ($\boldsymbol{D_j^M}$=1|B=1, F=1)	1.00	0.174	1.00	0.073
P ($\boldsymbol{D_j^M}$=1|B=1, V=1)	1.00	0.178	0.125	1.00
P ($\boldsymbol{D_j^M}$=1|C=1, F=1)	0.239	1.00	1.00	0.084
P ($\boldsymbol{D_j^M}$=1|C=1, V=1)	0.18	1.00	0.145	1.00
P ($\boldsymbol{D_j^M}$=1|F=1, V=1)	0.176	0.201	1.00	1.00
P ($\boldsymbol{D_j^M}$=1|B=1, C=1, F==1)	1.00	1.00	1.00	0.042
P ($\boldsymbol{D_j^M}$=1|B=1, C=1, V=1)	1.00	1.00	0.072	1.00
P ($\boldsymbol{D_j^M}$=1|B=1, F=1, V=1)	1.00	0.1	1.00	1.00
P ($\boldsymbol{D_j^M}$=1|C=1, F=1, V=1)	0.102	1.00	1.00	1.00
P ($\boldsymbol{D_j^M}$=1|B=1, C=1, F=1, V=1)	1.00	1.00	1.00	1.00

Note: D_j is a binary variable representing the likelihood of adopting j dairy technologies (Crossbred cows (B), concentrates (C), Improved forages (F) and veterinary service (V) in M combinations.

Determinants of probability for joint adoption of dairy technologies

Table 7 presents the estimates of pairwise correlation coefficients of the error terms in the four simultaneous equations. The correlation coefficients are all significant implying the MVP is a better specification than separate four univariate probit models. A non-zero correlation coefficient implies that there are unobservable factors influencing the choice of technologies and the decision to adopt them. The result showed a significant positive association (showing complementarities and synergies) between crossbred cow and concentrates, improved forages and veterinary service; and a significant positive association between concentrates and improved forage as expected, suggesting the adoption of one technology would enhance the chance of adopting another. Unexpectedly, among the posited variables veterinary service and concentrates, and veterinary service and improved forages showed a negative association (showing substitutabilities and trade-off). One intuitive explanation would be that the use of improved concentrates and forages enhanced the health condition of dairy cattle.

Table 7. Estimates of correlation coefficient for the error terms from MVP regression

Parameter	*Coefficient*	*Standard error*	*P-value*	*95% confidence interval*	
rho21	0.172	0.060***	0.004	0.053	0.287
rho31	0.096	0.057*	0.095	-0.017	0.206
rho41	0.174	0.055***	0.001	0.054	0.288
rho32	0.384	0.045***	0.000	0.292	0.469
rho42	-0.231	0.049***	0.000	-0.324	-0.133
rho43	-0.329	0.044***	0.000	-0.412	-0.240

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0: $\chi^2(6) = 123.66$ Prob > $\chi^2 = 0.0000$; *, *** indicates level of significance at 10% and 1% respectively

Note: 1= crossbred cow, 2= concentrate, 3= improved forage, 4= veterinary service

Table 8 presents the results of the MVP model regression. The Wald test for the hypothesis that all coefficients in each adoption equation are jointly equal to zero is rejected (χ^2 (60) = 792.60; P-value=0.0000), suggesting the variables included in the model explain important portions of variations in the dairy technologies. Regarding the determinants, the results revealed that a number of hypothesized households, institutional, resource endowment and economic variables have a significant and differential effect on the probability of adopting improved dairy technologies.

Regarding the determinants of dairy technologies adoption, the results showed that a number of variables have a significant and differential effect on the four dairy technology pillars. Sex of the respondent positively and significantly affected the choice decisions of adopting concentrates, improved forages and veterinary services. This implies that male headed households had more chances of adopting dairy technologies. This differential adoption by gender could be attributed to variations in resource endowments. Prior studies reported that men had more endowments of land, inputs and training services than their female counterparts and hence had higher adoption rates of improved forages (Kebebe *et al*., 2017). Age of the household head positively and significantly affected the choice decisions of adopting crossbred cows as a priori expectation, but negatively affected the adoption of veterinary services. Older farmers had more chances of adopting crossbred cows while younger households had more chances of adopting veterinary services. This result is consistent with Abdulai *et al.* (2008) and Kebebe *et al*. (2017)

who reported that older farmers had higher adoption rates of crossbred cows than their female counterparts.

Table 8. MVP model estimates for the simultaneous adoption of four dairy technologies and determinants

Independent variables	*Dependent variables (coefficients and standard errors)*			
	Crossbred cow	Concentrate	Improved forage	Veterinary service
Sex	-0.032 (0.121)	0.230 (0.095)**	0.143 (0.087)*	0.246 (0.084)***
Age	0.010 (0.004)**	-0.004 (0.003)	0.005 (0.003)	-0.017 (0.003)***
Education	0.092 (0.019)***	0.002 (0.016)	0.018 (0.015)	0.022 (0.015)
Family size	0.046 (0.026)*	-0.011 (0.021)	-0.004 (0.020)	0.104 (0.021)***
Training on breed	0.616 (0.152)***	0.162 (0.136)	-0.085 (0.133)	0.443 (0.134)***
Training on health	0.196 (0.155)	-0.053 (0.130)	0.003 (0.125)	0.507 (0.127)***
Credit	0.218 (0.157)	0.257 (0.123)**	0.116 (0.121)	-0.115 (0.120)
Membership	0.659 (0.282)**	0.386 (0.246)	1.311 (0.299)***	-0.804 (0.295)***
Off-farm	0.319 (0.136**)	0.005 (0.109)	-0.218 (0.106)**	0.138 (0.100)
Experience in crop adoption	-0.013 (0.009)	0.011 (0.007)	0.020 (0.006)***	-0.054 (0.007)***
Experience sharing	-0.136 (0.224)	-0.026 (0.194)	-0.545 (0.207)***	0.129 (0.202)
Extension	0.015 (0.084)	.332 (0.060)***	0.347 (0.058)***	-0.356 (0.059)***
Perception	0.445 (0.113)***	0.161 (0.091)*	-0.032 (0.086)	-0.103 (0.085)
Income	0.157 (0.010)***	0.026 (0.009)***	0.044 (0.009)***	0.003 (0.009)
Land holding	0.056 (0.039)	0.089 (0.030)***	-0.021 (0.023)	0.105 (0.025)***
Constant	-1.678 (0.237)***	-1.018 (0.177)***	-1.027 (0.166)	0.635 (0.162)***
Number of observations	1242			
Log likelihood	2253			
Wald χ^2(60)	792.60, Prob > χ^2 =0.0000			

*, *** indicates level of significance at 10% and 1% respectively

The results showed that educational level of the household head had positively and significantly affected the probability of adopting crossbred cows as per a priori expectation. The finding is in line with the work by Abdulai *et al.* (2008) and Deribe and Tesfaye (2017) who reported that education of the household head had positively and significantly affected the probability of crossbred cows' adoption. It is presumed that farmers with exposure to formal education have increased knowledge that helped for informed decision making and adopt packages of dairy technologies. Family size in terms of active working age groups (15-64 years) and training on breeding had positively and significantly affected the chances of adopting crossbred cows and veterinary services, implying that dairy breeding and health management practices are labor-intensive activities. This finding is in line with Kebebe *et al.* (2017) who reported that large family size in active working age group had positively and significantly affected adoption of crossbred cows and veterinary services. Abdulai *et al.* (2008) also reported that household size had positively and significantly affected the probability of adopting crossbred technologies. Deribe and Tesfaye (2017) have also reported that training on breeding had increased the probability of adopting crossbred cows. Access to training on improved health management (veterinary service) had also positively and significantly affected the probability of adopting veterinary services tandem with a priori expectation. This finding is consistent with Yitayih *et al.* (2016) who reported that continuous trainings had a positive and significant impact in adopting increased number of dairy technologies. Moreover, dairy farmers reported that availability of crossbred heifers and feeds hindered the decision to adopt crossbred cows.

Household access to credit had positively and significantly affected the choice decisions of adopting concentrates in the study areas in tandem with a priori expectation, implying that households facing liquidity constraints are less likely to buy concentrates. The provision of agricultural credit is one of the most important stages in dealing with adoption constraints. Households' membership in dairy cooperatives was positively and significantly associated with the probability of adopting crossbred dairy cows and improved forages as expected but negatively and significantly affected the probability of adopting veterinary services contrary to expectation. Households who are members of dairy cooperatives have better access to dairy inputs, information and credit which enhance their bargaining capacity in the markets. This finding is consistent with Yitayih *et al*. (2016) who reported that membership in livestock related cooperatives had positively and significantly affected the probability of intensifying livestock feed technologies. Households' participation in off-farm activities had positively and significantly affected the choice decisions of adopting crossbred cows but negatively affected the probability of adopting improved forages. These relationships may partly be explained by the fact that off-farm income might provide financial resources to buy crossbred cows, but may compete for family labor in managing improved forages. This finding is consistent with Abdulai *et al.* (2008) who reported that off-farm participation had positively and significantly affected the probability of adopting crossbred cows.

Household's experience in adopting improved crop varieties had positively and significantly impacted the probability of adopting improved forages but negatively affected the chance of adopting veterinary services. This finding is consistent with Tesfaye *et al.* (2016) who reported that experiences of a household in the adoption of improved crop varieties had positively and significantly affected the probability of adopting improved forages. One explanation for this is that crops and most of the forages are related in nature (Martinez-Garcia *et al*., 2016). Contrary to a priori expectation, experience sharing among dairy farms had negatively influenced the probability of adopting improved forages. One explanation for this might be lack of demonstrating improved forages for visitors.

Extension contacts positively and significantly affected the probability of adopting concentrates and improved forages as a priori expectation. Extension is the major source of agricultural information for many rural farmers through contacts with extension experts. This finding is in line with Deribe and Tesfaye (2017) who reported that frequent contacts with extension agents resulted in increased probability of adopting concentrates. Tadese (2020) also reported that extension service had positively and significantly affected both the probability and intensity of adopting improved dairy technologies. Household's perception about feed shortage as a major problem influenced the probability of adopting crossbred cows and concentrates, implying famers could take risks in dairying.

Income (gross income from milk, butter and cow dung sale per year) had positively and significantly impacted the choice decisions of adopting crossbred cows, concentrates and improved forages. This finding is consistent with a priori expectation and that of Paudel *et al*. (2008) who reported that net income had positively affected the chance of adopting best dairy management practices. Gunaseelan *et al*. (2017) also reported that family income had positively and significantly affected the probability of adopting improved dairy farming technologies.

Land holding size had positively and significantly affected the probability of adopting concentrates and veterinary services. This finding is in line with Rahelizatovo and Gillespie (2004) who reported that farm size had positively affected the probability of adopting best dairy management practices. Martinez-Garcia (2016) also reported that size of land holding had positively and significantly affected the choice decisions of adopting improved forage related technologies.

CONCLUSION AND POLICY IMPLICATIONS

This study provides useful insights to investigate the determinants of adoption of dairy technologies in Amahara and SSNP regional states The adoption rates of crossbred cows, concentrate, improved forage and veterinary services were 21% , 21%, 29% and 50%, respectively in the study area. Several factors have positively and significantly influenced adoption of bundles of dairy technologies. Gender, age, education, family size in terms of active labor force, access to credit, membership to dairy cooperative, participation in off-farm activities, extension contact, perception (awareness) of feed shortage as a problem for dairying, income from dairying and land holding size were found to influence the choice decisions of of dairy technologies by farm households.

Our results suggest that there is a need for improved setup of and supportive policies (research, extension, health, marketing, value chain and commercialization) for effective dairy technology promotion that is working together to enhance smallholder dairy productivity and alleviate poverty. Promotion of packages of technologies was observed to be very less in this study. It is essential to promote the importance of adopting packages of dairy production technologies, such as improved breeds, feeds, and health management practices. The adoption rate of crossbred cows is also very less in SNNP and Amhara regions. One of the reasons was attributed to the unavailability of reliable formal sources of crossbred bred cows/heifers and consequent high prices. It is strongly suggested for regional states establish formal crossbred heifer rearing ranches to ensure sustainable supplies of crossbred heifers at affordable prices.

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