THE IMPACT OF PARTICIPATION IN RURAL CREDIT PROGRAM ON ADOPTION OF INORGANIC FERTILIZER: A PANEL DATA EVIDENCE FROM NORTHERN ETHIOPIA

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Abstract: Technological change in agriculture in climate risk exposed developing countries requires for land-use intensification to feed the growing populations. The purpose of this article is to analyze the impact of participation in rural credit program on adoption of yield enhancing technology (inorganic fertilizer) using 1412 farm households surveyed in 2005/06, 2009/10, and 2014/15 cropping seasons from rural Tigrai, northern Ethiopia where smallholder farmers are financially constrained to purchase of improved agricultural technologies. The paper uses a double hurdle correlated random effect models with a control function approach to analyze the causal effect. Results show that controlling for the unobservable heterogeneity and the underlying determinants of fertilizer adoption and credit participation, for an increase of credit size by 1% from its mean, adoption rate of inorganic fertilizer has increased by 2.5% and supports the earlier hypothesis. The results imply that expanding and strengthening of rural credit program are crucial for smallholder agriculture and appeared to have a more robust impact on adoption of inorganic fertilizer.

Subjects: Sustainable Development; Rural Development; Economics and Development

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PUBLIC INTEREST STATEMENT

In developing countries, poverty, particularly rural poverty, is chronic and deep-rooted. The extent and form of rural poverty are thoroughly associated with the poor performance of country’s economy mainly agriculture. The sector depends on erratic weather conditions and vulnerable to shocks. Poor land-use management, high population pressure, input and output market imperfections, missing or limited access to credit, limited supply of agricultural technologies substantially contribute to declining agricultural productivity, and increasing food insecurity of smallholders. Reversing these scenarios should be one of the major tasks of policymakers of developing countries. This demands thorough economic reform and extension programs. This study suggests that promoting rural financial service encourages smallholders to adopt improved agricultural technologies (inorganic fertilizer) and ensuring high productivity and food security at household level. This also supported to the current push toward smallholders’ commercialization through producing surplus products through adoption of agricultural technologies.
Keywords: Credit program; inorganic fertilizer adoption; double hurdle; Tigrai; Ethiopia

1. Introduction
In developing countries, poverty is mainly a rural phenomenon and two-third of the world’s poor is living in rural areas (Venkatesh et al., 2000). In developing countries, almost 80% of economic activity of rural households is mixed agriculture (farming and livestock) (Gebremedhin et al., 2009). Agricultural policies in developing countries are more focused on poverty reduction and improving the living standard of smallholder households (Amare et al., 2012; Amare & Shiferaw, 2017; Asfaw et al., 2011). This has been effective by promoting adoption of improved agricultural technologies such as inorganic fertilizer and improved seed varieties. Over the last five decades, agricultural transformation through promoting improved agricultural technologies has received great attention from development and agricultural economics (Barrett, 2008). However, smallholder farmers in developing countries often face financial constraint to purchase the improved agricultural technologies.

In a land-scarce economy with high population pressure, adoption of improved agricultural technologies enabled to enhance agricultural productivity and poverty reduction (Bezu et al., 2014; Gebremedhin et al., 2009). However, poor and smallholders are challenged to finance the technologies and experienced a dis-adoption decision from two perspectives. First, due to the absence of collateral, poor farm households disencourage to take a loan from formal banking service (Berhane & Gardebroek, 2011; Tadesse, 2014). Second, although they can finance the improved agricultural technologies by retaining earnings from off-farm and own crop sales, the potential of financing is very limited (Sg et al., 2017). This is because the unskilled rural labor is less likely to join in the formal labor market and unable to earn better income and proportion of crop sale to total farm income in smallholder agriculture is relatively low.

Local conditions proxied by varieties of crop cultivation, rainfall availability, soil quality, and soil type also influence adoption of agricultural technologies (Yusuf & Bluffstone, 2009). The absence of social and economic infrastructure and variations in production systems in developing countries including Ethiopia also influence the demand for credit and considerably alter the adoption of improved agricultural technologies (Hagos & Holden, 2003; Tadesse, 2014). As a result of missing or input and output market imperfections, smallholder farmers in developing countries exhibit a non-separable farm household model (Singh et al., 1986). This infers that households’ participation in one market, for instance, credit fairly depends on or influences another market such as technology purchase. This integrated demand decision decreases less rapidly than they do in isolated decisions. Hence, participation in credit program and the adoption of agricultural technologies have an important synergy and analyzing this relationship could have an important implication on the appropriateness of policy intervention. The objective of this study is to examine empirically the impact of participating in the credit program on adoption of inorganic fertilizer. The motivation of analyzing the link between rural credit and adoption of inorganic fertilizer is due to the following reasons.

The first reason is the food security issue. Poverty particularly rural poverty is dominant in the study region and the regional government takes great commitment to agricultural growth. This has been demonstrated through promoting adoption of yield-enhancing agricultural technologies where inorganic fertilizer is one among the others. Second, relatively large number of smallholder farmers’ use of inorganic fertilizer and this gives enough information to investigate the adoption pattern compared to other technologies such as manure. Third, from an efficiency perspective. Bulk but low-value materials, such as manure dilutes the useful ingredients of by-products and residual relative to chemical fertilizer (Pingali & Rosegrant, 1995). Fourth, rural credit programs were first endorsed in the study region in the mid-1990s, and it is typically available to purchase farm inputs mainly inorganic fertilizer (Hagos, 2003). This gives an interesting intuition that promoting credit service and encourages smallholders to adopt yield-enhancing and relatively affordable agricultural
technologies in terms of food security and agricultural productivity. Nevertheless, the service is derived from one source that is, government which creates inefficiency in the implementation process, and perhaps limited to outreach in place and time to smallholder farmers.

Empirically, improved agricultural technologies enhanced land productivity and mitigating the challenge of land fragmentation and high population pressure. This has been fairly demonstrated by Boserup (1996), as land becomes increasingly scarce, farmers practiced land-use intensification and their use of inputs to keep and improve food security at the household level. Hence, adequate and efficient financial service is substantially important.

This paper builds on farmers' behavior of technology adoption in risk and land-scarce economy that smallholders are "poor but efficient" (Schultz, 1964). However, this could be true when smallholders operate under stable circumstances and a sufficient amount of time is given to learn about the new technology. This denotes that after the new agricultural technology is introduced, it demands considerable time until all have adopted and learned to apply the new technology efficiently. Given farmers in developing countries face resource constraints and imperfect information to make new investments and scale-up production, improving the efficiency of the existing production activities can be a cost-effective strategy. This is especially relevant in Sub-Saharan Africa where poverty is widespread and capital to make new investments is scarce. Thus, the hypothesis of the current study states that participating in rural credit program contributes positively and significantly adoption of inorganic fertilizer in a semi-arid economy of Ethiopia.

The study of Hagos and Holden (2003) using panel data of 1998/99 and 2002/03 from high land of northern Ethiopia investigated that participating in a credit program has a positive impact on adoption of inorganic fertilizer. However, their study fails to take strict exogenous instrumental variables when estimating participation in the credit program. They used the number of adult labor force in a given household to serve as an instrument for participation in credit program. However, adult labor force is an endowment (wealth) variable and it is potentially an endogenous regressor and less likely to use as an instrumental variable in the impact evaluation. Moreover, in a panel data set, wealth variables adjust themselves over time and inhibited strict exogeneity.

Using three rounds of farm households’ panel data (2007, 2009, and 2010) from southern Ethiopia, Tadesse (2014) revealed that access to credit has a positive effect on adoption of inorganic fertilizer. However, this study has suffered from estimation and identification strategy problem. First, the study uses wealth variables at right-hand side of the model specification, whereas they are potential endogenous regressor and reduce the reliability of the impact outcomes. Second, the researcher acknowledged that access to credit is potentially an endogenous regressor and demands proper instrumentation when estimating the impact. Nevertheless, he used landholding more than 0.5 hectares and a dummy variable where a given household lived in a specific village or locality (yes = 1; 0; otherwise) considered as an instrumental variable for access to credit. In this case, first, landholding is a wealth variable and cannot be used as an instrument due to lack of strict exogeneity. Second, the dummy variable residency in the specific village (yes = 1; 0; otherwise) is a time-invariant variable and cannot be used as an instrumental variable. Therefore, the current study aims to fill the methodological gap using long and rich farm household panel data and various econometrics tools.

The rest of the paper is organized as follows. Section two presents empirical literature. Section three deals with the study setting, sampling method, and data issue. Section four presents empirical models and estimation strategies. Section five presents the major findings and followed by the overall discussion in section six. Conclusions and policy recommendations are presented in the last section.
2. Review of empirical literature

2.1. Rural credit and technology adoption

The expansion and development of rural finance revealed the strength and promotion of the sustainability of smallholder agriculture in terms of market and adoption of improved agricultural technologies (Asfaw & Admassie, 2004; Gebremedhin et al., 2009; Asfaw et al., 2011, 2012; Amare et al., 2012; see for the detailed review). The correlation between credit participation and technology adoption is characterized by household perspective, where participation in credit program is conceptual equivalent to technology adoption. This implies that the decision about technology choice is equal to decision to participate in a credit program. Access to credit is crucial and enhanced agricultural productivity through financing the purchase of improved agricultural inputs (Gebremedhin et al., 2009). For the present study, attention is due to analyzing the impact of participating in credit program on adoption of improved agricultural technology, particularly inorganic fertilizer in the semi-arid economy of developing countries.

In recent years, governments of developing countries including Ethiopia give attention on promoting rural credit services among smallholders aimed to improve agricultural productivity, food security, economic growth, and employment opportunity (Asfaw et al., 2010). Many factors potentially affect adoption of improved agricultural technologies such as extension services, infrastructure, production risk, resource endowments, agro-ecologies features, and household behavior.

The rapid population growth of Africa not to be longer the continent is land abundant region and the expansion of agricultural land increasingly difficult. This leads to farm size fragmentations and lowers per capita landholding, especially in densely populated areas. Poverty is persistent and severely affected less developed countries, and calls for a sound intervention to meet the food requirement of the poor. This suggests there is a need for improvements in the efficiency of the existing production activity to boost production (Schultz, 1964). The practice of land-use intensification through the application of yield-enhancing technologies, such as inorganic fertilizer becomes important (Duflo et al., 2008). However, the rate of fertilizer use is substantially lower in Africa than in Asia and Latin America (Byerlee & Eicher, 1997). The recent higher world fertilizer price is also one major obstacle to fertilizer disadoption in sub-Saharan Africa (Mosier & Syers, 2005). The study of Hugo De Groote et al. (2007) assessed factors affecting adoption of inorganic fertilizer in Kenya. They found that access to credit and variations in agro-ecological features bring a positive and significant effect on fertilizer adoption by Kenyan Maize producers. Similarly, using cross-sectional data from Kenyan farmers, application of organic fertilizer (manure) explains positively and significantly adoption of inorganic fertilizer (Ouma et al., 2002).

In an imperfect input market, smallholders’ production and consumption decisions have been negatively influenced by high transaction costs and liquidity constraints. For example, adoption of improved technology requires an initial investment, while smallholders with limited endowment, limited access to credit, and low income may not have the capacity to purchase the improved agricultural technology compared to rich and households who are accessed to credit, with better endowment and income. According to the study of Wills (1972), lack of finance is a major hindrance factor of inorganic fertilizer use. Feder et al. (1985) revealed that credit plays an important role in promoting adoption of inorganic fertilizer.

In countries where high population growth and land scarcity are prevalent, gentle public intervention plays an important role in adoption of inorganic fertilizer. Ricker-Gilbert et al. (2011) assess to what extent public input subsidy program promotes adoption of inorganic fertilizer among Malawian farmers, where access to credit is included in the right-hand side of adoption specification. However, in this study, they give less attention to address the endogeneity of access to credit, and no effort is an attempt to fix the problem. They also addressed that production risk proxy by rainfall variability significantly and negatively influence smallholders’ fertilizer use. But, they
captured rainfall variable data from district-level experimental weather station records. While district-level weather station in countries like Malawi (in developing countries in general) is set to cover wider geographical areas and thus their use as climate shock variable at micro level could be less meaningful in this case.

The review of related literature for this study reveals that there are no comprehensive studies (in terms of methodology, accuracy, and long period shock data) that have thoroughly examined the impact of participating in credit program on adoption of inorganic fertilizer in a semi-arid economy. To fill this knowledge gap, this study attempts to test empirically the linkage.

3. Research methodology

3.1. Description of the study area

The study area is Tigrai regional state located in the northern part of Ethiopia, where smallholder agriculture is the main activity of the rural society. Agriculture contributes 38.7% to the Regional Gross Domestic Product (RGDP) (BoFED Tigray, 2010). The arable land of the study region accounts for 1.03 million hectares, and 83% of this area is covered with cereals in the main cropping season. The population growth rate of the study region reaches 2.5% per year, and the population density is 327 persons/km² (BPF (Cartographer), 2014). This high population density creates land fragmentation due to redistribution among inherited families, and drastically reduced per-capita landholding. The intensified rainy season of the region is from the middle of June to the middle of September.

Recurrent drought, degraded land, and imperfect or missing input and output markets characterize the region’s agriculture. Promoting access to credit and adoption of inorganic fertilizer become an important pathway to food security and poverty reduction at household level. The two agricultural inputs are endorsed at the same time (at the time of land preparation or ex-ante to crop planting). In the study region, agricultural credit is provided by Dedebit Rural Credit and Saving Institution (DECSI) (Hagos, 2003). Besides DECSI, recently, other financial institutions like cooperative unions and female-targeted micro-finance “Adeday” also play an important role in outreaching the credit service to the smallholder farmers. Credit service is accessible in all of the communities covered in the study region and every household that can repay the loan is eligible to participate in the program.

Bureau of agriculture and cooperative unions take the responsibility of distributing agricultural technologies among smallholders. This study focuses on inorganic fertilizer, as it is accessible to all of the communities in the study region and reduces sample selection problems. This also enables us to explore a large number of observations compared to other technologies such as organic fertilizer. This is because adoption of organic fertilizer such as manure is associated with livestock endowment and the economic linkage of participating in credit program and adoption of manure is less sound or indirect.

3.2. Study setting and sampling method

Ethiopia enjoys a strong political determination to grow smallholder agriculture. Agricultural Development Led Industrialization (ADLI) strategy is underpinned by agricultural transformation (MoFED, 2006). The country offers an opportunity to look at the importance of smallholder agriculture in the transformation of the entire economy and the role, function, and effectiveness of extension services in this promising strategy (Gebremedhin et al., 2009). Authority decentralization and devolution of administrative power to the region and district level encourage for demand-driven and participatory policy processes (MoFED, 2010). The current agricultural policy of Ethiopia has also sought to promote agricultural productivity and gate away from the traditional farming system to achieve food security, reducing rural poverty, and accelerate economic growth.

Households were sampled based on a two-stage-sampling technique as described in Hagos and Holden (2002/03). In the first stage, communities were purposely selected based on agricultural
potential, population density, agroecology diversification, and accessibility to market, road, and irrigation. In the second stage, based on a simple random sampling technique, households were selected from a list of households in a given community for a detailed interview. The study is conducted in low land, mid, and high land agro-ecologies of the region and comprises five administrative zones (i.e., southern, southeast, eastern, central, and northwest). The sampled communities and their distribution is depicted in Figure 1 below.

3.3. The data
The data used in this study come from three rounds of farm household surveys conducted in 2005/06, 2009/10, and 2014/15 production seasons from Tigrai region, northern Ethiopia. To look at the impact of participating in a credit program on fertilizer adoption, the study captures information on household and farm characteristics including land and non-land endowments, indicators of access to infrastructure (marketplace and road), and community-level characteristics expressed in terms of population density and rainfall data. Rainfall intensity and rainfall variation were captured at community level from monthly satellite record of the African Rainfall Climatology Version 2 (ARC2) precipitation estimates.

In the subsequent surveys, due to head’s death (if he/she lived alone), migration, and non-response of household heads to the interview, there were attrite households. For instance, 356 households were interviewed in the 2005/06 cropping season and only 347 households were reappeared in the 2009/10 survey period while nine households (2.5%) of households were attrite. In 2009/10, additional new 96 households were included and the total sample size of 2009/10 was 439. Similarly, only 429 households who interviewed in 2009/10 were again re-interviewed in 2014/15, and 10 households (2.2%) of households were attrite, while additional new 187 households were included and the total samples of the last survey were 626 and the panel data set become
unbalanced with 1412 pooled sample size. Attrition bias is the feature of an unbalanced panel data and uncontrolled to this attrition leads to sample selection bias. A probit attrition model was estimated to assess and control the attrition bias through exploiting the baseline data from 2005/06. The dropout and remaining households in each survey round were used to construct the dependent dummy variable and estimated on household and community-level variables. If the explanatory variables explain the attrition dummy significantly (at the 5% level), attrition is an issue in the analysis implying that it is systematic. See the estimation method section below for the details.

### 3.4. Estimation methods

Adoption is measured as the proportion of households who used inorganic fertilizer and the intensity of adoption is expressed in terms of quantity (kg) of fertilizer applied per hectare of land. As to Ricker-Gilbert et al. (2011); Tadesse (2014); Sg et al. (2017), fertilizer adoption is expressed as a function of unobservable individual heterogeneity, participation in credit program, household and endowment characteristics, and community-level variables.

\[
Q_t = \delta_0 + \delta_1 X'_t + \delta_2 C_t + \delta_3 D_t + \delta_4 Y_t + \alpha_i + \epsilon_t
\]  

(1)

where \( Q \) refers to the binary fertilizer use variable (1/0) or the amount of fertilizer used (in log kg/household). \( X' \) refers to a vector of demographic and endowment characteristics of households. \( C \) is participation and corresponding loan size in the credit program which is potential endogenous variable. \( D \) refers to the spatial variables. \( Y \) is the year dummy. \( \epsilon \) is the unobservable effect and \( \alpha_i \) refers to the unobservable individual heterogeneity effect. \( i \) and \( t \) are individual and time identifiers, respectively. Selection of control variables was based on adoption literature (see Feder et al., 1985 for the detailed review) and the full description of variables used in the analysis are presented on Table 1. Demographic feature is proxy by age, gender, literacy status of household head, and family size. Male, young, and literate-headed households are more likely to participate in credit programs and adoption of improved technology. This is because male, young, and literate heads are assumed to acquaint themselves with updated information and they exploit the benefits of credit services and agricultural technology compared to households headed by female, elder, and illiterate heads. Household endowments are expressed in terms of land and non-land resources. The non-land endowments are represented by wealth variables such as family labor, oxen and non-oxen livestock (in TLU), and farm and non-farm assets. Wealthier households are expected to adopt fertilizer compared to poor households due to the wealth or risk-neutralized effect.

The non-land endowments and access variables may not be considered as strictly exogenous and models were executed without and with these potential endogenous variables to check how susceptible results are robust to this possible endogeneity. The spatial variable refers to where household resides and expects to control the variation among localities in fertilizer adoption such as soil quality, farm size, rainfall, population density, and the district dummies.\(^1\)

Farmers with poor soil quality plots are expected to adopt fertilizer to improve soil fertility as well as land productivity. Households with large land size are expected to adopt inorganic fertilizer due to the endowment effect. Land size is sorted out into three groups (terciles) to assess how inorganic fertilizer adoption is sensitive to the size of landholding. Rainfall is a complementary input to the application of inorganic fertilizer, and households residing in areas with sufficient rainfall (less risk) are more likely to adopt inorganic fertilizer compared to households residing in areas with insufficient rainfall. This is derived from the risk-averse behavior of farmers that even if inorganic fertilizer is yield-enhancing but it is a risky technology and decline to adopt if there is shortfall in rainfall. Rainfall variable is captured in terms of average rainfall and rainfall variability of the previous three years of rainy seasons and assessed the lagged effect on latter periods fertilizer adoption. The year dummy variable is
Table 1. Descriptive statistics of variables used in the analysis by survey year

| Variable description | Survey year | 2005/06 | 2009/10 | 2014/15 | Total |
|----------------------|-------------|---------|---------|---------|-------|
| **Credit and technology adoption variables** | (N = 347) | (N = 439) | (N = 626) | (N = 1412) |
| Dependent variable: Household who asked and obtained Credit (yes = 1) | 0.39(0.02) | 0.41(0.02) | 0.43(0.02) | 0.41(0.01) |
| Dependent variable: Loan size demanded (Birr/hh) | 595(62.32) | 980(26.19) | 7132(1376) | 3395(615) |
| Dependent variable: Household adopts fertilizer (yes = 1) | 0.56(0.02) | 0.63(0.02) | 0.70(0.01) | 0.65(0.01) |
| Dependent variable: Intensity of fertilizer use (kg/hh) | 27.86(1.97) | 43.62(2.38) | 65.47(3.50) | 49.44(8.13) |
| **Household characteristics** | | | | |
| Gender of household head (female = 1) | 0.27(0.02) | 0.27(0.02) | 0.28(0.01) | 0.28(0.01) |
| Age of household head (year) | 54.4(0.77) | 54.3(0.68) | 57.8(0.60) | 55.9(0.40) |
| Literacy status of household head (Illiterate = 1) | 0.68(0.02) | 0.45(0.02) | 0.60(0.02) | 0.58(0.01) |
| **Resource endowments and service variables** | | | | |
| Male adult in a household (number) | 1.45(0.06) | 1.55(0.06) | 1.93(0.05) | 1.69(0.04) |
| Female adult in a household (number) | 1.40(0.04) | 1.38(0.04) | 1.54(0.04) | 1.46(0.03) |
| Household own an ox (yes = 1) | 0.57(0.02) | 0.65(0.02) | 0.59(0.02) | 0.61(0.01) |
| Oxen owned (number) | 0.92(0.05) | 1.08(0.05) | 1.08(0.04) | 1.04(0.03) |
| Non-ox livestock units (TLU) | 1.37(0.08) | 1.65(0.08) | 3.56(0.14) | 2.43(0.08) |
| Owned farm size (ha) | 1.13(0.04) | 1.14(0.04) | 1.12(0.03) | 1.13(0.02) |
| **Community and service variables** | | | | |
| Access to irrigation (1 = yes) | 0.09(0.01) | 0.28(0.02) | 0.29(0.01) | 0.24(0.01) |
| Average plot quality (1 = good) | 0.29(0.02) | 0.38(0.02) | 0.33(0.01) | 0.33(0.01) |
| Plot distance from homestead (hour) | 0.44(0.02) | 0.40(0.01) | 0.50(0.01) | 0.45(0.01) |
| Distance to nearby market (hour) | 0.32(0.03) | 1.27(0.04) | 1.28(0.03) | 1.04(0.02) |
| Mean rainfall of rainy season of past three years (mm) | 86.90(1.80) | 120.18(2.05) | 102.29(1.53) | 108.07(1.08) |
| Rainfall variability (Std. dev) of rainy seasons of past three years (mm) | 17.51(1.15) | 20.80(0.45) | 12.87(0.19) | 16.48(0.19) |

Numbers in parenthesis are standard errors. Source: NMUB and MU household panel data.

included in the model to analyze the variation of fertilizer adoption among households over time. The unobservable effect of the fertilizer adoption assumed with mean zero and constant variance.

The impact specification of equation 1 is estimated when C\text{reated} as a censored variable with a positive value for households who participated in a credit program, zero otherwise. The amount of loan taken in each survey period is inflation adjusted based on the base year (2005/06) consumer’s price index. The application of manure (organic fertilizer) may influence adoption of inorganic fertilizer. To test empirically whether this hypothesis is strong, fertilizer adoption model is estimated with and without manure and test how susceptible result are robust to this possible substituting or complementing among the two agricultural technologies. After having assessed the appropriateness of models compared to the censored tobit, this study applies craggit double-hurdle models with correlated random effects (see Burke, 2009; Ricker-Gilbert et al., 2011 for the detailed review).
To handle attrition problem, a probit model was estimated in the baseline survey of 2005/06 and the subsequent survey rounds (i.e., 2009/10 and 2014/15) as discussed in section 2.1. The probit attrition results are included in Appendix Table 3. The results indicate that several of the variables are significant and attrition is therefore non-random and leads to bias estimates. To correct the bias, Inverse Millis Ratio (IMR) was constructed and included as a regressor in the Mundlak-Chamberlin specification to test and solve the attrition problem. The significance of IMR in the adoption model results (Table 3) indicates that attrition does have an effect on the adoption estimations and fixed the problem accordingly.

3.5. Estimation strategy

3.5.1. Controlling unobservable heterogeneity effect (\(a_i\))
Participation in credit program is assumed uniform and all sample households in the study communities are eligible to take a loan from any of the rural micro-financial institutions. Here, the problem of sample selection bias is not much concerned. However, a farmer with better entrepreneurial skill, management ability, risk taker, and market information can capture the benefits of participation in a credit program and adoption of inorganic fertilizer in a better way than a farmer with low entrepreneurial skill, low managerial ability, and limited market information. This is expressed by self-selection, so-called unobservable individual heterogeneity effect. The intuition is that the unobservable heterogeneity effect may be correlated with other control variables and leads to bias the impact estimation, that is, \(\text{cov}(X_u, a_i) \neq 0\) in equation (1) above.

Conveniently, this study uses panel data and can ease the process of controlling the unobservable individual heterogeneity effect using the fixed-effect estimator through the demeaning process (Cameron & Trivedi, 2010; J M., 2010). However, due to the non-linearity of the models (i.e., either binary or censored), the fixed-effect model is not appropriate due to the incidental parameter problem. On the other hand, applying the random effect estimator leaves uncontrolled to the unobservable individual heterogeneity due to its strong assumption (Wooldridge, 1995). Therefore, the paper cannot use the pure fixed effect and pure random effect models, rather using a Correlated Random Effect (CRE) model, which is the work of Mundlak (1978), and Chamberlain (1982) specification. This MC device removes the unobservable individual heterogeneity effect from the technology adoption model.

In the CRE specification, the unobservable individual heterogeneity effect is expressed as a function of the mean value of time-varying variables.

\[ a_i = \psi + \phi \bar{X}_i + a_i \]  \( \sim \) \( \text{Normal}(0, \sigma_a^2) \) (2)

Plug equation (2) into equation (1) and formulate full Mundlak-Chamberlin equation by combining \( U_i + a_i = \mu_i \) as follows:

\[ Q_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 C_{it} + \beta_3 D_{it} + \beta_4 Y_{it} + \phi \bar{X}_i + \mu_t \] (3)

The mean value of the explanatory variable is the same for individual households in the panel while it differs across households (cross-sectional unit). Note that equation (3) is simply a form of a non-linear model when the dependent variable is binary as well as censored, then double hurdle correlated random effect model (CRE craggit) is used to estimate fertilizer adoption.

3.5.2. Controlling for unobserved shocks (\(e_R\))
Despite the elimination of the time-invariant and unobservable individual heterogeneity factors using the Mundlak-Chamberlin specification, still, there is a possibility that the extent of participation in the credit program could be endogenous in the outcome equations (3) due to potential correlation with leftover unobservable time-varying heterogeneity. The possible way of solving the endogeneity associated with unobservable time-varying heterogeneity in the impact estimation is
using the instrumental variable method. However, instrumental variable method is the horsepower of linear outcome models, but not appropriate for nonlinear models. Alternatively, for non-linear endogenous regressor, a control function approach is used on the similar kinds of identification conditions (Wooldridge, 1995, 2010).

Following the work of Smith and Blundell (1986), for testing and controlling the endogeneity in the adoption model of agricultural technology-like equation (3), there are two-step procedure. First, estimate the reduced form extent of participating in credit program equation (4) below using correlated random effect tobit model and capture the residual (i.e., the difference between the observable loan taken and its predicted value). Second, include the residual in the adoption equation (5) along with the endogenous credit variable.

\[
C_t = \gamma_1 Z_{it} + \gamma_2 X_t + \gamma_3 D_t + \gamma_4 \overline{X} + \gamma_5 Y_t + c_t + \mu_t \tag{4}
\]

\[
Q_t = \rho_1 X_t + \rho_2 C_t + \rho_3 \overline{X} + \rho_4 \overline{D} + \rho_5 Y_t + \rho_6 \overline{X} + \varepsilon_t \tag{5}
\]

The control function approach in the impact estimation model requires exclusion restriction variables \(Z_{it}\) in the instrumentation equation (4). These have to be uncorrelated with the error term in equation (5), \(\text{cov}(Z_{it}, \varepsilon_t) = 0\), but correlated with the endogenous variable in equation (4), \(\text{cov}(C_t, Z_{it}) \neq 0\). The error term generated from the correlated random effect tobit model \(\overline{Z}_{it}\) is then included as a regressor in equation (5). The statistical significance of the residual provides a test for endogeneity of the extent of participation in credit program. As in a two-stage instrumental variable model, the control function approach requires exclusion restriction(s) as discussed above. In this case, a dummy variable whether a household has taken a training program about credit management, benefits, and opportunities by relevant public institutions a head of deciding to participate or not in the credit program was served as an instrument. The causal mechanism states that after taking training and increasing awareness, farm households may decide to participate in the credit program as they may think that participating in the credit program solves the liquidity constraint to purchase agricultural inputs. Statistical validity test has been done by including the instrument in the fertilizer adoption equation in one specification. If the instrument(s) was insignificant in the fertilizer model but significant in the extent of credit participation program, and if the error term (the difference between the observed and predicted value of loan taken) was significant in the fertilizer adoption model then, endogeneity is an issue and was corrected for with the control function.

4. Results and discussions

4.1. Descriptive analysis

The mean and standard error of variables used in the credit and fertilizer adoption estimations are presented in Table 1. Households demand loan and fertilizer ahead of the next planting season. Among households who applied for credit and obtained a loan from various credit, institutions have increased from 39.5% in 2005/06 to 41.3% in 2009/10 and this has been further increased to 43.3% in 2014/15 cropping season. On average, 64% of the loan was taken for agricultural credit. The inflation-adjusted loan size taken per household was increased from Birr 595 in 2005/06 to Birr 958 in 2009/10 and significantly increased to Birr 7132 in 2014/15. Likewise, fertilizer adoption rate is increased from 56% in 2005/06 to 63% in 2009/10 and this has been further increased to 70% in 2014/15. The extent of fertilizer use per household is increased from 27.8 kg in 2005/06 to 43.6 kg in 2009/10 and increased to 65.5 kg in 2014/15 cropping season. On average 61% of farm households own at least one ox, given the importance of an ox in farming activities. On average, about 72% of farmers owned less than one hectare that is lower than the national average. This might be the reason that the paper does not show significant variation in owned farm size among households over the survey periods.
4.2. Distribution of credit service and fertilizer adoption

The paper assesses whether there is a difference in the distribution of participating in credit program and fertilizer adoption across key household-level variables. This helps to test whether the mean value of each variable is statistically the same across the treatment (participated in the credit program and fertilizer adoption). However, this does not mean that such differences can control for the confounding factors, rather it looks at the systematic difference across these variables between treatment and control households.

The objective of rural credit is to solve the liquidity constraints of the pro-poor, especially female-headed farm households. Yet, the data revealed that a greater portion of female-headed households was less likely to participate in the credit program on average. The result is consistent with Hagos (2003), using the data 1998/99 and 2000/01 from the same community to the current study, female-headed households were participated in the rural credit program significantly low compared to their counterpart male head households. Female-headed households were also less likely to adopt inorganic fertilizer compared to their counterpart male-headed households and the difference is statistically significant at the 5% level. This suggests that the application of inorganic fertilizer demands more male labor force due to multiple treatment of fertilized plots. Participation in credit program and adoption of fertilizer is markedly lower from illiterate-headed households. This suggests that illiterate household heads may lack the necessary human capital to exploit the package's benefit and declined to take a loan and adopt fertilizer. There is a significant variation in credit service participation among households with active labor force (male and female adults). Wealthier households were more likely to apply fertilizer, suggesting the importance of resource endowment in neutralizing the risk effects that may be associated with the attribute of the technology.

Tenancy status of households show a significant difference in credit participation and fertilizer adoption. This is to mean that landlord household (who rented out at least one plot in one of the previous cropping periods in sharecropping; the dominant land rental market arrangement in the study region) markedly declined to participate in the credit program. That is expected, as landlord, households were poor in non-land resource endowments and they may impotent to repay the loan in the case of default and they decline to take a loan. Whereas tenant households were more likely to participate in the credit program as well as adopt fertilizer across the survey periods due to the following reasons. First, tenant households are more efficient compared to non-tenant households and they are in a better place to exploit the benefit of participation in the credit program and technology adoption (Chamberlin & Ricker-Gilbert, 2016; Larson & Plessmann, 2009). Second, households who have access to land through the land rental market in sharecropping or fixed rent contract arrangement for crop production show larger area under fertilizer than those with no access to land. This is due to the wealth and financial possibilities of tenant households (Yu et al., 2011). As with total land under cultivation, having access to land rental market results in an absolute increase in the area under fertilizer compared to households with no access to land. Third, yield response of inorganic fertilizer is higher than organic fertilizer (manure) Edmeades (2003), so that, inorganic fertilizer is dominantly preferred for soil fertility and much maintained by potential tenants. This gives an interesting intuition that land rental market encourages participation in rural developmental packages like what this study found.

4.3. Econometric results

The estimated results of a correlated random effect double-hurdle model using crggit command (Hurdle −1) for the probability of fertilizer adoption and (Hurdle −2) for the intensity of fertilizer adoption are presented in Table 3. Test has been done to assess whether smallholder farmers make demand decisions (adoption and extent of adoption of inorganic fertilizer) simultaneously versus sequentially. This was done by examining how well the tobit model fit to the data compared to the DH model. Two separate models with the variables presented in Table 3 are estimated. Tobit results are presented in Annex Table 1 for comparison purposes. Comparable results are robust to
the model specifications. But, the likelihood ratio test shows that the censored tobit model nests in the two-stage double hurdle model and the test rejects the censored tobit model in favor of the double hurdle ($\chi^2_{123} = 2614.62, \text{prob} = 0.00$). Henceforth, the discussion was based on the results from the double hurdle model and states that the extent of adoption of the technology needs to be estimated conditional on the likelihood of adoption decision. This proposes that farmers in northern Ethiopia make fertilizer demand decisions sequentially that first deciding to adopt or not and then deciding how much to adopt.

Besides, the model allows different explaining power of a variable in hurdle 1 and hurdle 2. This suggests that a variable with a significant effect in hurdle 1 may not necessarily significant in hurdle 2 also. This confirms the assumption that the probability and degree of adoption are performed in a separate process. Double hurdle results are presented with and without the endogenous variables to check the robustness of the model estimation. Exclusion of the suspected endogenous variables do not affect model results and estimation results were interpreted based on strict exogenous controls.

The application of organic fertilizer (manure) improves crop productivity through enhancing the organic content of the soil, enriched water-holding capacity, and increases the efficiency of inorganic fertilizer use (Giller et al., 1998). This indicates that the use of manure is positively correlated with adoption of inorganic fertilizer. Tests have been done whether adoption of organic fertilizer (manure) fairly supplements or complements to the application of inorganic fertilizer through estimating two separate estimations with and without manure (see Annex Table 2). Results have shown that there is no variation on the effect of key control variables in fertilizer estimation with and without manure. Hence, the application of manure complements to fertilizer use in the study region. The findings of this study are similar to the work of Wubeneh and Sanders (2006) that farmers, who used manure and inorganic fertilizer in combination, are substantially benefited than for those using either of them separately.

As mentioned earlier, a control function approach is used to handle selection bias related to factors affecting loan size, which may be left out in the second-stage model. A dummy variable training taking (yes = 1, 0 otherwise) before decision to participate or not in the credit program was an instrument in the first stage reduced from. Results for factors affecting first-stage loan size are presented in Annex Table 4. As shown, the instrumental variable is significant in the first-stage model at the 1% level while, insignificant in the standard test level in the second-stage model (Table 3). This indicates that taking business training affects positively and significant adoption of inorganic fertilizer indirectly through participation in the credit program. The double hurdle model results include the residual from the first-stage model along with the observed credit variable. The inclusion of the residual tests and controls for the endogeneity of participating in the credit program. Standard errors are estimated using the bootstrapping method to account for the two-stage estimation.

The coefficient of the residual is significant with a negative sign in the adoption estimation of inorganic fertilizer at the 5% level. This indicates that participating in the credit program in the adoption model is potentially endogenous as expected and, therefore, the control function approach works nicely. The negative sign of the residual indicates that actual use of inorganic fertilizer in the study region is significantly lower than the expected (potential use). This is consistent with previous studies that the application of fertilizer in Sub Sahara Africa is below the required quantity per hectare of cultivated land compared to other Asian and Latin America (Ariga et al., 2006). The coefficient of loan size is positive and significant in the probit component, while insignificant in the linear component of fertilizer adoption. This suggests that the size of loan taking affects positively the probability of inorganic fertilizer adoption but not important in explaining the extent of inorganic fertilizer adoption. The marginal effect shows for an increase in loan size taken by 1%, from its mean the probability of fertilizer adoption increased by 2.5% at the 5% level. That is expected and supports to the prior expectation for the positive and significant
impact of participating in the credit program on technology adoption in smallholder agriculture. Farming, especially smallholder face a liquidity problem, and the accessibility of agricultural credit enables to solve the cash constraints and improves the potential of purchasing agricultural inputs. This finding is consistent with the report of Feder et al. (1985); Hagos (2003); Ogad et al. (2010); Tadesse (2014), that credit affects positively to purchase relatively expensive farm technologies such as inorganic fertilizer.

Examining the other variables in the double hurdle model typifies the variation of adoption and adoption intensity of inorganic fertilizer among farm households. As far as the correlation between household features and the probability of fertilizer use is concerned, there is a positive and statistically significant correlation between head’s age and the probability of fertilizer adoption, ceteris paribus. This may indicate that elder-headed households have long period of farming experiences in maintaining soil fertility and land management. The probability of fertilizer adoption correlated positively and significantly at the 10% level with female-headed households. This is indicated by 26.5% increasing in the probability of fertilizer adoption for female-headed households. The possible justification could be first, in the study region, female-headed households are poorer than their counterparts male-headed households in terms of adult labor, oxen and non-oxen livestock owned, and crop income. Thus, the issue of food security is more concerned with female-headed households, and to overcome the problem and reducing future food purchases, female-headed households increase adoption rate of the risky but yield-enhancing technology. Second, in the study region, there is female-targeted microfinance so-called “Aday” microfinance and provides loans only to females mainly to purchase of agricultural inputs. Households headed by illiterate are significant with negative sign explain fertilizer use. This indicates that farming in the study area is small scale, acquiring higher-level education is not much important to manage plots, and illiterate-headed households dis adopt inorganic fertilizer.

| Table 2. Credit program participation and fertilizer adoption distribution by key household control variables |
|---------------------------------------------------------------|
| | Credit program | Fertilizer | Joint input user |
| | Participant | Non-parparticip | Adopter | Non-adopter | User | Non-user |
| Variable’s description | N = 590 | N = 822 | Sig.diff | N = 915 | N = 497 | Sig.diff | N = 440 | N = 972 | Sig.diff |
| Head’s gender (female = 1) | 0.24 | 0.30 | ** | 0.22 | 0.36 | *** | 0.24 | 0.29 | ** |
| Head’s age (year) | 55.53 | 56.12 | 56.07 | 55.61 | 56.05 | 55.81 |
| Head’s education (illiterate = 1) | 0.53 | 0.60 | *** | 0.53 | 0.66 | *** | 0.49 | 0.61 | *** |
| Male adult (number) | 1.87 | 1.57 | *** | 1.92 | 1.28 | *** | 2.00 | 1.55 | *** |
| Female adult (number) | 1.56 | 1.38 | *** | 1.57 | 1.24 | *** | 1.64 | 1.37 | *** |
| Ox own (yes = 1) | 0.645 | 0.58 | *** | 0.70 | 0.43 | *** | 0.70 | 0.56 | *** |
| Non-ox livestock (TLU) | 2.59 | 2.31 | ** | 2.80 | 1.74 | ** | 2.90 | 2.21 |
| Household is landlord (yes = 1) | 0.24 | 0.28 | ** | 0.21 | 0.37 | *** | 0.22 | 0.29 | *** |
| Household is tenant (yes = 1) | 0.27 | 0.23 | * | 0.29 | 0.16 | *** | 0.30 | 0.22 | ** |
| Household is self-operator (yes = 1) | 0.50 | 0.48 | | 0.50 | 0.46 | | 0.49 | 0.49 | |
| Population density is high (yes = 1) | 0.47 | 0.43 | | 0.46 | 0.43 | | 0.48 | 0.44 | * |
| Access to irrigation (yes = 1) | 0.23 | 0.25 | | 0.26 | 0.20 | *** | 0.26 | 0.23 | |
| Distance to market is long (yes = 1) | 0.30 | 0.37 | *** | 0.35 | 0.33 | *** | 0.31 | 0.35 | *** |

Note: ***,**,* are t-values with significant level at 1.5 & 10 %, respectively. Numbers in parenthesis are standard errors. Source; NMUB and MU household panel data.
### Table 3. Impact analysis of loan size on fertilizer adoption (cragit model)

| Variables                                      | With endogenous variables | Without endogenous variables |
|------------------------------------------------|---------------------------|-----------------------------|
| Residual from first stage estimation           | Hurdle −1                 | Hurdle −2                   |
| Log of loan taken (Birr/hh)                    | 0.02***(0.013)            | 0.025***(0.013)            |
| Head’s gender (female = 1)                     | 0.246(0.167)              | 0.265*(0.156)              |
| Head’s age(year)                               | 0.015****(0.005)          | 0.015****(0.005)          |
| Head’s literacy (literate = 1)                 | −0.681****(0.213)         | −0.693****(0.169)          |
| Owned land (second tericle = 1)                | −0.168(0.119)             | −0.157(0.119)              |
| Distance to market (hour)                      | 0.100*(0.059)             | 0.094(0.058)               |
| Plots’ quality (1 = medium)                    | −0.708****(0.265)         | −0.688****(0.233)         |
| Plots’ quality (1 = good)                      | −0.151(0.443)             | −0.109(0.338)              |
| Rainfall previous 3 yrs rainy season (mm)      | −0.006(0.004)             | −0.007*(0.004)             |
| Rainfall variability (Std.Dev) pr.3 yrs rainy season (mm) | 0.005(0.007) | 0.006(0.007) |
| JMR                                            | 32.22****(8.880)          | 32.37****(4.361)          |
| Male adult (number)                            | −0.011(0.070)             | −0.038(0.062)              |
| Female adult (number)                          | 0.029(0.075)              | 0.021(0.061)               |
| Oxen owned (number)                            | −0.100(0.072)             | −0.067(0.064)              |
| Mobile own (yes = 1)                           | −0.060(0.225)             | −0.001(0.180)              |
| Year dummy = 2009/10                           | 0.153(0.206)              | 0.181(0.204)               |
| Year dummy = 2014/15                           | 0.365*(0.155)             | 0.406****(0.147)          |
| _cons                                          | −24.68****(6.800)         | −24.68****(3.44)          |
| sigma_cons                                     | 0.989****(0.024)          | 0.991****(0.024)          |
| Wald chi2(22)                                  | 271.66                    | 267.17                     |
| Log-likelihood                                 | −2037                     | −2042                      |
| Prob > chi2                                    | 0.0000                    | 0.0000                     |
| Number of obs                                  | 1412                      | 1412                       |

Note. H1 = probability of fertilizer use. H2 = log of fertilizer per hectare of land use. CRE controls for unobservable heterogeneity as the mean (not reported) of time-varying variables in the Mundlack-Chamberlin device extracted from a three-year panel data model for adoption and intensity of fertilizer use. ***, **: 1 %, **, 5 %, *: 10 %. refers to level of significance. Numbers in parenthesis are standard errors bootstrapping with 400 replication at household level. Source: NMBU and MU household panel survey.

Physical characteristics of plot also influence adoption decision of inorganic fertilizer. Table 3 shows households having plots with medium soil quality dis-adopt inorganic fertilizer. That is expected. First, the importance of inorganic fertilizer is to improve soil fertility and farmers who have plots with medium soil quality may be reluctant to invest more compared to plots with poor soil quality. Second, medium fertile (medium vertisols) soils have low moisture retention capacity and demand shorter growing periods, and are more likely to use early maturing varieties and other water abhorring technologies. Accordingly, the probability of fertilizer adoption decreased by about 68.8% by households with medium plot’s quality, *ceteris paribus*.

Results from the second hurdle show that head’s gender (female = 1), distance to market rainfall variability of previous three years rainy season, and the year dummy (2014/15) affect positively and significantly the extent of fertilizer use whereas own landholding affects negatively and significantly adoption intensity of inorganic fertilizer. Households headed by females increased the intensity of fertilizer use. This might be due to the risk-averse behavior of female-headed households to reduce future production risk (food purchase) via adopting yield-enhancing...
technology. The marginal effect shows that adoption intensity of fertilizer increased by 29.1% for female-headed households. For an increase in walking time to the nearby market by one hour, the intensity of fertilizer use increased by 8.3% at the 5% level which contradicts to the finding of Yu et al. (2011) that access to market shows a positive effect on adoption of inorganic fertilizer in cereal potential area of Ethiopia. Risk variables proxy by previous years rainfall variability (standard deviation) affects positively and significantly adoption intensity of fertilizer in the latter period. This implies that households live in a community with high rainfall variability in the previous three-year rainy season lead to use bulky amount of inorganic fertilizer per hectare of land in the latter period compared to households live in areas with low rainfall variability. This is because smallholders are risk-averse and to reduce future production shortfall and food purchase, they encourage to adopt yield-enhancing technology post of such shocks. Keeping others constant, for an increase of rainfall variability in the previous three years rainy season by 10 mm, the intensity of fertilizer use in latter period increased by about 20%.

Previous works revealed a mixed effect of farm size on technology adoption. This is because the correlation between farm size and technology adoption depends on many other factors (Feder et al., 1985 see for the detailed review). On the one hand, farm size influences positively fertilizer adoption because larger farmers can experiment with new technologies on a portion of land without worrying about risking the family food security due to wealth effect or risk neutralize effect (Pender & Alemu, 2007). Zepepa (2001) also shown that the benefit generated from large-scale adoption of new technologies are larger absolutely for large farm size. This is explained by fixed transaction cost and information acquisition costs associated with the new technologies and that there may be a lower limit on the size of adopting farms. On the other hand, farmers with smaller farm size than a certain critical level cannot or will not pay the information costs of adopting new varieties and fertilizer compared to farmers with larger than farm size above a certain critical level (Feder et al. 1985).

Accordingly, farm size is sorted out into three groups (terciles) to assess how fertilizer adoption is sensitive to farm size. The first tercile includes households with landholding between 0.03 hectares to 0.75 hectares, which accounts for 39% of sampled households. Households in the second tercile own land between 0.75 hectares to 1.0 hectares (32% of sampled households) and households within the third terciles own land between 1.03 hectares to 6.62 hectares (29% of the sampled households). Keeping others constant, results indicate that farm size from the second and third tricles have a negative and significant effect on adoption intensity of inorganic fertilizer compared to the base, first tricles. The possible explanation is that small farmers often practice land-use intensification, especially in labor-abundant economies. The study region is highly populated and households have more labor per unit of land while larger farms have higher transaction costs to acquire hired labor. This result is consistent with the finding of Hagos (2003) and Wubeneh and Sanders (2006) in the same community that farmers with higher farm size use less amount of fertilizer per hectare of land.

The year dummy variable (2014/15) has a significant with positive effect on adoption intensity of fertilizer. Compared to the base year (2005/06), the adoption intensity of fertilizer has been increased by 53.8% in 2014/15 at the 1% level.

5. Overall discussion
Guaranteeing welfare of smallholders in a semi-arid economy is comprehensive and complex, which demands various complementary and interviewing dynamics. This study examines to what extent the recent public intervention i.e., prompting access to rural credit influence adoption of improved agricultural technology (inorganic fertilizer) in the semi-arid economy of northern Ethiopia. This could be more prominent by solving financial constraints of the poor farmers and improving smallholder agriculture. Adoption process of improved agricultural technology has been increased since the Green revolution in 1964 and smallholder farmers allocate large portion of their land to genetically high yield varieties where an adequate supply of inorganic fertilizer fundamentally supported the adoption process (Matuschke et al., 2007).
It is noteworthy that adoption of improved agricultural technologies plays an important role in improving food security, adapted and mitigating to climate change, and facilitates market integration in countries that exhibited lower per capita land holding, high population pressure, and production risk. The study of Bezu et al. (2014) in Malawi shows that yield variability due to rainfall stress was overcome through adoption of drought-tolerant Maize. Public intervention in terms of subsidy to purchase the improved Maize among Malawian smallholders was an important strategy in reducing vulnerability to climate change. Similarly, using national representative farm household data, adoption of high yield Maize variety in Tanzania accounts 43% and the adoption pattern of the improved technology significantly increased over time (Amare et al., 2012). Amare and Shiferaw (2017) found that Ugandan farmers planted only 8% of with improved seed varieties in 2009/10 while three years later (2011/12), the adoption dynamic of the improved technology has been increased to 38%. The importance of access to credit, input subsidy, on the adoption of the above-mentioned agricultural technologies were crucial. This indicates that inorganic fertilizer is one complementary input to other agricultural practices in a semi-arid economy.

Therefore, the prevalent of well-functioning rural institutions such as rural finance, unions, cooperate, and agricultural extension becomes the key solution to the supply and demand sides of the technology. One can think a similar approach to improve technology adoption among smallholders is necessary to meet food sufficiency, environmentally friendly farming practices in the semi-arid of Ethiopia.

6. Conclusion and policy implication
Improving agricultural productivity and facilitating the transformation from subsistence agriculture to market-oriented agriculture has been a major policy concern of Ethiopia. This underpinned to boost the investment in infrastructure and provision of extension services. This paper investigates the impact of participation in credit program on adoption of inorganic fertilizer using farm households data surveyed in the 2005/06, 2009/10, and 2014/15 production seasons from rural Tigrai, northern Ethiopia. Although this is not the first study, it is among the very few studies that utilize long and rich farm household-level panel data and applied demanding econometrics methods and identification strategies that enriched the previous empirics.

This paper builds on Schultz (1964) that risk-averse farmer technology adoption behavior appears to be correlated to local conditions, human capital, endowment, and production risk. The estimated results from this study are based on a correlated random effect double hurdle model with a control function approach to fix for important econometric problems, such as the endogeneity and unobservable individual heterogeneity of participating in credit program and fertilizer adoption.

Results show an increasing pattern in fertilizer used and participation in credit programs since 2005/06. However, the proportion of households adopting inorganic fertilizer are higher than the proportion of households participated in the credit program across the survey periods. This may indicate that farm households in the study region used other sources of cash income to finance agricultural input such as inorganic fertilizer. Despite the various factors that affect positively to participation in the extent of loan taken the study finds evidence that getting a training program a head of taking the loan positively and significantly influences the amount of loan taken.

To conclude, participating in credit program did not improve fertilizer adoption to a higher level in the study region. The possible reasons could be: First, the system seems not efficient in reaching out the credit service to the ultimate users. This may be due to poor infrastructure and bureaucratic barriers that exclude some farmers from participating in the program. Second, farmers in the study region may have increased relative risk aversion behavior, meaning that households compensate for the additional risk of increasing area of a crop under inorganic fertilizer by reducing input intensity for that crop. The best way to improve the performance of the credit service is that the government should be functioning the credit market effectively and look at better diffusion
effort as some people adopt the idea when they are first introduced; others wait a long time, while some never participate. This may help to improve access to rural credit and enable to finance fertilizer purchase in smallholder agriculture.

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Declaration of interest statement
The authors declare that the data and do file supporting the findings of this study are available within the article.

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Notes
1. Farmers have different plot with different biophysical characteristics, for example, a farmer may have a plot with low soil quality (1), medium soil quality (2), and higher soil quality (3). I take the average plot quality characteristics of a household by taking an index (multiplying plot quality characteristics low, medium or higher by the number of plots belongs to group and divided by the total number of plots).

2. Bir is the official currency of Ethiopia

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### Table A1. Factors affecting the extent of participation in the credit program (CRE tobit)

| Variables | Coefficients |
|-----------|--------------|
| Instrument: Dummy .household takes training program before participation in credit(yes = 1) | 6.766*** (1.572) |
| Head’s gender(female = 1) | −0.104 (0.196) |
| Head’s age(years) | 0.003 (0.009) |
| Head’s education(illiterate = 1) | −0.332 (0.253) |
| Own land (ha) | 0.177 (0.115) |
| Distance to market (hour) | −0.014 (0.048) |
| IMR | 16.561*** (6.950) |
| Year dummy = 2010 | −0.456*** (0.189) |
| Year dummy = 2015 | 0.816*** (0.179) |

CRE Control for unobservable heterogeneity was included as the mean (not reported) of time-varying variables in the Mundlack-Chamberlin device extracted from a three-year panel data model for adoption and intensity of fertilizer use. ***: 1 %. **: 5 %. *: 10 %. refers level of significance. Numbers in parentheses are standard errors bootstrapping with 400 replication at household level. Source: NMBU and MU household panel survey.

### Table A2. The impact of manure adoption on inorganic fertilizer use (CRE tobit)

| Variables | Without manure use | With manure use |
|-----------|--------------------|-----------------|
| Hurdle −1 | Hurdle −2 | Hurdle −1 | Hurdle −2 |
| Residual from first stage estimation | −0.019*** (0.010) | −0.008 (0.010) | −0.019*** (0.010) | −0.008 (0.009) |
| Log of loan taken (Birr/hh) | 0.025*** (0.013) | −0.011 (0.012) | 0.025*** (0.013) | −0.011 (0.011) |
| Head’s gender (female = 1) | 0.265** (0.156) | 0.291*** (0.145) | 0.262* (0.158) | 0.294** (0.143) |
| Head’s age(year) | 0.015*** (0.005) | −0.002 (0.004) | 0.015*** (0.005) | −0.002 (0.004) |
| Head’s literacy (illiterate = 1) | −0.693*** (0.169) | −0.026 (0.138) | −0.647*** (0.177) | −0.033 (0.143) |
| Owned land (second tercile = 1) | −0.157 (0.119) | −0.195** (0.1029) | −0.138 (0.113) | −0.196** (0.095) |
| Owned land (third tercile = 1) | −0.203 (0.172) | −0.321*** (0.148) | −0.179 (0.169) | −0.326** (0.141) |
| Distance to market (hour) | 0.094 (0.058) | 0.083** (0.045) | 0.093* (0.056) | 0.083** (0.044) |
| Plot’s quality (1 = medium) | −0.688*** (0.233) | −0.237 (0.171) | −0.680*** (0.199) | −0.236 (0.168) |
| Plot’s quality (1 = good) | −0.109 (0.338) | −0.218 (0.292) | −0.071 (0.323) | −0.213 (0.292) |
| Rainfall previous three years rain season (mm) | −0.007 (0.004) | 0.005 (0.003) | −0.008** (0.004) | 0.005 (0.003) |
| Rainfall variability (Std.Dev) previous three years rainy season (mm) | 0.006 (0.007) | 0.020*** (0.007) | 0.0075 (0.007) | 0.020*** (0.007) |
| IMR | 32.37*** (4.364) | 2.808 (4.250) | 30.2 (5.109) | 3.078 (4.264) |
| Year dummy = 2010 | −0.150 (0.175) | 0.201 (0.203) | −0.159 (0.179) | |
| Year dummy = 2015 | 0.406*** (0.147) | 0.538*** (0.137) | 0.456*** (0.141) | 0.538*** (0.144) |
| _cons | 3.447 (0.418) | 2.114 (3.34) | −23.121*** (3.473) | 1.903 (3.30) |
| Manure_adoption (yes = 1) | 0.449*** (0.092) | 0.011 (0.070) | |
| Wald chi2(23) | 267.17 | 279.22 | |
| Log-likelihood | −204.2 | −2028.4288 | |
| Prob > chi2 | 0.0000 | 0.0000 | |
| Number of obs | 1412 | 1412 | |

Note: Log of fertilizer per hectare of land use. CRE controls for unobservable heterogeneity as the mean (not reported) of time-varying variables in the Mundlack-Chamberlin device extracted from a three-year panel data model for adoption and intensity of fertilizer use. ***: 1 %. **: 5 %. *: 10 %. refers level of significance. Numbers in parenthesis are standard errors bootstrapping with 400 replication at household level. Source: NMBU and MU household panel survey.
### Table A3. Probit estimation of attrition based on the baseline sample of 2005/06 (Dependent variable: Drop out in 2009/10 and 2014/15 =1, otherwise = 0)

| Variables                      | Coeff.  |
|-------------------------------|---------|
| Head’s gender (female = 1)    | 0.111(0-152) |
| Head’s age (years)            | 0.002(0-004) |
| Head’s education (illiterate = 1) | −0.367**(0.143) |
| Oxen owned (number)           | −0.086(0.0769) |
| Male adult (number)           | −0.130**(0.062) |
| Female adult (number)         | −0.079(0.072) |
| Own land (ha)                 | 0.031(0.105) |
| _cons                         | −1.497***(0.307) |

Note: ** *** refers to a significant level at 5 & 1 % level, respectively. Numbers in parenthesis area robust standard errors, Source: NMBU and MU household panel.

### Table A4. The impact of loan size on fertilizer adoption (CRE tobit)

| Variables                                | Coefficient |
|------------------------------------------|-------------|
| Residual from first stage estimation     | −0.043**(0.020) |
| Log of credit taken (/hh)                | 0.034(0.023) |
| Head’s gender (female = 1)               | 0.597**(0.310) |
| Head’s age (years)                       | 0.027*** (0.008) |
| Head’s education (illiterate = 1)        | −1.287*** (0.385) |
| Own land (ha)                            | −0.196(0.179) |
| Distance to market (hour)                | 0.236**(0.103) |
| Male adult (number)                      | −0.042(0.129) |
| Female adult (number)                    | 0.066(0.124) |
| Oxen own (number)                        | −0.212(0.137) |
| Mobile own (yes = 1)                     | −0.133(0.364) |
| Rainfall of prev 3 yrs (mm)              | −0.016**(0.008) |
| Rainfall variability (STD.Dev) of prev 3 years (mm) | 0.029**(0.014) |
| IMR                                      | 68.21*** (18.502) |
| Year dummy = 2009/10                     | 0.721** (0.384) |
| Year dummy = 2014/15                     | 1.468*** (0.301) |
| _cons                                   | −52.614 (14.171) |
| Wald chi2(22)                            | 332.60 |
| Log-likelihood                          | −2608.0156 |
| Prob > chi2                              | 0.0000 |
| Number of obs                            | 1412 |

Note: Log of fertilizer per hectare of land use. CRE controls for unobservable heterogeneity as the mean (not reported) of time-varying variables in the Mundlack-Chamberlin device extracted from a three-year panel data model for intensity of fertilizer use. ** : 1 %, *** : 5 %, * : 10 %, refers to level of significance. Numbers in parenthesis are standard errors bootstrapping with 400 replication at household level. Source: NMBU and MU household panel survey.
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Appendix

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