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Market Imperfections and Farm Technology Adoption Decisions - A Case Study from the Highlands of Ethiopia

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Abstract

This paper investigates the impacts of market and institutional imperfections on technology adoption in a model that considers fertilizer use and soil conservation to be joint decisions. Controlling for plot characteristics and other factors, we found that a household's decision to adopt fertilizer significantly and negatively depends on whether the same household adopts soil conservation. The reverse causality, however, was insignificant. We also found that outcomes of market imperfections, such as limited access to credit, plot size, risk considerations, and rates-of-time preference, were significant factors in explaining variations in farm technology adoption decisions. Relieving the existing market imperfections will most likely increase the adoption rate of farm technologies.

Key Words: Bivariate probit, fertilizer adoption, market imperfections, risk aversion, time preferences, soil conservation

JEL Classification Numbers: C35; D43; Q12, Q24

Contents

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Introduction

Sustainable agricultural development is widely acknowledged to be a critical component of a strategy to combat both poverty and environmental degradation. In many countries, degradation of agricultural land poses a serious threat to future production potential and current livelihoods of the peasant households (Scherr et al. 1996; IFPRI 1999). Ethiopia is one of the poorest countries on earth and is heavily dependent on peasant agriculture. The extensive degradation of its agricultural lands is most severe in the highlands of Ethiopia where pressure from humans and livestock is the greatest. According to a recent review, the annual cost of on-site soil losses from soil degradation is estimated to be between 2–7 percent, with a likely value of 2–3 percent of Ethiopia's agricultural gross domestic product (Yesuf et al. 2005). In the last two decades, per capita food production has lagged behind the population growth rate, and food shortages and rural poverty have become chronic problems.

Currently Ethiopia faces the challenge of achieving food security while at the same time slowing or reversing agricultural land degradation to ensure sustainability of future agricultural production. Recognizing the seriousness of its soil fertility problems and the necessity of improving agricultural productivity, the Ethiopian government and international donors have initiated a number of programs that promote yield-enhancing and soil-conserving technologies (dissemination of fertilizers and improved seeds, and adoption of soil conservation structures), but most of them have failed. The average technology adoption rate of modern fertilizers in Ethiopia, for example, is estimated to be less than 33 percent of the cultivated lands, and the average level of use of modern fertilizer is only 11 kilogram (kg) per hectare, compared to 48 kg

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per hectare in Kenya and 97 kg per hectare worldwide (Mulat et al. 1997; FAO, 1998). Ethiopia's technology adoption and dissemination rates are low even by African standards.

These unsuccessful programs were often based on superficially perceived causes of land degradation, deterioration of soil productivity, and physical processes, such as over-cultivation, over-grazing, over-population, deforestation, climatic factors, etc. (Bojö and Cassells 1995). However, a growing consensus in recent literature warns that these factors are more likely physical manifestations of underlying market and institutional failures (Bojö and Cassells 1995; Holden, Shiferaw and Wik 1998; IFPRI 1999; Shiferaw and Holden 1999; Hagos and Holden 2003; Yesuf et al 2005). Many of the programs also failed because they did not integrate efforts to disseminate yield-enhancing inputs (such as fertilizers) with soil and water conservation efforts. Instead, conservation and yield enhancement were conducted in separate programs with different objectives, with poor to no coordination of efforts (Hurni 1993). This was unfortunate, since soil and water conservation and yield-enhancing technologies can substantially complement each other. For example, the returns from soil conservation could be much higher if farmers also adopted fertilizers and vice versa, because the soil conservation structures would help conserve soil moisture and reduce runoff (and thus loss of other inputs).

Many of the previous studies of decisions on soil conservation and fertilizer adoption identified (ad-hoc) several personal, physical, economic, and institutional elements and analyzed them separately in a single equation model. From an econometric point of view, a single equation estimation approach could cause bias, inconsistency, and inefficiency in parameter estimates if simultaneity in decision was detected and/or unobserved heterogeneities were correlated for these decisions (Greene 2000; Maddala 1983). It also could obscure possible interlinkages and synergies that might exist between the different forms of technology adoption decisions.

In the context of estimating several adoption decisions simultaneously, one might uncover interactions that could be extremely useful in attempts to manipulate the adoption process (Feder et al. 1985). For example, farmers might be more likely to adopt fertilizers if they also adopted soil conservation—but not necessarily vice versa. If this is true, it suggests that extension work might concentrate more profitably on soil conservation, since fertilizer use is likely to follow. It is also possible that a farmer might abandon one technology in favor of the other, e.g., substituting fertilizer for lost soil, even if adopting both at the same time was more beneficial to production. This less-than-optimal scenario is quite likely should farmers face a binding resource or liquidity constraint in their investment decisions (Feder et al. 1985). The possibility of this result suggests that resources and efforts should be geared toward relieving some of the constraints, in order to reap potential gains from complementarities, rather than offering incentives for one technology—which might retard the adoption of the other—and the potential gains would be lost.

In this study, we investigated the market and institutional constraints behind the low adoption rate of farm technologies in Ethiopia in a simultaneous equation model that considered soil conservation and fertilizer use as related decisions. In section 2 of this paper, we discuss the conceptual framework and hypotheses. Section 3 deals with the econometric approach, and in section 4, we discuss the data and econometric results. Section 5 concludes the paper.

2. The Conceptual Framework and Hypotheses

The literature contains several theoretical approaches to modeling farm technology-adoption decisions, depending on the specific objective of the study. (For a survey, see Feder et al. 1985.) Many of the existing approaches assume a perfectly competitive market structure and clearly defined property rights (perfectly working institutions). However, in many developing countries, decisions are made under imperfect market structures with incomplete or unclear property right regimes. Models that partially or fully incorporate market and institutional imperfections into their formulations include Feder and Onchan (1987) and Hayes et al. (1997) for unsecured property right regimes, Pender and Kerr (1998) for missing labor and land markets, and Yesuf (2004) for imperfect institutional arrangements and imperfect factor markets (such as land, labor, and credit market imperfections). Our conceptual framework mainly draws from Feder and Onchan (1987) and Yesuf (2004).

In general, decisions by farmers over a given period of time are assumed to be derived from the maximization of a discounted expected utility of farm profit subjected to credit and labor constraints and tenure insecurity perceptions of farm households. Farm profit is a function of the farmer's choice of a mix of technologies, such as chemical fertilizers and soil conservation structures. This implies that for a discounted expected utility-maximizing decision maker, the two technology choices are joint decisions. Other factors that affect farm profit include yield uncertainties, subjective discount rates, and household and plot characteristics. The farm household adopts a given technology if the discounted expected utility obtained from adoption is larger than without adoption.

We used the reduced form of this optimization problem for our empirical estimation of adoption decisions. More specifically, we assume that modern fertilizer (fa_{hp}) and soil conservation (sc_{hp}) adoption[1] decisions by household h on plot p are conditioned on the adoption decision of the other technology, the household's perception of soil erosion and soil fertility problems ($perc_{hp}$), the profitability index of the technologies adopted in plot p ($prof_{hp}$), the household's perception of tenure security ($tenu_h$), the household's access to credit and labor markets (cmp_h), the household's attitudes towards risk and rates-of-time preferences—or, in general, behavioral measures—($beha_h$), and other random factors, such as ε_{hp}^{f} and ε_{hp}^{c} for fertilizer and soil conservation adoption decisions, respectively.

A decision to adopt soil-conserving and/or output-enhancing technologies begins with the perception of soil erosion and soil fertility (Ervin and Ervin 1982; Norris and Batie 1987; Pender and Kerr 1996; Shiferaw and Holden 1999). This perception is a product of observed factors that might determine the level of the household's awareness of soil and plot characteristics (PC_p), such as plot size, slope, and soil quality; the human capital of the household (HC_h), such as gender, age, and education; and village-level factors (X_v), such as agro-ecological factors including rainfall variability. Since we were not able to measure perception of erosion at the plot level in our study, we substituted PC_p, HC_h, and X_v into $perc_{hp}$ and got the following expression for fertilizer use and soil conservation adoption decisions, respectively:

$$fa_{hp} = fert\ \left(sc_{hp}, PC_{hp}, HC_h, X_v, prof_{hp}, cmp_h, tenu_h, beha_h, \varepsilon_{hp}^{f}\right) \tag{1}$$

$$sc_{hp} = cons\ \left(fa_{hp}, PC_{hp}, HC_h, X_v, prof_{hp}, cmp_h, tenu_h, beha_h, \varepsilon_{hp}^{c}\right). \tag{2}$$

[1] Although measures of soil conservation vary in the literature, our definition of soil conservation was restricted to the construction of any physical structures on a plot to reduce runoff and soil loss. The most common structures in the Ethiopian highlands include stone and soil bunds, cut-off drainage, and grass strips. Our definition of modern fertilizer was also restricted to use of any chemical fertilizers. The most common types in the Ethiopian highlands include diammonium phosphate (DAP) and urea fertilizers. Both soil conservation and fertilizer adoption variables were defined as dummy variables, as this study is mainly interested in probabilities of joint adoption decisions but not intensities of adoptions.

By increasing the profitability of agricultural production, greater market access may promote adoption of both modern fertilizers and soil conservation technologies. Proximity to roads and markets also reduces transaction costs associated with access to credit and labor markets. However, better access to markets and roads may increase non-farming opportunities as well and conceivably attract labor away from agricultural activities—which could discourage investments in soil conserving and output-enhancing activities. Therefore, the effect of access to markets and roads on farm technology adoption decisions is ambiguous.

It is often discussed in the literature that rural markets and institutions in developing countries are generally poorly developed and characterized by high transaction costs, arising from transportation costs; heavy search, recruitment, and monitoring costs; and limited access to information, capital, and credit (de Janvry et al. 1991; Sadoulet et al. 1996). As imperfect as they are, credit institutions in rural Ethiopia extend short-term credit for productive activities (mainly purchase of modern fertilizers and improved seeds) and consumption smoothing—but significantly they fail to offer credit for long-term investments like soil conservation. Formal credit institutions in rural Ethiopia currently require that loans for agricultural inputs be repaid immediately after harvest, forcing farmers to sell when prices are low and precluding the option of storing their harvests and selling when food is scarcer and prices are higher.

According to a recent study, failure to repay this commodity-specific credit was mainly due to crop failure and has increased indebtedness among the peasantry (IDR, 2000). This is likely to inhibit particularly risk-averse households from taking credit, which subsequently affects their decisions to adopt new farm technologies. Furthermore, availability of credit affects soil conservation decisions by reducing the subjective discount rate and the consumption risk of farm households. We therefore hypothesized that households with better access to credit or other sources of cash liquidity would be more willing to adopt farm technologies than credit- or liquidity-constrained households. On the other hand, as long as credit is available only for short-term farm activities and not for long term investments like soil conservation, greater provision of credit might draw labor away from conservation activities. Hence, the impact of access to credit on soil conservation is ambiguous.

Another factor that is likely to affect the adoption decisions is tenure security. Insecurity of land rights is generally regarded as an important deterrent of long-term land investment decisions (see Alemu 1999; and Gebremedhin and Swinton 2003). Apart from its direct incentive for long-term investment ventures (like soil conservation), properly secured tenure with tradable or transferable rights reinforces yield-enhancing and soil-conserving efforts by relaxing the credit market constraints by providing collateral in the credit market. In the empirical literature, people use various measures to capture tenure security, such as duration of tenure (years of continuous land use), tenure arrangements (whether the plot is owner-operated, sharecropped in or sharecropped out, and leased in or leased out), and the perceived degree of tenure security. Application of each measure depends on the type of land policy that a country pursues.

In Ethiopia, all land is state property, and it may not be sold or mortgaged. Although the constitution guarantees peasants and pastorialists free access to land, it is not clear how this right is assured in practice, given the scarcity of land and the ever-exploding population pressure. Under the current land tenure arrangements, this free access to land has been implemented through redistribution and reallocation of plots. Although the basic criteria used in the redistribution are not clearly defined, farm size relative to family size and the ability to manage existing plots are perceived to be the major ones (Alemu 1999). Thus, tenure insecurity in this context is defined as the perceived probability or likelihood of losing ownership of a part or the whole of one's land without consent (Sjaastad and Bromley 1997; Alemu 1999).

Given this and given the land tenure structure in Ethiopia, we hypothesized that households with insecure tenure perceptions would be less willing to invest in either soil-conserving or yield-enhancing technologies. Apart from deterring long-term investment decisions, the current land policy of the Ethiopian government on land redistribution has had an adverse effect on farm technology adoption decisions through its impact on reducing and fragmenting individual plots in response to overwhelming population pressure.

There is an ongoing debate in the literature on the impact of population pressure and decreasing farm sizes on agricultural intensification or technology adoptions. One group (the Boserupians) argues that when population pressure leads to smaller plots, it will induce intensive use of the land through the adoption of new farm technologies. The other group (the neo-Malthusians) argues that population pressure does not lead to intensive use of the land, but instead leads to cultivation of marginal lands and further land degradation. Thus, the impact of plot size on technology adoption decisions is an empirical issue.

The other group of factors that affects technology adoption decisions is behavioral factors, such as farm household risk and time preferences. In the absence of good access to credit and poor cash liquidity, poor farm households face significant consumption-smoothing problems and, thereby, high subjective discount rates. These, in turn, discourage land investment decisions that have short-term costs but long-run benefits (Pender 1996; Holden et al. 1998; Godoy et al. 2001; Yesuf 2003a). Therefore, households with high subjective discount rates are less likely to adopt soil conservation technologies.

Incentives to invest in new agricultural technologies may also be substantially less effective when outcomes of adopting such technologies are conditioned by other stochastic or random factors, such as rainfall variability. Hence, the consideration of risk also plays an important role in the choice of production inputs and the adoption of technologies, particularly in a situation where insurance markets function so poorly (or are completely missing), that it is difficult to pass the risks to a third party (Just and Zilberman 1988; Rozenzweig and Binswanger 1993; Shively 1997, 2001; Yesuf 2003b). In rain-fed agriculture (as in Ethiopia), returns from fertilizer use are highly conditional on many stochastic events, but primarily weather. Under such farming conditions, risk-averse households are the least expected to adopt modern fertilizer due to the high risk of indebtedness.

3. The Econometric Model

The purpose of this study was to identify the determinants of soil conservation and fertilizer adoption decisions, in a situation where institutions and factor markets are imperfect. We assumed that all non-technology variables that affected the adoption decisions were exogenous. In order to deal with the simultaneity of the technology adoption decisions, we adopted the bivariate probit model of Maddala (1983, model 6 in section 8.8). Consider a joint fertilizer and soil conservation adoption decision of a farm household given by the following bivariate simultaneous equation model:

$$fa_{hp}^{*} = \gamma_1 sc_{hp}^{*} + \beta_1' X_1 + \varepsilon_f , \qquad fa_{hp} = 1(if \quad f\text{c} \tag{3}$$

$$sc_{hp}^{*} = \gamma_2 fa_{hp}^{*} + \beta_2' X_2 + \varepsilon_c , \qquad sc_{hp} = 1(if \quad sc \tag{4}$$

$$\left[\varepsilon_f , \varepsilon_c\right] \sim BVN\left[(0,0), \quad \sigma_f^2 , \sigma_c^2 , .\right.$$

where ρ is the correlation, σ_j is a standard deviation, and fa_{hp} (fa_{hp}^{*}) and sc_{hp} (sc_{hp}^{*}) are observed binary (latent) variables indicating the household's fertilizer and soil conservation adoption decisions. X_1 and X_2 are vectors of explanatory variables, and ε_f and ε_c are error terms for the respective equations.

There are three interesting aspects of this model. First, the two dependent variables (decisions) were observed as binary variables. Second, the binary dependent variable of the first equation was entered as covariate in the second equation and vice versa. Third, the unobserved heterogeneities of the two decisions were correlated. Maddala (1983) proposed an estimable two-stage bivariate approach that produces consistent and efficient parameter estimates. The reduced form that was used to produce consistent and efficient parameter estimates of the structural model is given by equation (5):

$$\left.\begin{aligned} fa_{hp} &= \pi_1^{'} X + v_f, \\ sc_{hp} &= \pi_2^{'} X + v_c, \end{aligned}\right\} \quad (5)$$

$$\left[v_f, v_c\right] \sim BVN\left[(0,0), \theta_f^2, \theta_c^2, \tau\right],$$

where τ is the correlation, θ_j is the standard deviation, and *X* is the union of exogenous variables in the system. The predicted values of fa_{hp} and sc_{hp} from the reduced form were used to estimate the structural bivariate model. Maddala (1983) derived a way to recover consistent estimates of the structural form of coefficients from the reduced form coefficients that took into account the cross equation relationships, and was, therefore, asymptotically more efficient than a single equation estimation. Since the consistent parameter estimates, and not actual values of fa_{hp} and sc_{hp}, were used in the estimation of the structural equations, the estimated asymptotic covariance matrix must be corrected.[2]

Like the standard simple probit model, an attempt to directly interpret the coefficients of a bivariate probit model is misleading, since the absolute scale of the coefficients gives a distorted picture of the response of the dependent variable to a change in the stimuli (Greene 1996). A general approach to calculating marginal effects in a bivariate probit model is illustrated in Greene (1996). In our model, ρ was not statistically different from zero (i.e., the two equations were independent). In this case, the marginal effects were easier to calculate since the joint probability would be the simple product of marginal probabilities. The unconditional expected value of *sc* and *fa* are given by equations (6) and (7), respectively.

[2] See Maddala (1983, 246–7) and LIMDEP (2002) on the identification of consistent parameter estimates and derivation of the asymptotic covariance matrix.

$$E[sc \mid X_1, X_2] = E_{fa} E[sc \mid X_1, X_2, fa] = prob[fa=1] E[sc \mid X_1, X_2, fa=1] + prob[fa=0] E[sc \mid X_1, X_2, fa=0]$$

$$= \Phi(\beta_1' X_1 + \gamma_1) \Phi(\beta_2' X_2 + \gamma_2) + \Phi(-\beta_1' X_1) \Phi(\beta_2' X_2), \qquad (6)$$

$$E[fa \mid X_1, X_2] = E_{sc} E[fa \mid X_1, X_2, sc] = \Phi(\beta_2' X_2 + \gamma_2) \Phi(\beta_1' X_1 + \gamma_1) + \Phi(-\beta_2' X_2) \Phi(\beta_1' X_1). \qquad (7)$$

4. Results and Discussion

The above models were estimated using survey data collected from 847 plots of 206 randomly selected households in 7 villages of highland Ethiopia. The households were located in five *weredas* (Machakel, Gozamin, Enemay, Tehuldere, and Kalu) of two different zones (Eastern Gojjam and South Wollo), one with high agricultural potential and the other with a history of recurrent drought and famine.[3] These households were part of a larger land-use survey that was conducted in 2000 and 2002. A separate experiment administered in 2002 estimated risk and time preferences among the farmers. In the risk experiment, households were confronted with six farming alternatives that differed both in expected outcomes and spread (risk levels) of good and bad outcomes. These six alternatives represented six levels of risk, where 1 was extreme risk aversion and 6 was risk-loving behavior, and the associated risk coefficients were calculated using a constant partial-risk aversion utility function.

On the other hand, in the rate-of-time preference experiment, households were confronted with choices of money that differed both in magnitude and time, from which the associated subjective discount rate (rate-of-time preference) was calculated for each farm household.[4] The basic descriptive statistics of the sampled households are provided in table 1.

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[3]A wereda (or woreda) is an administrative district of local government in Ethiopia. Weredas, which are made up of *kebeles*, or neighborhood associations, are typically collected together (usually contiguous weredas) into zones.

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[4] More detailed analyses on the measurement and determinants of risk and time preferences of the same sample of farm households are provided in Yesuf (2003a, 2003b).

Table 1 Basic Descriptive Statistics (n=847)

Variable	Description	Mean	Standard deviation
Technology adoption			
Conserve	A dummy where the household has adopted any soil conservation structure in the plot	0.26	0.44
Fert	A dummy where the household has used any modern fertilizer in the plot	0.43	0.50
Consfert1	A dummy where the household has adopted both soil conservation and fertilizer at the same time in the same plot	0.09	0.28
Consfert2	A dummy where the household has adopted both soil conservation and fertilizer at the same time in the same plot, given the household adopts either of the technologies in the plot	0.15	0.36
Tenure security			
Tenure	A dummy for expecting a reduction in land size over the coming five years due to any perceived reason	0.30	0.46
Factor-market participation	–	–	–
Formal credit	A dummy for borrowing any amount greater than ETB 50 in the last two years from formal sources	0.45	0.50
Plot and soil characteristics			
Steep slope	A dummy for steep-slope plots	0.28	0.45
Poor soil	A dummy for poor soil quality	0.24	0.43
Plot size	Plot size in hectares	0.27	0.20
Human capital			
Gender	A dummy for male-headed households	0.97	0.17
Age	Age of head of the household	46.49	14.51
Literate	A dummy for literate household heads	0.26	0.44
Family labor	Family size of the household	5.88	2.49
Behavioral measures			
Risk aversion	Constant partial risk aversion coefficient, measured in a separate experimental study	2.31	2.60
Time preference	Subjective discount rate, measured in a separate experimental study	0.42	0.34
Village-level factors			
Distown	Distance from homestead to nearest town in walking minutes	60.81	36.61
Machekel	Wereda1* dummy	0.29	0.45
Gozamin	Wereda2 dummy	0.24	0.43
Enemay	Wereda3 dummy	0.19	0.40

Tehuldere	Wereda4	dummy	0.12	0.32
Kalu	Wereda5	dummy	0.16	0.36

* A wereda is a group of contiguous villages or kebeles.

The results of a two-stage bivariate probit model of equations (3) and (4) that estimated soil conservation and fertilizer adoption decisions are shown in table 2. For purposes of comparison, parameter estimates of the standard univariate probit model are also provided in table 2. In all the models, the problem of multicollinearity was tested and found not to be serious (with variance inflation factors less than two in most cases). The resulting marginal effects of selected variables, which are decomposed into direct, indirect, and total effects, are separately provided in table 3.[5] In all the cases, standard errors for marginal effects were calculated using the delta method (Greene 2000).

The p-value of 0.224 for the test of ρ equals zero showed that the unobserved heterogeneities of both decisions were uncorrelated. This result, however, did not lead us to the conclusion that the two decisions were uncorrelated. Instead, a significant parameter estimate of the endogenous soil conservation variable in the fertilizer adoption equation showed that one of the important determinants (although negative) of whether a household adopts fertilizer was whether the same household has adopted soil conservation on that plot. The reverse causality, however, was insignificant. That is, a household's decision to adopt soil conservation did not depend on whether the same household adopted fertilizer. On the margin, controlling for other factors, households that adopted a soil conservation structure were 16 percentage units less likely to adopt modern fertilizers as well.

[5] Direct effect accounts for the direct impact of a change in an explanatory variable (X) on the probability of adopting fertilizer in equation (3) or soil conservation in equation (4). The indirect effect accounts for the impact of a change in the same explanatory variable (X) on fertilizer adoption in equation (3) via its effect on soil conservation, or soil conservation in equation (4) via its effect on fertilizer adoption.

Table 2 Determinants of Soil Conservation and Fertilizer Adoption Decisions

(Figures in parentheses are standard errors.)

Variable	Soil conservation adoption		Fertilizer adoption	
	Univariate probit	*Two-stage bivariate*	*Univariate probit*	*Two-stage bivariate*
Technology adoption				
Fertilizer adoption	0.196 (0.135)	0.009 (0.492)		
Soil conservation adoption			0.117 (0.129)	-0.277* (0.165)
Tenure insecurity				
Tenure perception	-0.143 (0.117)	-0.147 (0.127)	-0.065 (0.113)	-0.095 (0.116)
Factor-market participation				
Formal credit	0.040 (0.138)	0.082 (0.382)	0.651*** (0.109)	0.697*** (0.116)
Plot and soil characteristics				
Steep slope	0.624*** (0.113)	0.614*** (0.123)		
Poor soil			0.088 (0.111)	0.196 (0.139)
Plot size	0.616** (0.298)	0.686 (0.689)	1.264*** (0.273)	1.444*** (0.289)
Human capital				
Gender	0.950** (0.480)	0.920 (0.584)	-0.638** (0.283)	-0.376 (0.350)
Age	-0.014*** (0.004)	-0.014*** (0.005)	-0.006 (0.004)	-0.009** (0.004)
Literate	0.170 (0.128)	0.165 (0.148)	-0.133 (0.122)	-0.072 (0.130)
Family labor	0.038 (0.025)	0.038 (0.026)		
Behavioral measures				
Risk aversion			-0.025 (0.021)	-0.041* (0.024)
Time preference	-0.421** (0.199)	-0.428** (0.203)		

Variable	Soil conservation adoption		Fertilizer adoption	
	Univariate probit	***Two-stage bivariate***	***Univariate probit***	***Two-stage bivariate***
Access to market and road				
Distance to town	0.006*** (0.002)	0.006*** (0.002)	-0.002 (0.002)	-0.0001 (0.002)
Village dummies[+]				
Machakel	-1.830*** (0.245)	-1.760*** (0.559)	1.095*** (0.188)	0.493 (0.379)
Gozamin	-1.228*** (0.185)	-1.196*** (0.287)	0.472*** (0.189)	0.025 (0.304)
Enemay	-0.228 (0.166)	-0.229 (0.175)	-0.052 (0.185)	-0.193 (0.202)
Tehuldere	-0.186 (0.196)	-0.177 (0.202)	0.151 (0.198)	0.061 (0.224)
Intercept	-1.128** (0.580)	-1.055* (0.602)	-0.226 (0.412)	-0.408* (0.165)
Number of observations	847	847	847	847
R^2	0.275	-	0.210	-
Log-likelihood function	-351.18	-352.32	-458.46	-352.32
Rho	0.000	0.224	0.000	0.224

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

[+] Kalu is the reference village.

Table 3 Marginal Effects of the Two-Stage Bivariate Probit Model

(Figures in parentheses are standard errors. Kalu is the reference village.)

Variable	Direct	Indirect	Total	Type of variable, mean
Soil conservation adoption decision				
Tenure insecurity	-0.020 (0.023)	-0.014 (0.013)	-0.034 (0.029)	Binary, 0.30
Formal credit	-0.032 (0.072)	0.046** (0.019)	0.014 (0.065)	Binary, 0.45
Subjective discount rate	-0.104** (0.053)		-0.104** (0.053)	Continuous, 0.42
Plot size	0.167 (0.137)	0.177* (0.094)	0.344*** (0.089)	Continuous, 0.27

Variable	Direct	Indirect	Total	Type of variable, mean
Steep slope	0.124*** (0.033)		0.124*** (0.033)	Binary, 0.28

Variable	Direct	Indirect	Total	Type of variable, mean
Distance to town	0.001** (0.001)	-0.00001 (0.0003)	0.001** (0.001)	Continuous, 60.81
Literate	0.036 (0.033)	0.006 (0.013)	0.042 (0.041)	Binary, 0.2574
Gender	0.112*** (0.033)	0.031 (0.035)	0.142** (0.071)	Binary, 0.97
Age	-0.001 (0.001)	-0.003** (0.002)	-0.005*** (0.002)	Continuous, 46.49
Family labor	0.009 (0.007)		0.009 (0.007)	Continuous, 5.88
Fertilizer adoption	0.002 (0.033)		0.002 (0.033)	Endogenous, 0.43
Fertilizer adoption decision				
Tenure insecurity	-0.015 (0.035)	-0.014 (0.013)	-0.029 (0.040)	Binary, 0.30
Formal credit	0.195*** (0.045)	0.046** (0.019)	0.241*** (0.057)	Binary, 0.45
Risk aversion rate	-0.014* (0.008)		-0.014* (0.008)	Continuous, 2.31
Plot size	0.502*** (0.111)	0.101 (0.082)	0.603*** (0.112)	Continuous, 0.27
Poor soil quality	0.058 (0.041)		0.058 (0.041)	Binary, 0.24
Distance to town	-0.0001 (0.001)	0.001 (0.001)	0.001 (0.001)	Continuous, 60.81
Literate	-0.035 (0.039)	0.006 (0.013)	-0.029 (0.044)	Binary, 0.26
Gender	-0.187 (0.142)	0.031 (0.035)	-0.156 (0.139)	Binary, 0.97
Age	0.0004 (0.002)	-0.003** (0.002)	-0.003 (0.002)	Continuous, 46.49
Soil conservation adoption	-0.163** (0.081)		-0.163** (0.081)	Endogenous, 0.26

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

Although soil conservation and fertilizer adoption are complements in agricultural production, they are substitutes in terms of decision. Given the potential gains through complementarities of the two forms of technologies, this decision behavior of farm households in our sites looks perverse at a first glance. However, as in many other developing countries, farm households in the Ethiopian highlands work under severe cash liquidity and other resource constraints, which might force them to abandon one of the choices, even if adopting both at the same time would give higher yields. This behavior is consistent with the prediction of decision theory in economics where factor markets are imperfect (Feder et al. 1985). In that case, policies that enhanced the adoption of one component might retard the adoption of the other.

Among the exogenous variables included in our model, perception of tenure insecurity, family labor, educational level of farm households, and soil quality did not seem to explain variations in either of the two technology adoption decisions. Given other more binding constraints, such as resource poverty, cash liquidity, and lack of appropriate incentives, perception of tenure insecurity did not seem to deter farm technology adoption decisions. The current land tenure policy that advocates for continuous redistribution, however, had a strong indirect effect on technology adoption decisions through its effect on plot size and land fragmentation. In our model, this was captured by a separate variable called plot size. Farm households with bigger plot sizes were more likely to adopt new farm technologies. In the literature, this result was more often attributed to confounding factors, such as poor soil quality, fixed costs of implementation or adoption, credit access, or risk preferences (Feder et al. 1985). In our case, controlling for soil quality, access to credit markets, risk preferences and other factors, plot size still had a positive and significant impact on the decision to adopt either of the technologies. This result supports the neo-Malthusian argument that land redistribution and fragmentation resulting from ever-increasing population pressure does not lead to more intensification of farming.

Access to a formal credit market was found to be a major determinant of fertilizer adoption decisions, although it did not have a direct strong impact on the soil conservation adoption decision. Households with access to formal credit were 24 percentage units more likely to adopt fertilizer than those without access. Access to a credit market offers farm households the opportunity to obtain the resources necessary to adopt technologies. Given the fact that credit institutions in rural Ethiopia provide short-term credit only for productive activities or consumption smoothing (and nothing for long-term investments like soil conservation), our result showing a positive and significant effect on fertilizer adoption but not on soil conservation adoption decision was not surprising.

There are, however, two other indirect channels through which better access to credit and cash liquidity can affect both types of technology adoption decisions. First, better access to credit for productive, consumption, and other purposes will reduce consumption-smoothing problems and the subjective rates-of-time preference of farm households—a significant factor explaining variations in soil conservation adoption decisions in our study. This effect was captured by a separate variable called discount rate. Second, better access to credit and better cash liquidity can enhance technology adoption decisions by encouraging farmers to take risks. This effect was also captured in our model by a separate variable called risk aversion. In countries where credit and insurance markets do not function well or do not exist, and where households suffer from liquidity constraints and consumption-smoothing problems and are surrounded by a multitude of risks, people tend to have high subjective discount rates (higher than the market interest rate), and mimic risk-aversion behavior (Pender 1996; Yesuf 2003a, 2003b). Under these circumstances, variations in such behavioral measures are often major determinants of household investment decisions. This assertion in the literature was consistent with our findings that variations in farm households' rates-of-time preferences and degree-of-risk aversion explained a significant portion of variations in soil conservation and fertilizer adoption decisions, respectively.

Among soil characteristic indicators, only the slope of the plot seemed to explain significant variations in soil conservation adoption decisions. With regard to household characteristics, male-headed households were more likely to adopt soil conservation technologies than female-headed households, and older household heads were less likely to adopt soil conservation technologies than younger heads.

Finally, proximity to town seemed to affect the soil conservation adoption decision, but not the fertilizer adoption decision. Recall that the expected sign of the market access variable was ambiguous. In this case, the probability of adoption decreased with proximity to town. This was probably because households with closer proximity to a town had higher opportunity costs of labor than distant households. This made decisions to participate in labor-intensive soil conservation tasks more expensive to them.

Significant parameter estimates for many of the village dummies also depicted the role of village level factors, such as variations in geographic, climatic, cultural, and other factors, as important determinants of variations in adoption decisions.

5. Conclusions and Policy Implications

Land degradation and deterioration of agricultural productivity are major threats to current and future livelihoods of farm households in developing countries. Following this concern, governments and development agencies have invested substantial resources to promote rapid dissemination of yield-enhancing and soil-conserving technologies. The results so far, however, are discouraging because adoption rates are low and adoption is limited to certain villages and groups of farm households.

Although there is a growing literature looking into technology adoption decisions of farm households in developing counties, both theoretical and empirical studies that deal with the institutional and factor market imperfections behind such low adoption rates are scarce. Even more disturbing is the absence of any empirical study that looks into the possible links and synergies between different forms of technology adoption decisions. This is despite the fact that understanding the synergies across the different forms of technology adoption decisions might help policy makers and development agents exert more effective and better coordinated efforts to address the problem.

In this paper, we investigated the impacts of market and institutional imperfections on technology adoptions in a model that considers fertilizer and soil conservation adoptions as related decisions. Controlling for soil characteristics and other factors, we found that a household's decision to adopt fertilizer significantly and negatively depended on whether the same household adopted soil conservation. The reverse causality, however, was insignificant. On the margin, controlling for other factors, households that adopted soil conservation structures were 16 percent less likely to adopt modern fertilizer as well. For our sample households, these two technologies were thus found to be substitutes. This is consistent with decision theory in economics where factor markets are imperfect. The returns for using fertilizer would be much higher if farmers adopted soil conservation as well, since these structures help conserve soil moisture and reduce losses of such inputs from run-off. However, if the decision maker faced binding cash liquidity or credit constraints, the decision maker could neglect one technology in favor of the other, and thus any incentive that promoted the adoption of one might retard the adoption of the other. Under such circumstances, efforts should be geared toward relieving some of the constraints or searching for least-cost technologies that suit the resource base of the farm households, which could enable them to adopt the technologies and reap the benefits of the potential complementarities of farm technologies.

Most of the other factors that significantly affected either of the technology adoption decisions were reflections of the prevailing factor market and institutional imperfections in the study villages. Households with relatively high subjective discount rates and higher degrees of risk aversion were less likely to adopt soil conservation structures and modern fertilizers, respectively. These results are consistent with the poverty induced–environmental degradation argument in the literature that holds that in countries where poverty and environmental degradation are closely intertwined, and credit and insurance markets are imperfect or completely absent, the critical factors affecting sustainability of resource use are the extent to which people discount the future and their willingness to undertake risky investment decisions (WECD 1987; World Bank 1996). In an imperfect credit and insurance market environment, variations across households in these two behavioral measures were mainly explained by differences in households' physical and financial endowments.

Limited access to the formal credit market was another outcome of factor market imperfection. This variable strongly explained variation in fertilizer adoption decision, but not the soil conservation adoption decision. Households with better access to formal credit were 24 percent more likely to adopt modern fertilizers than those without access. Unlike the findings in other recent studies in Ethiopia (e.g., Alemu 1999; Gebremedhin and Swinton 2003), but consistent with the findings of Holden and Yohannese (2002) and Hagos and Holden (2003), we did not find tenure insecurity to be a significant determinant of either of the technology adoption decisions. Instead, we found that plot size and land fragmentation, which are direct results of the current Ethiopian policy of land redistribution, significantly and positively explain variations in both technology adoption decisions. This result seems to support the neo-Malthusian argument on population pressure, land size, and agricultural intensification.

This study generally showed the importance of investigating factor market imperfections to understanding farm household behavior in adopting yield-enhancing and soil-conserving technologies. In the short-run, any effort that reduces poverty and asset scarcity helps reduce a farm household's subjective discount rate and degree of risk aversion (Yesuf 2003a; Yesuf 2003b), which subsequently leads to dissemination of new farm technologies. In the long-run, broad-based economic development, including the development of credit and insurance markets, are needed to correct the existing market imperfections and reduce their negative impacts on different forms of farm investment decisions.

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