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RISK, TIME AND LAND MANAGEMENT UNDER MARKET IMPERFECTIONS: APPLICATIONS TO ETHIOPIA

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To my mother and father

Abstract

This Ph.D. thesis addresses both theoretical and empirical issues pertaining to land management decisions of farm households in developing countries working under an imperfect market and institutional setting (with case studies from Ethiopia). Using techniques in experimental economics, efforts are also made to assign some quantitative measures to the most important parameters (such as risk and time preferences) in the same decision making process.

Paper I: A Dynamic Economic Model of Soil Conservation with Imperfect Markets and Institutions

In this paper, we develop a dynamic soil conservation model that explicitly incorporates labor, capital and land market imperfections and their interactions to suit the problems of smallholders in many developing countries. We use the model to analyze the impact of these institutional and market imperfections on the optimal levels of labor allocations into cultivation and conservation efforts. Increased transaction cost in factor markets is found to have a direct impact on soil conservation effort by increasing its shadow prices and curtailing its demand. It also has an indirect impact on soil conservation by affecting the shadow price of the soil stock and hence enhancing or curtailing its demand depending on the initial factor endowments of farm households, the relative strength of conservation and cultivation inputs on the soil dynamics, the profit share of cultivation input, and the degree of interaction across the factor markets. The overall impact is thus inconclusive. Various possible scenarios are explored in the model.

Paper II: Risk Preferences of Farm Households in Ethiopia

This study measures farmers' attitudes towards risk using an experimental approach for a sample of 262 farm households in the Ethiopian highlands. We find more than 50 percent of the households in the severe to extreme risk aversion category, with a constant partial risk aversion coefficient of more than 2.00. With careful construction of the experiment, the natures of absolute and partial risk aversion are examined, and our data supports the presence of Decreasing Absolute Risk Aversion (DARA) and

Increasing Partial Risk Aversion (IPRA) behavior. The validity of some of the expected utility theory predictions is tested, and the predictions of risk neutrality for smaller stakes and predictions of similar preferences for gains and losses, which stem from the major tents of the theory (concavity and asset integration), are not supported by our experiment.

Paper III: Time Preferences of Farm Households in Ethiopia

This study measures farmers' time preferences (subjective discount rates) using an experimental approach with monetary incentives for a sample of 262 farm households in the Ethiopian highlands. The median discount rates are found to be more than 43 percent, which are more than double the interest rate on the outstanding debt. Given imperfect credit markets, household wealth (physical asset) levels are found to be highly correlated to this attitude measure. Time frame and magnitude effects, and delay/speed up asymmetries are anomalies found in the experiment.

Paper IV: Market Imperfections and Farm Technology Adoption Decisions: An Empirical Analysis

In this paper, we investigate the impacts of market and institutional imperfections on farm technology adoptions in a model that considers fertilizer and soil conservation adoptions as related decisions. Controlling for plot characteristics and other factors, we find that a household's decision to adopt fertilizers does significantly and negatively depend on whether the same household adopts soil conservation. The reverse causality, however, is insignificant. We also find outcomes of market imperfections such as limited access to credit, plot size, risk considerations, and rates of time preference to be significant factors explaining variations in farm technology adoption decisions. Relieving the existing market imperfections will more likely increase the adoption rate of farm technologies.

Key words: land degradation, market imperfections, transaction costs, soil conservation, fertilizer adoption, risk preference, time preference, experimental studies, Ethiopia.

Preface

My first inspiration into the field of Environmental Economics came from the African Economic Research Consortium's (AERC) joint-elective program that I took part in Nairobi in the summer of 1997. My vision to explore the area further might have vanished in the air and I would probably have pursued another field, if I had not been given a chance to join the capacity building PhD program at the Environmental Economics Unit (EEU), Department of Economics of Gothenburg University, in September 1999. For that I am very much grateful to the Swedish International Development Agency (Sida) for supporting the program financially, and the program organizers (Sida's desk officers at EEU), mainly Thomas Sterner and Gunner Köhlin, for their effective and wise execution.

Since I joined the program, I have been receiving continuous support and encouragement from Thomas Sterner. He taught me the exciting world of Environmental Economics, and kindly comforted my stay in Sweden with many social events including parties, skiing, and excursions. For that I will always be grateful. My very special thanks goes to my twin supervisors, Fredrik Carlsson and Gunnar Köhlin. In the process of writing the thesis and throughout my stay in Sweden, I gained relentless support, guidance and moral boosts from both of them. We have always been working with a smooth and fascinating team spirit. I couldn't imagine finishing the program on time without their support and encouragement. I look forward to working with them again and learning more from their wisdom of knowledge and kindness.

EEU is full of people with diversified backgrounds, and stimulating experiences. I benefited a lot from them through individual and group discussions over coffee breaks, lunch meetings and seminars. My fellow colleagues with whom I enjoyed exploring the first two years of course work: Astrid Nunez, Minhaj Mahmud, Nesima Chowdhury, Razack Bakari, and Wilfred Nyangena were the first people to have many interactions. Later on, when I started to engage in research work, I found Gunnar Köhlin, Fredrik Carlsson, Thomas Sterner, Olof Johansson-Stenman, Håkan Eggert, Peter Martinsson, and Anders Ekbom. They were always the first to comment on my papers in many of my seminars. I am very grateful for that. Other squads in the unit that in one way or another I feel connected to and received support from over the last five years include: Ada Jansen, Adolf Mkenda, Anabel Martinez, Anna-Karin Ågren, Björn Olsson, Daniel Slunge, Daniela Roughsedge, Edwin Muchapondwa, Elizabeth Földi, Eseza Kateregga, Francisco Alpizar, Gerd Georgsson, Hala Abou-Ali, Henrik Hammar, Innocent Kabenga, Jessica Andersson, Johanna Jussila, Jorge Garcia, Katarina Renström, Lena Höglund, Martin Linde-Rahr, Martin Visser, Mintewab Bezabih, Mohammed Belhaj, Precious Zikhali, Qin Ping, Rahimasisa Abdula, Susanna Lundström, Wei Jiegen, Wisdom Akpalu, and Åsa Löfgren. Thank you all!

I also benefited from discussions and comments from other professors and visitors in the department. In particular, I would like to thank Professor Lennart Flood for his comments on one of my papers. Comments and encouragements from Professor Gardner Brown, Professor Dale Whittington, and Professor Stein Holden were helpful in improving the quality of some of the papers in the thesis. My visit in the fall of 2003 to the Department of Agricultural and Resource Economics at the University of Maryland was very stimulating and fruitful in particular in shaping my theoretical paper. For that, I am very much indebted to Professor Kenneth McConnell for offering me his valuable time. An early fall visit to the Beijer Institute every year gave me a chance to meet very prominent professors in the field including the likes of Professors Kenneth Arrow, Partha Dasgupta, Karl-Göran Mäler, David Starret, Geoffrey Heal and many others. It was really a privilege to have presented our work and research ideas in front of them, and to listen to their encouraging words. I thank EEU and Karl-Göran Mäler and his Beijer colleagues for arranging such an opportunity.

I received various administrative help from the most kind and efficient administrators in the department including Ulla Mellgren, Eva Jonason, Eva-Lena Neth Johansson, Katarina Renström, and Elizabeth Földi. Thank you so much! Elizabeth Földi deserves extra words of thanks for her kind support and comfort for my family as well. *Amesegenalehu*! Debbie Axlid corrected the language and made the papers much better. Thanks!

The presence of my country fellows in the department, Abebe Shimeles, Mintewab Bezabih, Mulu Gebreeyesus, and Daniel Zerfu, makes me feel at home as we can always talk in local language about other aspects of life. This is not to forget the good friendship I had with Wilfred Nyangena. We not only discussed issues on soil conservation, but also spent good and unforgettable times together on many occasions. Thanks Wilfred for your friendship!

Last but not least, my very special gratitude goes to my family and my parents. First and foremost, my family, Zewditu and Sumaya, are always my sources of inspiration and joys. Thank you so much for your love, support and understanding. Next come my father and mother, who are from a humble educational background but always believed in education and in me. Their joint support, love and prayers for me throughout my life are priceless! Thank you for being there! This thesis is for you! My sister, Momina, has always been my counselor when stresses have built up in my system. Her therapy and support always inject fresh energy into my system. Thank you sister. I also got lots of support from my brothers and other sisters, which I could not mention their names since they are many in number. I have lots of friends outside Vasagatan, who shared their time with me and made my life in Sweden and vacation in Ethiopia enjoyable and full of fun. I don't have enough space to mention all the names. Thank you anyway!

On top of everything, I would like to thank God for giving me all the beautiful things in life and all the strength and endurance to accomplish my long journey in Sweden with this piece of work!

Despite the numerous suggestions and comments I received from people, I take full responsibility for any errors and omissions in the thesis.

Mahmud Yesuf
Göteborg, August 2004.

Contents

Introduction

Land degradation and deterioration of agricultural productivity are major threats to current and future livelihoods of farm households in many developing countries. Due to this, governments and development agencies have invested substantial resources for a better management of agricultural lands by promoting dissemination of yield-enhancing and soil-conserving technologies. The results so far, however, are discouraging as the adoption rates are low and adoption is limited to certain villages and groups of farm households.

Although there is a growing literature that looks into technology adoption decisions of farm households in developing countries, both theoretical and empirical studies that deal with the institutional and factor market imperfections behind such low adoption rates are scarce. Even the existing few empirical evidences are inconclusive and anecdotal in nature. In the empirical literature of farm technology adoption, the reasons for including certain variables such as farmers' wealth, household labor endowments, cash liquidity and off-farm income are not always clear, and the hypotheses about their effects are not clearly derived from a theory of investment behavior. If the assumption about a perfectly functioning market were satisfied, many of these variables would be irrelevant. Incorporating market imperfections into a theoretical model of soil conservation, therefore, clarifies why many household-specific variables are included in previous studies of soil conservation and why coefficients of similar variables may have different signs in different studies.

The first paper of this thesis provides a theoretical basis for why household-specific endowments are important in household land management decisions, and why similar variables may have different signs in different studies when decisions are made under imperfect market conditions and institutional constraints. The paper explicitly incorporates a more realistic market structure for developing countries into a dynamic soil erosion and soil conservation model. Three different household-specific market and institutional imperfections - labor, credit markets, and tenure insecurity are explicitly treated in a dynamic setting, and their impacts on land management decisions are analyzed. Labor and capital market imperfections are captured by way of transaction costs incurred to get access to the respective markets. Transaction costs are modeled as endogenous and household specific and as functions of household's asset endowments and village level factors. Land market imperfections are reflected through the variable benefits obtained from the scrap value of the land at the end of the planning horizon. Greater labor and credit market imperfections curtail the optimal level of soil conservation efforts directly through an increase in the shadow price of the conservation input and indirectly through the effect on the shadow price of the soil stock. It is shown that indirect impacts of market imperfections on soil conservation could either be negative or positive depending on the relative strength of conservation and cultivation efforts on the soil dynamic, and the contribution of cultivation input to the farm profit. The total effect thus is ambiguous. Various possible scenarios are explored in this paper.

The impact of tenure status or type of land ownership on soil conservation adoption decisions is also found to be ambiguous. It is shown in the paper that more secure tenure status guarantees greater benefits from the scrap value of the farm at the end of the planning horizon, and hence motivates more investment in soil conservation. But if land is tradable and serves the purpose of collateral, more secure tenure might lead to cheaper access to the credit market for the purchase of cultivation inputs which degrades the soil and hence reduces efforts in soil conservation. In the absence of the latter effect, a more secure land tenure system is more likely to boost investment in soil conservation. The only parameter that unambiguously discourages investment in soil conservation is an increase in the discount rate of farm households. A rise in the household's discount rate reflects a preference to meet short-term livelihood requirements, which may in turn compel the household to adopt a myopic behavior that discourages investment in soil conservation. Thus, theoretically any policy option that reduces farm households' subjective discount rates encourages long-term farm investments such as investments in soil conservation.

Although the role of time preferences (subjective discount rate), and uncertainty (risk) in land management decisions have been discussed in theoretical literature, their empirical application has been limited due to difficulties in measurements. In papers two and three, we use techniques from experimental economics to reveal and quantify risk and time preferences of farm households in the Ethiopian highlands. We design the experiments so as to resemble actual farm investment decisions, and provide the necessary monetary incentives to the farm households in order for them to reveal their true preferences. We find that the majority of the farm households in the Ethiopian highlands are rather risk averse and that their subjective discount rates are more than double the interest rate on their outstanding debt. The median constant partial risk aversion coefficient and subjective discount rate are found to be more than 2.00 and 43%, respectively, which are excessively high by any standard. Given imperfect credit and insurance markets, household wealth (physical asset) levels are found to be highly correlated to the two behavioral parameters. We also use the experiments to test whether some of the predictions of the expected and discounted utility theories hold in reality, and find a number of anomalous results.

The high degree of risk aversion and excessive discount rates found in the experiments led to the next research agenda in the thesis that tries to answer the following questions: (i) Does the excessive subjective discount rate significantly explain why many of the farm households in Ethiopia disregard farm investment decisions that entail short-term costs but long run benefits, like investments in soil conservation? (ii) Does the high degree of risk aversion explain why many farm households in Ethiopia are reluctant to adopt new production technologies such as chemical fertilizers even when these technologies provide higher returns to land and labor than traditional technologies? (iii) Does tenure insecurity affect new farm technology adoption decisions given that farm households are facing other overriding constraints like poverty and asset scarcity? (iv) Do farm households consider adopting both fertilizer and soil conservation technologies on the same plot to reap the potential production gain from complementarities of the two technologies or do they abandon (substitute) one in favor of the other since they are constrained due to market imperfections?

Fertilizer and soil conservation adoption decisions are related decisions. The returns to soil conservation would be much higher if farmers adopted fertilizers as well and vice versa since the structures could help in conserving soil moisture and reduce losses of other inputs through runoff. However, it might also be possible that a farmer would abandon one of the technologies in decision in favour of the other even if adopting both at the same time could be more beneficial in production. This could happen when the farmer faces a binding resource or liquidity constraint or in general market imperfections in his/her investment decisions. Our findings in the fourth paper, based on a bivariate simultaneous equation model on fertilizers and soil conservation decisions, are consistent with this assertion. Although soil conservation and fertilizer are complementary in production, we find them to be substitutes in decisions. Controlling for plot characteristics and other factors, we find that a household's decision to adopt fertilizers negatively depend on whether the same household adopts soil conservation. Despite the benefits from complementarities, few households adopt both technologies on the same plot in the studied villages. Most of the other factors that significantly affect either of the technology adoption decisions are reflections of the prevailing factor market and institutional imperfections. Households with relatively high subjective discount rates are less likely to adopt soil conservation. Risk averse households are also less likely to adopt modern fertilizers. Households with better access to formal credit are more likely to adopt modern fertilizers than those without access. Unlike the findings in other recent studies in Ethiopia, we do not find any significant effect of tenure insecurity per se on the technology adoption decisions. Instead, we find that plot size and land fragmentation, which are direct results of land redistribution in the current land policy in Ethiopia, significantly and positively explain variations in both of the technology adoption decisions.

In general, this thesis underscores the importance of investigating factor market imperfections in understanding farm households' behaviours in land management decisions. Factor market imperfections compel poor farm households to discount the future excessively, disregard any investment ventures involving some degree of risk, and as a result obliged them to act in a seemingly perverse and environmentally destructive and yet rational manner. Any effort to relieve some of the constraints or imperfections would reduce the subjective discount rate and risk levels and enable the farm households to manage their land in more productive and sustainable manner.

A Dynamic Economic Model of Soil Conservation with Imperfect Markets and Institutions[+]

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Abstract
In this paper, we develop a dynamic soil conservation model that explicitly incorporates labor, capital and land market imperfections and their interactions to suit the problems of smallholders in many developing countries. We use the model to analyze the impact of these institutional and market imperfections (mainly through changes in transaction costs in factor markets) on optimal levels of labor allocations into cultivation and conservation efforts. In the model, labor allocated to cultivation is assumed to enhance crop production in the short run and degrade the soil stock in the long run, whereas conservation has no impact on production in the short run, but improves the soil resources in the long run. Increased transaction cost in factor markets is found to have a direct impact on soil conservation efforts by increasing its shadow prices and curtailing its demand. It also has an indirect impact on soil conservation by affecting the shadow price of the soil stock and hence enhancing or curtailing its demand depending on the initial factor endowments of farm households, the relative strength of conservation and cultivation inputs on the soil dynamics, the profit share of cultivation input, and the degree of interaction across the factor markets.

Key Words: Institutional and market imperfections, Land degradation, Optimal control, Soil conservation, Transaction costs.

JEL Classification: C61, D43, Q21, Q24

[+] The author thanks Kenneth McConnell for frequent discussions and valuable comments. Comments from Gardner Brown, Stein Holden, Gunnar Köhlin and Fredrik Carlsson in the later version of the paper were also valuable. Financial support from Sida is also greatly acknowledged.

1. Introduction

Soil erosion is a widespread problem in many developing countries, causing substantial losses of land productivity (Hurni, 1993), and siltation of rivers and reservoirs (Burch et al., 1987; Troeh et al., 1991). In some countries, including Ethiopia, the problem of soil erosion has constituted a major hindrance to rural development and a threat against future livelihood (Hurni, 1993; Scherr and Yadav, 1996). In the past, many of the well-intended efforts and projects to combat soil erosion in these countries have shown little success as adoption and maintenance of introduced conservation technologies has been limited. In these projects, the basic causes of soil erosion have not been efficiently tackled, and the problem has too often been seen as a narrow technical one (physical process), rather than a socio-economic one (Bojö, 1991). Research into market and institutional factors behind this excessive soil degradation of small holders in developing countries is scanty and fragmented. The existing empirical evidences on the impact of market and institutional constraints on the adoption and level of use of soil conservation efforts contain mixed results.

In the theoretical literature, the problem of soil erosion and soil conservation is frequently analyzed through optimal control models, since the choice is inherently a dynamic one, involving both inter-temporal and intra-temporal tradeoffs (see McConnell, 1983; Barbier, 1990; Barrett, 1991; LaFrance, 1992). Many of these models assume a perfectly competitive market structure. However, rural markets and institutions in developing countries are generally poorly developed and characterized by high transaction costs due to high transportation costs, high search, recruitment and monitoring costs, and limited access to information, capital and credit (de Janvry et al., 1991; Sadoulet et al., 1996). In such circumstances, farmers' rational responses to policies and market incentives might differ and can even be contrary to what would be expected in conditions of perfectly functioning markets (de Janvry et al., 1991; Bulte et al., 1999; Readon et al., 2000). To our best knowledge, no published theoretical work except the one by Pender and Kerr (1998) explicitly incorporates the issue of factor market imperfections in analyzing incentives and constraints of soil erosion and soil conservation. Pender and Kerr (1998) treat the issue of market imperfection using a two period model, and assume missing labor and capital markets. A missing market is an extreme case of market failure. However, in many developing countries the market exists but the transaction costs and therefore market imperfections differ between households and hence the gains from market participation for a particular household may be below or above costs with the result that some households will use the market while others will not. This makes market imperfections household specific rather than commodity specific (de Janvry et al., 1991).

In the empirical literature of soil conservation, the reasons for including certain variables such as farmers' wealth, household labor endowments, and off-farm income are not always clear, and the hypotheses about their effects are not clearly derived from a theory of investment behavior. Many of these variables would be irrelevant if the perfect market assumptions were held. Incorporating market imperfections into a theoretical model of soil conservation therefore clarifies why many household-specific variables are included in previous studies of soil conservation and why coefficients of similar variables may have different signs in different studies.

This paper is an attempt to explicitly incorporate the more realistic market structure of developing countries into a dynamic soil erosion and soil conservation model. Three different household-specific market and institutional imperfections[1] - labor, credit markets, and tenure insecurity - and their interaction are explicitly treated in a dynamic setting. The study focuses on analyzing the impact of relaxing or tightening these market and institutional constraints on the use of labor devoted to cultivation and conservation activities both at the temporary and steady state equilibrium. This kind of study can help policy makers in the design of more effective conservation policies and programs. The rest of the paper is organized as follows. In Section 2, we assess issues in the literature on the link between market and institutional constraints and soil conservation decisions. Section 3 deals with the model. In Section 4, we derive and discuss market and institutional constraints and incentives by way of comparative static analysis both at the temporary and steady equilibrium states. Conclusions and policy implications are drawn in Section 5.

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[1] Although market imperfections are defined in several ways in the literature, throughout the paper, we define market imperfections or constraints as a situation where trade between two parties cannot take place without incurring a transaction cost, TC>K, where K is transaction cost under a perfectly competitive market structure.

2. Market and institutional imperfections and soil conservation decisions

The separable household model in Singh et al. (1986) was an important benchmark approach to the analysis of rural economies. This model is developed based on the assumption of perfect markets, except for one market, that of land. Later on, de Janvry et al. (1991) developed a more general theoretical rural model, allowing for market imperfections in rural economies. This later model is widely applied to test for the presence of market imperfections and the efficiency of factor use in many poor rural household economies (see Udry, 1996; Barrett, 1999; Gavian and Fafchapms, 1996; Gavian and Ehui, 1999; Holden et al., 2001). Since these studies are static in nature and focus only on cultivation inputs, they do not explicitly discuss the impact of market imperfections on the use of soil conservation and its subsequent effect on the shadow price of the soil. Since the problem of soil erosion and the decision to adopt soil conservation technologies involve inter-temporal trade-offs, a dynamic soil conservation model is an appropriate benchmark approach to deal with these problems. As mentioned, most of the dynamic soil conservation models in the literature are developed under the assumption of a perfectly competitive market structure for one or all of the farm inputs despite the fact that many developing countries that are highly hit by the problem are operating in poorly developed market conditions. The purpose of this section is therefore to indicate the major sources of these market imperfections, and their impact on soil conservation investments.

2.1 Labor market imperfections and soil conservation

In many developing countries there are a number of factors that limit the availability and accessibility of rural labor markets, e.g. poor infrastructure, dispersed settlement patterns, overlapping seasonal demands of labor across households, and search and monitoring costs.

High transaction costs of accessibility lead to a divergence between the effective wage received when selling labor and the effective wage paid when hiring labor. This creates wide idiosyncratic price bands around the market wage (Sadoulet et al., 1996). de Janvry et al. (1991) show how price bands caused by transaction costs affect the labor markets. When the shadow wage rate falls within this price band, it is more advantageous for the households not to trade labor, and thus to be self-sufficient in labor supply. If the shadow wage is above the price band, then the households should hire in labor until the shadow wage that equates supply and residual demand of labor for home production falls to the purchase price of labor. If the shadow wage is below the price band, then the household should sell out labor until the shadow wage rate that equates residual supply (after sale of a marketed surplus) and demand rises to the sale price of labor.

When a farm technology is labor intensive and labor markets are fully or partially missing, its adoption becomes less attractive for households with low initial labor endowment. Thus, labor market constrained households would be forced to allocate farm labor sub-optimally compared to households facing perfectly working labor market conditions. Since soil conservation is highly labor intensive in many developing countries, adoption of conservation practices and the subsequent effect on soil quality, among other things, would depend on the nature of labor market conditions. Holden et al. (2001) find evidence of market imperfections in labor markets in Ethiopia leading to differences in farm profitability among farm households that only differ in their initial labor endowments.

Reductions of labor market constraints affect soil conservation decisions through different channels: directly through the provision of the necessary labor for conservation activities (positive effect) and indirectly through the provision of off-farm income (positive or negative effect). Off-farm income may affect soil conservation decisions in several ways. Access to off-farm income may provide resources for soil conservation as the liquidity constraint may be relieved. Increased cash liquidity also reduces the individual discount rate, which in turn triggers long-term investment decisions like soil conservation. Involvement in off-farm activities, however, may take labor directly away from conservation activities and weaken soil conservation efforts if hired labor is an imperfect substitute for family labor and there are significant search and monitoring costs related to hiring of labor. The effect of relaxing labor market constraints on soil conservation is, therefore, much more complicated than an equivalent change in the price of conservation input derived in the traditional land use models with perfect market assumptions.

2.2 Credit market imperfections and soil conservation

Due to asymmetric information, problems of collaterals, and high fixed costs of lending, formal rural credit markets are not well functioning in many developing countries (Stiglitz and Weiss, 1981). Land is supposed to be the major form of collateral in many rural credit markets. But due to tenure insecurity and non-tradability of land, it does not serve that purpose in many developing countries including Ethiopia. Since small farm households have very limited access to the rationed and commodity specific government credit, they rely on informal lenders to finance most of their production activities and consumption smoothing. Due to high risk of default and enforcement problems, credit from the informal markets are obtained at excessively high interest rates.

In many developing countries, soil conservation is a labor-intensive task. Hence at first glance, imperfections in the credit market might seem to be of lesser importance in conservation decisions unless credit is needed to hire labor. But there are three other important channels through which credit market imperfections affect soil conservation decisions. First, an improved liquidity through better access to credit implies more use of cultivation inputs such as fertilizers and pesticides, which in turn affects cultivation intensity and labor allocation decisions. Second, better access to capital markets will reduce consumption smoothing problems and the subjective rates of time preference of farm households. In the absence of better access to credit, personal rates of discount would be higher and individual farmers would fail (even with complete information and property rights) to undertake investments with rates of return lower than their subjective rates of discount (Pender, 1996; Holden et al., 1998; Yesuf, 2003a). Third, the absence of credit for consumption purposes, which serves as a form of insurance, also inhibits productive development (as well as food security) by causing farmers to be highly risk averse when considering the use of new technologies and inputs. The estimated average rate of discount and constant partial risk aversion coefficient for farm households in the Ethiopian highlands, for example, were more than 43 % and 2.00 respectively (Yesuf, 2003a; 2003b). Unlike the traditional soil use models, when credit market imperfections are considered, a change in the cost of borrowing through a better or tighter access to the credit market affects the soil conservation efforts through several channels (some are opposite to each other), and the final effect is thus neither simple nor obvious.

2.3 Tenure insecurity and soil conservation (land market imperfections)

Insecurity of land rights is generally regarded as an important deterrent to conservation investment (eg. See Southgate et al., 1990; Scherr and Yadav, 1996), which has been confirmed through empirical adoption studies (e.g. See Besley 1995; Alemu, 1999). Private land rights may be incomplete or insecure due to temporal attenuation (e.g. short term leasehold), spatial attenuation (e.g. use rights that restrict the type of land use), lack of transferability (usufruct rights) or a combination of all of these (Feder et al., 1985; Feder and Feeny, 1991). When the system of property rights fails to provide sufficient security to private agents to reap the future benefits from their investments, they may fail to undertake otherwise profitable and environmentally benign investments.

Apart from its direct effect of providing incentives to undertake long-term investment ventures like soil conservation, properly secured tenure with tradable or transferable rights reinforces soil conservation efforts by relaxing the credit market constraints through the provision of collateral in the credit market.

All the traditional soil use models derived their policy relevant comparative statics based on the assumption of properly secured tenure status of farm households. One exception to these is the work of McConnell (1983) in which the end of period of land value is specified to depend on soil quality and tenure arrangements.

3. The Model

In what follows, we develop a dynamic model of soil conservation. This model is an adoption of the traditional dynamic soil conservation model by McConnell (1983), Barbier (1990), Barrett (1991), LaFrance (1992), Grepperud (1997), and Shiferaw and Holden (1998). This model extends these traditional models by introducing multiple factor market imperfections. We explicitly incorporate three different kinds of market imperfections to reflect the actual market structure of many developing countries. Labor and credit markets and tenure insecurity, and their interaction are explicitly treated in a dynamic setting. The main additions to the standard traditional soil use models are briefly described below.

a) Labor market imperfection: If the farm household's initial endowment of labor, $\bar{N}$, is lower than labor employed in cultivation (N^p) and conservation (N^c) activities, then the farm household hires in N^m units from the market; otherwise the household hires out the surplus labor to an off-farm activity.

$$N^p + N^c = \bar{N} + N^m \tag{1}$$

However, the farm household is constrained to access the labor market due to an increase in the transaction cost (T^{LM}) of hiring an additional unit of labor or an increase in the transaction cost of finding access to employ the surplus labor in any kind of off-farm activity. This transaction cost is set in an implicit function and is assumed to be increasing with the quantity of labor demanded or supplied (N^m), and increasing /decreasing with geographic factors, search and monitoring costs which are denoted by a vector (I).

$$T^{LM} = T^{LM}(N^m, I) \tag{2}$$

For simplicity, we assume zero fixed costs, and hence $T^{LM}(0, I) = 0$.

b) Credit market imperfection: Due to asymmetric information, problems of collateral, and a high fixed cost of lending, the small farm households have limited access to the rationed and commodity specific government credit. They rely on informal lenders to finance most of their productive investment activities and consumption smoothing tasks. Due to a high risk of default and enforcement problems, credit from the informal markets are obtained at high interest rates. The interest rates levied over and above the formal government specific credit (r^M) is reflected in the cost of borrowing by T^{CM} (an implicit function), which depends on total supply of rural credit (Q), tenure status

(θ), labor market conditions (particularly availability of off-farm income) and physical asset holdings (A) (including livestock) of the borrowers. Transaction cost in the credit market is assumed to be a decreasing function of total supply of credit in the village (Q), tenure status of the household (θ), and the farm household's asset holdings (A), but increases with tight labor market conditions (β). A well-functioning labor market relieves the cash liquidity constraints of the farm households through the provision of off-farm income. Households with better tenure status and strong wealth standings are more likely to face lower interest rates in the credit markets since their land and wealth (mainly livestock) serve the purpose of collateral for borrowing.

In farming activities of many developing countries, there is a lag between expenditure and revenue. Many inputs are bought on credit early in the farming season and paid back later after harvest. Thus, farm credits including commodity specific government credits are given in advance early in the farming season and debts are paid back immediately after harvest. This makes credit essential in our model.

In both (a) and (b), the market imperfections create a divergence between buyer's and seller's prices (create price bunds), and hence a necessary condition for the farm household to participate in the labor market is $W^M \le \left(w + T^{LM}\right)$ when they are net buyers and $W^M \ge \left(w + T^{LM}\right)$ when they are net sellers, where w^M is the market wage rate, and w the shadow wage rate with zero transaction cost (equivalent to a market wage rate under perfect labor market assumption). Similarly, a necessary condition for participating in the credit market is $r \ge \left(r^M + T^{CM}\right)$ when they are net borrowers and $r \le \left(r^M + T^{CM}\right)$ when they are net lenders, where r is the shadow interest rate and r^M the commodity specific government credit interest rate. This kind of setup makes market participation an endogenous and household specific rather than a commodity specific decision, which is missing in many empirical studies on soil conservation.

Given an output price, *p*, the profit function of the farm household that incorporates the above market imperfections is given by the following equation:[2,3]

[2] For notational conveniences, time indices are suppressed.

[3] In our model we assume the output markets to be prefect. Imperfections and transaction costs are considered only for the factor markets.

$$\pi(t) = \int_0^T \left[pf(N^p, S) - w(1 + r^M + \alpha T^{CM}(Q, \theta, \beta, A))N^m - \beta T^{LM}(N^m, I) \right] e^{-\delta t} dt \,. \tag{3}$$

Our specification of the production function is similar to that of Barbier (1990) where output is a function of cultivation input (labor) and an index of productive capacity of the soil that depends on the depth as well as the stock of physical and chemical characteristics of the soil. Since credit taken early in the farming season is paid back immediately after harvest, costs on the purchase of cultivation inputs include interest payments including transaction costs incurred in the process of obtaining credit. Purchased labor is also subjected to search and monitoring costs which is indicated by the implicit labor market transaction cost function, T^{LM}. Note that α and β are simply theoretical constructs that are used later to derive the comparative statics. An increase in α and β signifies an increase in the transaction cost of accessing the credit and labor market, respectively.

The production function, $f(\cdot)$, is twice continuously differentiable and satisfies $f_{N^p} > 0$, $f_S > 0$, $f_{N^pN^p} < 0$, $f_{SS} < 0$, f_{N^pS}, $f_{SN^p} > 0$. Current output increases with cultivation efforts, and soil quality index. Both inputs are subjected to the law of diminishing marginal returns, and one input enhances the marginal productivity of the other.

c) Tenure insecurity: At the end of the planning horizon, the farm household collects scrap value from the sale of the land, $R(T)$, which depends on the tenure status (θ) of the farmer, and soil quality (S).[4] θ takes a value between 0 and 1. In the extreme case where $\theta = 1$ (highly secured tenure), the farm household gets the full benefits of the scrap value. If $\theta = 0$, then the farm household gets nothing from the scrap value. In the intermediate case where $0 < \theta < 1$, the farm household gets a portion of the salvage value depending on the tenure arrangement. The intermediate case, where $0 < \theta < 1$, represents for example the type of land policy in Ethiopia today where land is owned by

[4] The planning horizon, *T*, could either be the life span of the farm household (for owner operated farms), the duration of the contract (for leased farms) or duration of user rights with some probability of losing the rights (for government owned farms).

the state and farmers are given only user rights, and are unsure whether they could hold their land in the future. Tenure insecurity in this context is defined as the perceived probability or likelihood of loosing ownership of a part or the whole of one's land without his/her consent.

A strong bequest motive or a smoothly functioning land market induces the farmer to value $R(T)$ as part of his income stream.

$$R(T) = \theta R(S(T))e^{\delta T} . \tag{4}$$

The soil dynamics can be described by the following equation, where *G* is a natural soil regeneration rate, and $h(.)$ a twice continuously differentiable implicit function of soil erosion.

$$\dot{S} = G + h(N^p, N^c) \tag{5}$$

Like many of the traditional soil use models, we assume $h_{N^p} < 0$, $h_{N^c} > 0$, $h_{N^c N^c}, h_{N^p N^p} < 0$, $h_{N^p N^c}, h_{N^c N^p} < 0$. The use of cultivation inputs is assumed to degrade the soil and conservation inputs to save the soil. The routine farming practices such as plowing, and planting are believed either to break the structure of the soil and expose it to different agents of erosion or contaminate the soil which affects its fertility characteristics without a decline in the soil depth (see Troeh et al., 1991; Burch et al., 1987; and LaFrance, 1992 for further details). Soil conserving input is also assumed to counteract the soil degrading effect of the cultivation input and vice versa.

Assuming complete foresight about the consequences of the actions on the productivity of the land, and given a farming technology, the problem that the farm household faces is to make a decision on allocating his/her labor time into cultivation and conservation activities on a given piece of land so as to maximize its farm profit (Equation 3) and end of period land value (Equation 4), given the equation of motion for its soil loss (Equation 5), an initial soil quality index of S_0, and total labor time availability (Equation 1).

Maximization of Equation (3+4) subject to (1) and (5) is a standard optimal control problem with scrap value. The current value Hamiltonian for this problem is given by

$$H^c = pf(N^p, S) - w\left[(1 + r^M + \alpha T^{CM}(Q, \theta, \beta, A)\right](N^p + N^c - \bar{N}) - \beta T^{LM}(N^p + N^c - \bar{N}, I) + \lambda(G + h(N^p, N^c)). \tag{6}$$

Assuming an interior solution, the maximum principle and the transversality conditions for this problem then become

$$\left.\begin{aligned} &H_{N^p} : pf_{N^p} - w(1 + r^M + \alpha T^{CM}) - \beta T^{LM}_{N^p} + \lambda h_{N^p} = 0 \\ &H_{N^c} : -w(1 + r^M + \alpha T^{CM}) - \beta T^{LM}_{N^c} + \lambda h_{N^c} = 0 \end{aligned}\right\} \tag{7}$$

$$\left.\begin{aligned} &\dot{\lambda} - \delta\lambda = -pf_s \\ &\dot{S} = G + h(N^p, N^c) \end{aligned}\right\} \tag{8}$$

$$\lambda(T) = \partial\theta R(S(t)) \big/ \partial S(T) = \theta R_S(S(t)) > 0. \tag{9}$$

In order for the maximum principle conditions (7) and (8) and the transversality condition (9) to be sufficient for a global maxima, the Mangaserian sufficient condition requires the Hamiltonian to be concave in (N^p, N^c *and* λ) for all t, or the maximized Hamiltonian evaluated at N^{p*}, N^{c*} to be concave in λ for all t (Seierstad and Sydsaeter, 1987).

The maximum principle conditions indicate the rules for optimal allocation of labor for cultivation and conservation activities. By increasing marginal costs, market imperfections rigidify the existing low responses of farm level adoption of soil conservation technologies in the same way as the rigidify supply responses as discussed in the farm household model of de Janvry et al. (1991). According to the first equation in (7), labor for cultivation activities will be used until its value of marginal product (pf_{N^p}) equals its marginal cost which is composed of direct wage payment, adjusted by the market interest rate and transaction cost of borrowing ($w(1+r^M+\alpha T^{CM})$), direct user costs to the soil stock through increasing depreciation of the land (λh_{N^p}), and indirect costs in terms of marginal additions to the transaction cost of the labor market due to higher demand in purchased labor ($\beta T^{LM}_{N^p}$). Similarly, according to the second equation in (7), labor for conservation activities will be used until its direct positive contribution to the soil quality (λh_{N^c}) is equalized to costs in terms of direct wage payment, adjusted for the market interest rate and the transaction cost of borrowing ($w(1+r^M+\alpha T^{CM})$), and indirect costs through increased transaction costs of the labor market due to higher demand in purchased labor ($\beta T^{LM}_{N^c}$). Re-arranging the first equation in (8) gives the standard Hotelling's rule for holding the soil stock. Soil is an asset, and hence in equilibrium, the returns from holding this stock in terms of capital gains $\left(\dot{\lambda}/\lambda \right)$ and contribution to current profit $\left(pf_s(.)/\delta \right)$ must be equal to the returns from other assets (δ). Therefore, the shadow price of the soil (λ) must grow at the rate of discount less soil's contribution to the current profit.

The transversality condition in (9) indicates that it is uneconomical for the farm household to deplete the soil near the end of the planning horizon if the shadow price of the soil is below the marginal return from the resale value of the land. This condition holds only if the farm household has a well-secured tenure status ($\theta > 0$) and is hence aware of the soil's contribution to both current production and the resale value of the farm. In the absence of a well-secured tenure ($\theta = 0$), the farm household depletes the soil towards the end of the planning horizon until the shadow price of the soil is zero. Various forms of tenure arrangements influence soil conservation efforts and the state of soil stock by affecting the shadow price of the soil stock.

4. Analysis of market and institutional constraints/incentives to soil conservation

The purpose of this section is to analyze a farm household's response to different market and institutional imperfections in terms of soil conservation decisions. Of particular interest are impacts of changes in transaction costs of accessing labor and credit markets, and changes in the degree of tenure security on the steady state level of soil conservation efforts. Most of the market-based incentives (such as changes in output and input prices) are discussed in the traditional dynamic soil use models and are hence excluded in our analysis (see for example McConnell, 1983; Barbier, 1990; Barrett, 1991; LaFrance, 1992; Grepperud, 1997; and Shiferaw and Holden, 1998).

Totally differentiating the maximum principle conditions in (7) and re-arranging in matrix notation, we get the following:

$$[J]\begin{bmatrix} dN^p \\ dN^c \end{bmatrix} = \begin{bmatrix} f_{N^p}dp - (1+r)dw - wdr^M - wT^{CM}d\alpha - (w\alpha T_\beta^{CM} + T_{N^p}^{LM})d\beta - h_{N^p}d\lambda - pf_{N^pS}dS \\ -(1+r)dw - wdr^M - wT^{CM}d\alpha - (w\alpha T_\beta^{CM} + T_{N^c}^{LM})d\beta - h_{N^c}d\lambda \end{bmatrix}$$

where,

$$r = r^M + \alpha T^{CM}$$

$$[J] = \begin{bmatrix} H_{N^pN^p} & H_{N^pN^c} \\ H_{N^cN^p} & H_{N^cN^c} \end{bmatrix} = \begin{bmatrix} pf_{N^pN^p} + \lambda h_{N^pN^p} & \lambda h_{N^pN^c} \\ \lambda h_{N^cN^p} & \lambda h_{N^cN^c} \end{bmatrix}. \tag{10}$$

Strict concavity of the Hamiltonian requires that $|J| > 0$. The following list summarizes the signs of the second order derivatives of the Hamiltonian for this problem (see LaFrance, 1992 for details): $H_{N^pN^p}, H_{N^cN^c} < 0$; $H_{N^cN^p}, H_{N^pN^c} < 0$;

$H_{N^pN^c}, H_{N^cN^p} > H_{N^pN^p}$ *or* $H_{N^cN^c}$ in absolute values.

Steady state solutions are obtained in stages. First, the conditions in (7) are solved to obtain N^p and N^c as functions of λ and *S*. Next, the conditions in (8) are set to zero, and steady state values of λ and *S* are calculated. Because of complexities in finding analytical solutions of λ at the steady state (given our general specification of the various functions), we use phase diagrams to discuss the direction of changes in λ due to changes in the market and institutional parameters.

Substituting the optimal values of N^p and N^c into the conditions in (7), we obtain the following isoclines:

$$\left.\begin{aligned} \dot{\lambda} &= \delta\lambda - pf_S(N^p(\lambda, S, \xi), S) \\ \dot{S} &= G + h(N^p(\lambda, S, \xi), N^c(\lambda, S, \xi)) \end{aligned}\right\} \qquad (8')$$

where ξ is a vector of market, transaction, and household parameters. At steady state, $\dot{\lambda} = \dot{S} = 0$, and totally differentiating (8') with respect to λ and *S*, we obtain the slope of the two isoclines above. The phase diagram, the slope of its isoclines, and inter-temporal movements out of the steady state are derived and attached in Appendix A2.

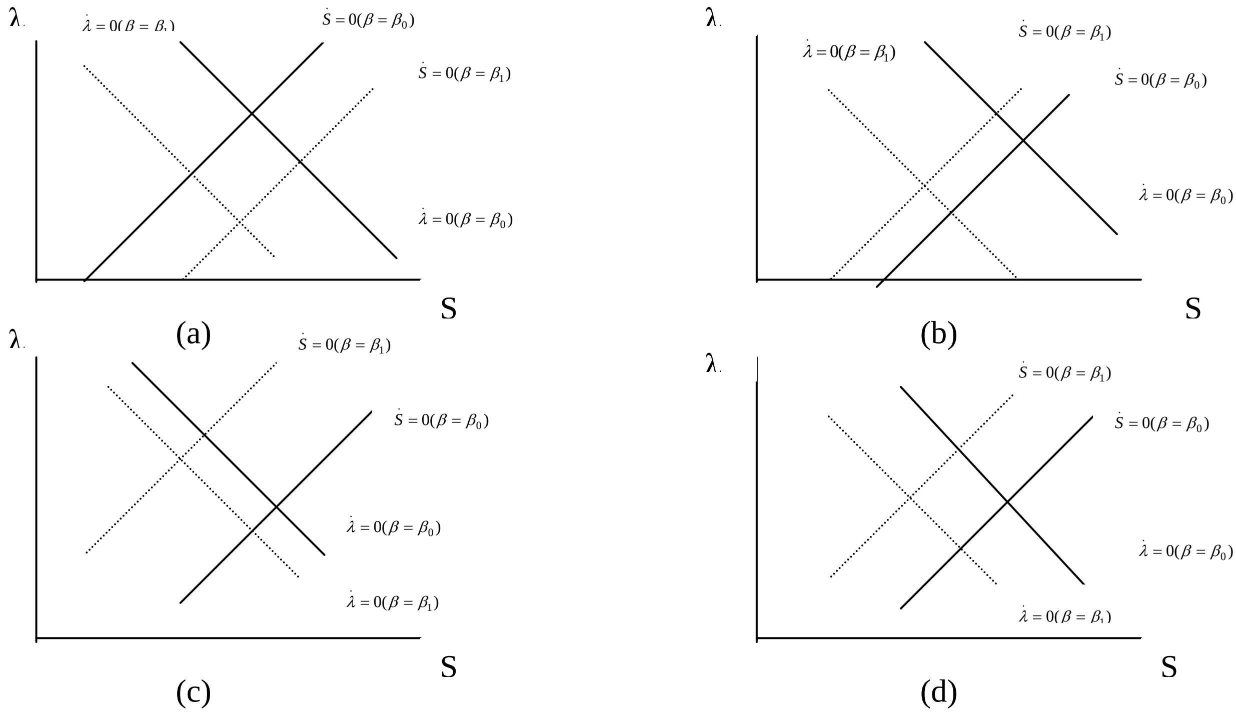
Incorporating market and institutional imperfections into a dynamic soil use model makes the comparative static in some senses more complicated. We decompose the total effect of market and institutional parameters into a direct and an indirect effect. The direct effects are impacts of tightening the market and institutional imperfections directly on the demand for labor in soil conservation activities as if the farm household operates at the temporary equilibrium levels. These results are summarized in Appendix A1. The indirect impacts are the ones that affect the decision via the impacts on shadow price of the soil. These are discussed by way of phase diagrams. When both the direct and indirect effects move in the same direction, then we unambiguously sign the impact. In a situation where the direct and indirect effects move in opposite directions, we cannot unambiguously sign the impact but can outline the possible scenarios and propose the conditions under which steady state efforts on soil conservation increase or decrease for each scenario.

4.1 Increased transaction cost in the labor market

More tight labor market conditions (via a rise in the transaction cost) increase the cost of labor and directly reduce the demand of hired labor for labor scarce households. However, for labor abundant households it limits opportunities to participate in off-farm activities, which results in overstocking of labor for use in both cultivation and conservation activities. However, the impact on the shadow price of the soil, λ, is ambiguous. In order to better understand the impact on λ, we substitute the labor market parameter, β, into ξ in the set of equations in (8'). Totally differentiating these equations with respect to β, we obtain the following expressions to determine the direction of shift of the two isoclines in the phase diagram, to determine the impact on λ.

$$\left.\frac{d\lambda}{d\beta}\right|_{\dot{S}=0} = \frac{-(h_{N^p} N_\beta^p + h_{N^c} N_\beta^c)}{h_{N^p} N_\lambda^p + h_{N^c} N_\lambda^c} \gtrless 0, \qquad \left.\frac{d\lambda}{d\beta}\right|_{\dot{\lambda}=0} = \frac{(f_{SN^p} N_\beta^p)}{\delta - p f_{SN^p} N_\lambda^p} < 0 \tag{11}$$

Since the impact on λ is ambiguous, the overall impact on the steady state efforts in soil conservation is also ambiguous. The source of the ambiguity is the effect of changes in transaction cost on the shadow price of the soil, λ, which is composed of two opposite effects, i.e. the profit and the soil erosion effect of labor market parameters on λ. Four possible scenarios of the impact of increased labor market transaction cost on the optimal shadow price of the soil are summarized in the phase diagrams below.



In panel (a) both isoclines shift downward and hence the shadow price of the soil decreases unambiguously. The impact on the optimal soil stock, however, is ambiguous. Panels (b) and (c) demonstrate the case where the $\dot{S}=0$ isocline shifts up and the $\dot{\lambda}=0$ isocline shifts down, but the shift in $\dot{\lambda}=0$ isocline outweighs that of the $\dot{S}=0$ isocline in panel (b) and vice versa in panel (c). As a result the steady state shadow price of the soil stock decreases in panel (b) and increases in (c). Finally, in panel (d) we observe the case where the shifts in the two isoclines are balanced and hence the steady state shadow price of the soil remains unchanged. Understanding the effect of labor market imperfections on farm profit and the soil dynamic, and how a household's labor endowment influences the various effects of labor market imperfections are the keys to get a clear picture of all the possible effects of an increase in transaction cost on optimal level of soil conservation efforts, and the subsequent effect on the optimal soil stock. The first and second equations in (8') can be used to link farm profit and λ, and soil erosion and λ, respectively.

For labor scarce households, the direct own price effect is negative since the constraint is binding. The indirect effect however is unclear. A reduction in the use of hired labor reduces output and farm profit and thus negatively affects λ (the negative profit effect). However, reduced cultivation and soil conservation due to scarcity of labor might decrease or increase the total depreciation of the soil stock and thus affects λ positively or negatively (soil erosion effect) depending on the relative impact of the two types of labor inputs on the dynamics of soil erosion.

If soil erosion is mainly driven by cultivation intensity, then labor scarcity might lead to a reduction in soil erosion (positive soil erosion effect), and hence the indirect effect will be negative (panel a). As a result the overall impact will be a reduction in the optimal level of soil conservation efforts. On the other hand, if soil erosion is mainly driven by lack of conservation structures, then labor scarcity will foster soil erosion (negative soil erosion effect). If the negative profit effect is strong enough to crowd out the negative soil erosion effect, then the indirect impact on λ will be negative (panel b). Hence, the overall impact on the optimal level of soil conservation efforts will also be negative. If, however the negative soil erosion effect is strong enough to crowd out the negative profit effect, then the indirect effect on λ will be positive (panel c) and the overall impact on optimal N^c depends on the relative magnitude of the direct and indirect effects. If this indirect effect on λ is strong enough to crowd out the direct own price effect, then the overall net impact will be positive and hence more efforts will be geared towards soil conservation activities, otherwise optimal efforts on soil conservation will decline. These results are summarized in the left column of Table 1.

Table 1: Summary of effects of labor market imperfections on optimal soil conservation efforts

Labor scarce households	Labor abundant households
1. Direct effect on N^c ⇒ (negative)	1. Direct effect on N^c⇒ (positive)
2. Indirect effect on N^c (via impacts on λ)⇒ ambiguous	2. Indirect effect on N^c (via impacts on λ)⇒ ambiguous
Impacts on λ ♦ Profit effect (-) ♦ Soil erosion effect (+/-) o If N^p driven, then (-) and overall impact on λ (-) (panel a) o If N^c driven, then (+) and, if stronger than the profit effect, overall impact on λ (+) (panel c) o If N^c driven, then (+) and, if weaker than the profit effect, overall impact on λ (-) (panel b) o If N^c driven, then (+) and, if equally counteracted by the profit effect, overall impact on λ (0) (panel d)	Impacts on λ ♦ Liquidity effect, high δ, since off-farm income declines (-) ♦ Soil erosion effect (+/-) since both inputs might increase o If N^p driven, then (+) and if this dominates the liquidity effect, overall impact on λ (+) (panel c) o If N^p driven, then (+) and if this is dominated by the liquidity effect, overall impact on λ (-) (panel b) o If N^p driven, then (+) and if this is equally counteracted by the liquidity effect, overall impact on λ (0) (panel d) o If N^c driven, then (-) and overall impact on λ (-) (panel a)
3. Overall impact on N^c	3. Overall impact on N^c
♦ If N^p driven, then N^c falls ♦ If N^c driven, and if the soil erosion effect is stronger than the profit effect and the direct effect, then N^c increases, otherwise N^c falls.	♦ If N^p driven and if the soil erosion effect dominates or equally counteracts the liquidity effect, then N^c increases, otherwise N^c falls. ♦ If N^c driven, and if the soil erosion effect + liquidity effect is greater than the direct effect, N^c falls, otherwise N^c increases.

For labor abundant households, the direct own price effect is positive since the existing labor stock could be used for both cultivation and conservation efforts. The indirect effect however is still unclear. Limited opportunities in off-farm activities curtail cash liquidity in the household which in the absence of well-functioning credit markets might lead to tight consumption smoothing problems, high cost of borrowing, and high discount rates which together affect λ negatively (liquidity effect). On the other hand, constraints in access to off-farm activities will provide a chance to use the excess labor stock for soil conservation or cultivation activities, which in turn decreases or increases total depreciation of the soil stock depending on the soil dynamics, and thus affects λ positively or negatively (positive or negative soil erosion effect).

If soil erosion is driven mainly by lack of conservation activities, then an increase in the transaction cost of labor will lead to a reduction in the soil erosion rate for the labor abundant households (negative soil erosion effect), and the overall impact on the shadow price of the soil will be negative (panel a), but the overall impact on the optimal level of soil conservation depends on the relative magnitude of direct and indirect effects. If the negative indirect effect is strong enough to counteract a positive direct effect, then optimal levels of soil conservation efforts will decrease; otherwise optimal N^c will increase as a result of an increase in the transaction cost of labor.

If soil erosion is driven mainly by cultivation intensities, then an increase in the transaction cost of labor will led to an increase in the soil erosion rate for the labor abundant households (positive soil erosion effect) and the overall impact on the shadow price of the soil depends on the interaction of the positive soil erosion effect, then the negative liquidity effect, and the positive direct effect. If the liquidity effect is stronger than the positive soil erosion effect, the indirect impact on λ will be negative (panel b), and the overall impact on the optimal level of conservation efforts will be negative. If the liquidity effect is weaker than the positive soil erosion effect, then the indirect impact on λ will be positive (panel c), and the overall impact on the optimal level of conservation efforts will be positive. These results are summarized in the right column of Table 1.

In general, for labor scarce households the overall negative effects are more pronounced and the steady state level of soil conservation investment is more likely to decrease due to tighter labor market conditions (via increases in transaction costs) either when conditions in panels (a), (b) and (d) prevail, or when conditions in panel (c) prevail and when the indirect positive impact on λ is overshadowed by a direct negative impact on the labor demand for conservation activity. The only case where a tighter labor market condition leads to an increase in the optimal level of soil conservation for labor scarce households is when conditions in panel (c) prevail and when their indirect positive effect is strong enough to outweigh the negative direct effect on labor demand for soil conservation. On the other hand, for labor abundant households the overall positive effects are more pronounced and the steady state level of soil conservation efforts are more likely to increase due to tighter labor market conditions either when conditions in panel (c) prevail or when conditions in panels (a), (b) and (d) prevail and when their negative indirect impact on λ is overshadowed by a direct positive impact of tight labor market conditions on mobilizing existing excess labor endowment for conservation activity. The only case where a tighter labor market conditions lead to a reduction in the optimal level of soil conservation for labor abundant households is when conditions that lead to a fall in λ in panel (a), (b), and (d) are strong enough to outweigh the direct positive effect on the use of labor for conservation activities.

4.2. Increased transaction cost in the credit market

When credit constraints are binding, tighter credit market conditions (via an increase in the transaction cost of obtaining credit) augment the cost of purchased labor and hence curtail their demand. Therefore, given our model specification, a tight credit market condition obviously results in a direct negative impact on the use of labor both for cultivation and conservation activities if the households are liquidity constrained. However, the impact of credit market constraints on the shadow price of the soil, λ, is far from obvious.

Substituting the credit market parameter, α, into ξ in the set of equations under (8') and totally differentiating with respect to α, we obtain the following expressions to determine the direction of shift of the two isoclines:

$$\left.\frac{d\lambda}{d\alpha}\right|_{\dot{S}=0} = \frac{-(h_{N^p}N_\alpha^p + h_{N^c}N_\alpha^c)}{h_{N^p}N_\lambda^p + h_{N^c}N_\lambda^c} \gtrless 0 \qquad (12)$$

$$\left.\frac{d\lambda}{d\alpha}\right|_{\dot{\lambda}=0} = \frac{(f_{SN^p}N_\alpha^p)}{\delta - pf_{SN^p}N_\lambda^p} < 0 .$$

As in the case of labor markets, the effect of an increase in transaction cost on λ is ambiguous. Like the labor market conditions, increased transaction cost in the credit market affects the shadow price of the soil via two different channels. Increased transaction cost increases cost and curtails purchased input use, and hence total output and profit decline, which in turn affects λ negatively (negative profit effect). However, less use of purchased labor for cultivation and conservation efforts also implies lower or higher soil erosion and hence a higher or lower shadow price of the soil stock, depending on the relative strength of the two input on the dynamics of soil erosion (a positive or a negative soil erosion effect, respectively). Furthermore, in the absence of other ways of relieving the cash liquidity problem, a tight credit constraint might also lead to a serious consumption smoothing problem and hence higher individual discount rates and higher λ, and lower incentives for soil conservation (liquidity effect). The four panels of phase diagrams described in the labor market conditions above also apply here although the underlying shift mechanisms are somehow different.

If soil erosion is mainly driven by cultivation intensity, then an increase in transaction cost in the credit market will lead to a reduction in the soil erosion rate (negative soil erosion effect), and hence the indirect impact on λ will be negative (panel a), and the overall impact on the optimal level of soil conservation will be negative. On the other hand, if erosion is mainly driven by lack of soil conservation efforts, then an increase in the transaction cost in the credit market will led to an increase in the soil erosion rate (positive soil erosion effect). If the positive soil erosion effect is overshadowed by the sum of other negative (liquidity and profit) effects, then the indirect impact on λ and the overall impact on the optimal level of soil conservation will be negative (panel b). If the positive soil erosion effect more than offsets the negative liquidity and profit effects, then the indirect impact on λ will be positive (panel c), but the overall impact on the optimal level of soil conservation depends on the relative magnitude of the direct and indirect effects. If the positive indirect effect is strong enough to counteract the negative direct effect, then the optimal levels of soil conservation effort will increase; otherwise optimal N^c will decrease as a result of an increase in the transaction cost of credit. All the possible results discussed so far are summarized in Table 2.

Table 2: Summary of effects of credit market imperfection on soil conservation efforts

Liquidity and Labor Scarce Households
1. Direct effect on N^c $\Rightarrow$ (negative)
2. Indirect effect on N^c (via impacts on λ)$\Rightarrow$ ambiguous
Impacts on λ ♦ Profit effect (-) ♦ Liquidity effect (-) ♦ Soil erosion effect (+/-) o If N^p driven, then (-), and overall impact on λ (-) (panel a) o If N^c driven, then (+) and if the positive soil erosion effect is overshadowed by the negative liquidity and profit effects, then the overall impact on λ (-) (panel b) o If N^c driven, then (+) and if the positive soil erosion effect dominates the negative liquidity and profit effects, then the overall impact on λ (+) (panel c) o If N^c driven, then (+) and if the positive soil erosion effect is equally counteracted by the negative liquidity and profit effects, then the overall impact on λ (0) (panel d)
3. Overall impact on N^c
♦ If N^p driven, then N^c falls ♦ If N^c driven, and if the positive soil erosion effect dominates the negative liquidity + profit + direct effect, then N^c increases, otherwise N^c falls

In general, the overall negative effects are more pronounced and the optimal level of soil conservation efforts is more likely to decrease due to increased transaction costs in the credit market either when conditions in panels (a), (b) and (d) prevail or when conditions in panel (c) prevail and the indirect positive impact on λ is overshadowed by a direct negative impact on the demand for labor for conservation activity. The only case where tighter credit market conditions lead to an increase in the optimal level of soil conservation for liquidity and labor scarce households is when conditions in panel (c) prevail and when their indirect positive effect is strong enough to outweigh the negative direct effect on labor demand for soil conservation.

4.3 Increased tenure security

Unlike the labor and credit market imperfections, changes in tenure security do not directly affect the demand for labor for conservation activities. The effect on conservation efforts comes indirectly through its effect on the scrap value of the soil as indicated by the transversality condition (9). For one extreme case of complete tenure insecurity, $\theta = 0$, the farm household gets nothing from the scrap value of the soil, and hence the farm household will have no incentive to keep the productive potential of the soil through more efforts on soil conservation. On the other hand, in the presence of full tenure security, $\theta = 1$, the farm household is granted the full benefit of harvesting the benefit of the land at the end of the planning horizon, and hence is better motivated to keep the productive capacity of the land through more efforts in soil conservation. There are other confounding effects. If land could serve the purpose of collateral and were tradable, then more secured tenure would imply better access to credit for buying cultivation inputs, and hence more efforts on cultivation and less effort on soil conservation (the negative credit effect). By the same token, more secured tenure also implies lower discount rates due to a better access to credit and reduced consumption smoothing problems, which further motivates more conservation efforts (the positive credit effect). Unless the negative credit effects are strong enough to outweigh the scrap value and the positive credit effects, increased tenure security is more likely to enhance soil conservation efforts.

4.4 Increased individual discount rate

A rise in the household's discount rate reflects a strong preference to meet short-term livelihood requirements, which may in turn compel the household to adopt a myopic behavior that discourages efforts on soil conservation. Poverty and capital market imperfections are frequently cited as important factors that influence the discount rate of small farm households (Perrings, 1989; Pearce et al., 1990; World Bank, 1992).

Changes in the household's discount rate do not directly affect the demand of labor for conservation activities. The effect on conservation efforts comes indirectly through its effect on the shadow price of the soil. To get more insights on the impact of discount rate on the shadow price of the soil, we totally differentiate the set of equations in (8') with respect to δ, and obtain the following expressions to determine the direction of shift of the two isoclines:

$$\left.\begin{aligned} &\left.\frac{d\lambda}{d\delta}\right|_{\dot{S}=0} = 0 \\ &\left.\frac{d\lambda}{d\delta}\right|_{\dot{\lambda}=0} = \frac{-\lambda}{\delta - f_{SN^p} N_\lambda^p} < 0 \,. \end{aligned}\right\} \qquad (13)$$

The results in (13) indicate that with an increase in the individual discount rate, the shadow price of the soil will decline and hence conservation efforts will be unambiguously discouraged. This result has a very important policy implication towards more sustainable land management. Unlike efforts that improve input market conditions, any policy that directly influences the individual discount rate is more likely an effective mechanism for influencing soil conservation decisions and better management of the soil stock. This result is empirically supported in studies by Holden et al. (1998), and Yesuf (2004).

5. Conclusions and policy implications

The problem of soil erosion has been given much attention in recent years in many developing countries. Government and development agencies have invested substantial resources to promote adoption of technologies that control erosion. However, there is little understanding of the factors that determine farmers' investments in soil conservation. Particularly, research into market and institutional factors behind the excessive soil erosion of small holders in developing countries is scanty and fragmented. Even the existing few empirical evidences are inconclusive and anecdotal in nature.

This study is one attempt to incorporate labor, capital and land market imperfections into the standard dynamic economic model of soil conservation. We use this model to analyze the impact of tighter labor, capital and land market imperfections on the optimal level of soil conservation efforts. Labor and capital market imperfections are captured by way of transaction costs incurred to get access to the respective markets. Land market imperfections are reflected through the variable benefits obtained from the scrap value of the land at the end of the planning horizon.

The impacts of labor and credit market imperfections are similar qualitatively though not quantitatively. Tighter labor and credit market imperfections curtail the optimal level of soil conservation efforts directly through an increase in the shadow price of the conservation input and indirectly through the effect on shadow price of the soil stock. It is shown in this paper that indirect impacts could either be negative or positive depending on the relative strength of conservation and cultivation efforts on the soil dynamic, and their relative contributions to the farm profit. Thus the overall effect of tighter labor and credit market imperfections on soil conservation is ambiguous. Various possible scenarios are explored in this paper. This explains the inconclusive results we find in empirical studies of soil conservation adoption decisions.

The impact of tenure status or type of land ownership on soil conservation adoption decisions is also ambiguous. It is shown in the paper that a more secure tenure status guarantees greater benefits from the scrap value of the farm at the end of the planning horizon, and hence motivates more investments in soil conservation. However, if land is tradable and serves the purpose of collateral, more secure tenure might lead to a cheaper access to the credit market for the purchase of cultivation inputs which degrades the soil and hence discourages investments in soil conservation. In the absence of the latter effect, a better-secured land tenure system is more likely to boost investment in soil conservation.

The only policy parameter that unambiguously encourages investment in soil conservation is a reduction in the discount rate of the farm households. Any policy option that reduces a farm household’s discount rates encourages long-term farm investments such as investments in soil conservation.

In general, this study shows the importance of investigating factor market imperfections in understanding farm households’ behaviors in soil conservation adoption decisions. In many poor farm households, soil conservation investments are undertaken if they are cheap in terms of monetary, labor and other material requirements. Factor market imperfections, by way of inflating the shadow prices might prohibit otherwise profitable investments from occurring. Investment in soil conservation is one of them. However, in our model, it is shown that it is possible for soil conservation efforts to increase even with tighter factor market imperfections, depending on soil erosion dynamics (mainly a function of agro-climatic conditions), factors’ profit share, and initial factor endowments. This is not to support market distortions. Instead, it must be stressed that since factor market distortions and agro-climatic conditions vary by location, efforts to promote soil conservation must be designed according to local conditions.

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Appendix

A1: Comparative static at the temporary equilibrium

Changes in	**The effect on**	
	Cultivation input (N^p)	*Conservation input(* N^c*)*
Initial soil stock, S_0	$\frac{dN^p}{dS} = \frac{-\left[pf_{N^pS}H_{N^cN^c}\right]}{\lvert J\rvert} > 0$	$\frac{dN^c}{dS} = \frac{\left[pf_{N^pS}H_{N^cN^p}\right]}{\lvert J\rvert} < 0$
Shadow price of the soil, λ	$\frac{dN^p}{d\lambda} = \frac{\left[h_{N^c}H_{N^pN^c} - h_{N^p}H_{N^cN^c}\right]}{\lvert J\rvert} < 0$	$\frac{dN^c}{d\lambda} = \frac{\left[h_{N^p}H_{N^cN^p} - h_{N^c}H_{N^pN^p}\right]}{\lvert J\rvert} > 0$
Transaction cost in the credit market, α	$\frac{dN^p}{d\alpha} = \frac{wT^{CM}\left[H_{N^pN^c} - H_{N^cN^c}\right]}{\lvert J\rvert} < 0$	$\frac{dN^c}{d\alpha} = \frac{wT^{CM}\left[H_{N^cN^p} - H_{N^pN^p}\right]}{\lvert J\rvert} < 0$
Transaction cost in the labor market, β	$\frac{dN^p}{d\beta} = \frac{w\alpha T_{\beta}^{CM}\left[T_{N^c}^{LM}H_{N^pN^c} - T_{N^p}^{LM}H_{N^cN^c}\right]}{\lvert J\rvert} < 0$	$\frac{dN^c}{d\beta} = \frac{w\alpha T_{\beta}^{CM}\left[T_{N^p}^{LM}H_{N^cN^p} - T_{N^c}^{LM}H_{N^pN^p}\right]}{\lvert J\rvert} < 0$

A2. The phase diagram

At steady state, $\dot{\lambda} = \dot{S} = 0,$ and totally differentiating (8') w.r.t λ and *S*,

$$\left.\frac{d\lambda}{dS}\right|_{\dot{\lambda}=0} = \frac{p(f_{SN^p} N_S^p + f_{SS})}{\delta - p(f_{SN^p} N_\lambda^p)} < 0 \qquad \text{(Assuming } f_{SS} > f_{SN^p} N_S^p \text{ in absolute terms)}$$

$$\left.\frac{d\lambda}{dS}\right|_{\dot{S}=0} = \frac{-\left[h_{N^p} N_S^p + h_{N^c} N_S^c\right]}{h_{N^p} N_\lambda^p + h_{N^c} N_\lambda^c} > 0 \quad .$$

Inter-temporal movements of the steady state

$$\frac{\partial \dot{\lambda}}{\partial S} = -p(f_{SN^p} N_S^p + f_{SS}) > 0$$

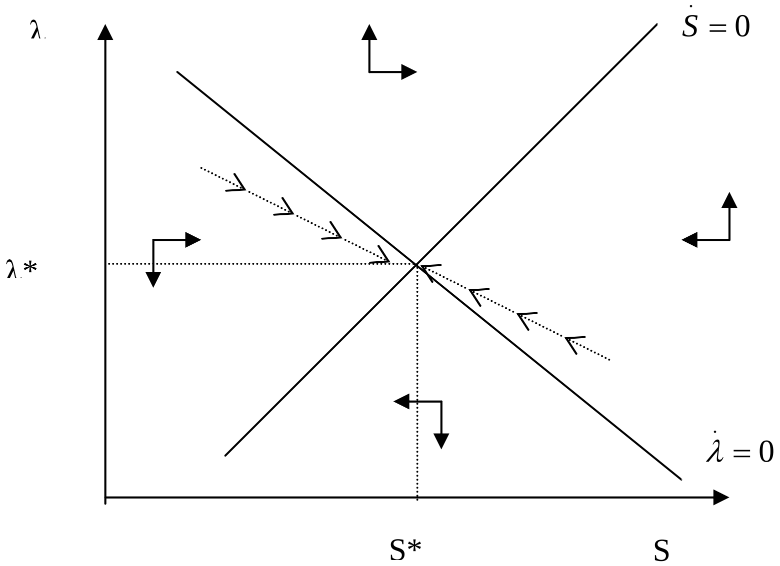
$$\frac{\partial \dot{S}}{\partial \lambda} = \left[h_{N^p} N_\lambda^p + h_{N^c} N_\lambda^c\right] > 0 \,.$$

Summary of steady state movements

$$\dot{\lambda} > 0 \;\; if \;\; S > S^*; \dot{\lambda} < 0 \;\; if \;\; S < S^*$$

$$\dot{S} > 0 \;\; if \;\; \lambda > \lambda^*; \dot{S} < 0 \;\; if \;\; \lambda < \lambda^* .$$

The phase diagram:



Risk Preferences of Farm Households in Ethiopia[+]

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Abstract
This study measures farmers' attitudes towards risk using an experimental approach for a sample of 262 farm households in Ethiopian highlands. We find more than 50 percent of the households in the severe to extreme risk aversion category, with a constant partial risk aversion (CPRA) coefficient of more than 2. With careful construction of the experiment, the natures of absolute and partial risk aversion are examined, and our data supports the presence of Decreasing Absolute Risk Aversion (DARA) and Increasing Partial Risk Aversion (IPRA) behavior. A significant difference in behavior between games involving actual loss and opportunity loss is also observed. The validity of some of the expected utility theory predictions is tested, and the predictions of risk neutrality for smaller stakes and predictions of similar preferences for gains and losses, which stem from the major tents of the theory (concavity and asset integration) are not supported by our experiment.

Key Words: Ethiopian farm households; experimental studies; loss aversion; risk aversion

JEL Classification: C93; D81; Q12; Q21

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1. Introduction

Production and investment decisions of farm households in the third world are highly overshadowed by multitude of risks including yield, price, and consumption risks. Because of poorly developed or absent credit, insurance, and forward markets, it is difficult to pass the risks to a third party. Hence, consideration of risk plays a vital role in the choice and level of use of production inputs and adoption of technologies. In the empirical literature, it is not uncommon to find third world farm households using less fertilizers and other production inputs than they would have used, had they tried to maximize expected profit. It is also not uncommon to observe them being reluctant to adopting new technologies even when these technologies provide higher returns to land and labor than traditional technologies.

Sandmo (1971) was first to establish and prove the fact that a risk averse firm facing output risk will produce less output than a risk neutral firm. Following Sandmo's work, we find some attempts in the empirical literature to come up with ways to measure the degree of risk aversion of farm households. Some have used actual production data while others have applied an experimental approach to derive farm household risk aversion estimates. Studies using production data include the works of Antle (1983, 1987,1989), Pope and Just (1991), Chavas and Holt (1996), and Bar-Shira et al. (1997). Studies employing the experimental approach in developing countries include Binswanger (1980), and Wik and Holden (1998). The production data approach can be criticized for confounding risk behavior with other factors such as resource constraints faced by decision makers (Eswaran and Kotwal, 1990). This is particularly important in developing countries where market imperfections are prominent and consumption and production decisions are non-separable (Wik and Holden, 1998). On the other hand, the most pervasive problem of the experimental approach is hypothetical bias when the experiments are launched in hypothetical settings.

Both approaches adopt expected utility theory as the underlying standard theory of choice under uncertainty. More basic concerns, which are not addressed by either of these groups of thought, are whether the predictions of the standard theory work in the mentioned studies. While Expected Utility (EU) theory has a number of attractions, notably its tractability, it has recently been losing ground slowly to other alternative theories due to growing empirical evidence of anomalies to its axioms and predictions. In their recent calibration theorem, Rabin (2000) and Rabin and Thaler (2001) show how the EU theory fails to describe risk aversion to small stake outcomes. Kahneman and Tversky (1979), and later Benartzi and Thaler (1995) and Thaler et al. (1997), also show the presence of loss aversion in risk preferences that emanates from the different weights that people attach to gains and losses, and to outcomes of high and low probabilities.

Using real pay-off experimental data, this paper seeks to measure farmers' risk attitudes. By incorporating both small and large stakes and gains and losses into the experiment, we test for the presence of low stake risk aversion and loss aversion. The rest of the paper is organized as follows. Section 2 discusses the theory on measuring risk aversion. Section 3 describes the experiment. Sections 4 and 5 discuss the descriptive and econometric outputs. Section 6 concludes the paper.

2. Measuring Risk Aversion

Traditionally, risk aversion is defined with reference to the von Neumann-Morgensten expected utility function. Specifically, the second derivative of this utility function contains important information as to the degree of risk aversion of the individual decision maker. In empirical studies, the three most commonly used measures of risk aversion are absolute risk aversion ($A(W) = -{U_{WW}}/{U_W}$), relative risk aversion ($R(W) = -W\,{U_{WW}}/{U_W}$) and partial risk aversion ($P(w,m) = -m\,{U_{WW}}/{U_W}$).[5] They were first introduced by John W. Pratt in 1964, Kenneth J. Arrow in 1965, and Menezes and Hanson, and Zeckhauser and Keeler in 1970 respectively,

Absolute risk aversion traces the behavior of an individual towards risk when his/her wealth rises and the prospect remains the same. Partial risk aversion traces the behavior when the prospect changes by a certain factor but wealth remains the same. Relative risk aversion traces the same behavior when both the initial wealth and the level of the prospect rise proportionally. A Decreasing Absolute Risk Aversion (DARA) hypothesis implies that a person will be more willing to accept a risky prospect as wealth increases. An Increasing Relative Risk Aversion (IRRA) postulates that a person's willingness to accept a risky prospect declines when both the outcome of the

[5] Where *m* is a monetary gain or loss, *w* is initial wealth, and *W (=w+m)* is final wealth level.

prospect and wealth increase proportionally. An Increasing Partial Risk Aversion (IPRA) implies a decrease in the willingness of the individual to take a gamble as the scale of the prospect increases.

In our experimental studies, we design the experiment in a way that enables us to test the natures of these measures of risk aversion. The state of absolute risk aversion across farm households is investigated by presenting identical outcome choice sets to different individual farm households with different levels of unstochastic initial wealth. Furthermore, we boost the outcome of the first choice set by the factors 5, 10, 20 and 30 to examine the nature of partial risk aversion for each farm household.

In order to compute a risk aversion coefficient which can serve as a measure of household level of risk aversion, we employ a Constant Partial Risk Aversion (CPRA) utility function of the form $U = (1-\gamma)c^{(1-\gamma)}$, where γ is the coefficient of risk aversion, and c is the certainty equivalent of a prospect. If a respondent is indifferent between two consecutive prospects (say 1 and 2) given that both prospects have equal probabilities of a good or bad outcome, then we have $E(U_1)=E(U_2)$, and hence $(1-\gamma)c_1^{(1-\gamma)} = (1-\gamma)c_2^{(1-\gamma)}$. Since there is no algebraic solution to this equation, we solve for γ using a standard numerical method. The upper and lower limits of the CPRA coefficients for each prospect of our experiment are given in Table 1 in the next section.

For nearly half a century, EU theory has been used as the dominant theory of choice under uncertainty. While EU theory has a number of attractions, notably its tractability, it has recently been losing ground slowly to other alternative theories due to growing empirical evidence of anomalies to its axioms and predictions. Most of the criticism stems from two of the major tents of the theory, i.e. the assumptions of concavity of the utility function and asset integration in the evaluation of utility functions.

Concavity of the utility function: Using EU theory, risk aversion is modeled with the assumption that the utility function over wealth is concave. Arrow (1971) shows that an expected-utility maximizer will always want to take a sufficiently small stake in any positive expected-value bet. That is, expected-utility maximizers are (almost everywhere) arbitrarily close to risk neutral when stakes are small. If subjects in experimental studies are found to be risk averse for small stakes, then they are not expected-utility maximizers. Given the assumption of diminishing marginal utility, risk aversion in small stakes implies an extreme risk aversion for larger stakes. In their recent calibration theorem, Rabin (2000) and Rabin and Thaler (2001) show how for any concave utility function, even a very little risk aversion over modest stakes leads to an absurd degree of risk aversion over large stakes. According to Rabin and Thaler, the fact that most people are not virtually risk neutral over small stakes and the fact that most people are not insanely risk averse over large stakes imply that expected utility does not describe the risk attitude of most people accurately. This claim of Rabin and Thaler is supported in a number of studies; see for example Davis and Holt (1993), Eggert and Martinsson (forthcoming), and Holt and Laury (forthcoming), which show evidence of risk aversion in low stake experiments.

Asset integration: In EU theory, outcomes of a given prospect are evaluated at the final wealth level after integrating the monetary gains into the initial wealth levels. This assumption implicitly assumes identical value function and equal decision weights for choices that involve both gains and losses. This idea is frequently challenged by modern research in behavioral economics where evidence of loss aversion in decision-making is found. It is generally found that individuals are more sensitive to losses than to gains. Loss aversion was introduced by Kahneman and Tversky (1979) as part of the more general prospect theory. Along with other new concepts of behavioral economics such as mental accounting and narrow bracketing, Benartzi and Thaler (1995) and Thaler et al. (1997) use loss aversion to describe discrepancies in choices for gains and losses. They also use the same concept to explain a long time puzzle in financial markets that questions why stocks have outperformed bonds over the last century by a surprisingly large margin: the equity premium puzzle. EU theory does not have any explanation to this puzzle.

In our experiment, subjects are offered choices to reveal their risk preferences for both small and large stake outcomes, and gains and losses. This gives us the possibility to test whether respondents are small stake risk averse and loss averse, or simply general expected utility maximizers. Furthermore, any evidence of significant differences in the gain and loss game responses can also be taken as proof of the absence of asset integration, the main premise of the EU model.

3. Description of the experiment

We follow an experimental design developed by Binswanger (1980) to reveal risk preferences of farm households in the Ethiopian highlands. We frame the choices to reflect real life farming decisions. The farm households were told to assume that there are six different farming systems, all with similar costs but different output levels depending on a 50 % probability of good or bad harvest. Then they were shown the good and the bad outcomes of each of the six different techniques. For the successive alternatives, the expected gains and the spreads increased. Once they had chosen one of the techniques, a coin was tossed to determine whether they would be given the good or bad outcome as a reward. The basic structure of the experiment is given in Table 1.

In order to observe a farm household's behavior following different outcomes, and hence the nature of partial risk aversion, the experiments were made to be conducted at different levels (see the full format of the game in the Appendix). Experiment sets 2 to 5 were derived by multiplying (scaling) all the amounts of the first set by 5, 10, 20 and 30 respectively. Furthermore, in order to test the prevalence of significant differences in risk behaviour towards gains and losses, choice sets involving actual losses to farm households were incorporated into the experiment. Only those farm households who won enough money in the gains-only part and were willing to participate in this part of the experiment played this part of the experiment. As a result only 29 percent of the farm households played this part. This distinction between gains-only and gains and losses games can help us test whether preferences revealed with opportunity losses are different from those of actual losses (a test for asset integration and loss aversion). Because of the budget constraint, we made the last sets of the experiment hypothetical.

Table 1: The basic structure of the experiment

Alt. Prospects	Bad harvest	Good harvest	Expected gain (EV)	Standard deviation (SDV) or Spread	Constant Partial Risk Aversion Coefficient (γ)	Risk classification
1	0.50	0.50	0.50	0	∞ to 7.47	Extreme
2	0.45	0.90	0.675	0.225	7.47 to 2.00	Severe
3	0.40	1.20	0.80	0.40	2.00 to 0.85	Intermediate
4	0.30	1.50	0.90	0.60	0.85 to 0.32	Moderate
5	0.10	1.90	1.00	0.90	0.32 to 0	Slight to neutral
6	0	2.00	1.00	1.00	0 to - ∞	Neutral to preferring

On average, each household won a sum of Birr 30, which is about 10 percent of the monthly income of unskilled labor in the country[6]. This was felt to be a significant incentive for respondents to carefully consider the options and reveal their true preferences.

The experiment was administered to a random sample of 262 farm households in 7 villages in highland Ethiopia in February of 2002. The villages were located in five *weredas* in two different zones (Eastern Gojjam and South Wollo) of highland Ethiopia. Eastern Gojjam is generally considered to have a good potential for agriculture, whereas South Wollo is considered to be seriously affected by soil erosion and subjected to recurrent drought. The basic descriptive statistics are given in Table 2.

Table 2: Basic descriptive statistics for participating farm households, N=262

Variable	Mean	Std dev	Min	Max
Gender of the respondent (1=male)	0.85	0.34	0	1
Age of the respondent	46.73	15.77	15	90
Literacy (1=yes)	0.27	0.45	0	1
Family size	5.39	2.44	1	15
Household dependency ratio (the ratio of number of household members below age15 to above age 15)	1.02	0.80	0	5
Household farm size	0.96	0.70	0.01	3.38
Number of plots	4.91	2.55	1	9
Number of oxen	1.38	1.15	0	4
Value of domestic animals in ‘000 Ethiopian Birr (Proxy for stock of wealth)	1.95	1.76	0.01	8.87
Annual liquid cash availability to a household in ‘000 Ethiopian Birr (Cash collected from all sources of cash revenue less cash expenditure in one year)	0.35	0.93	-2.37	9.57
Subjective discount rates[7]	0.39	0.34	0	0.83

[6] An average reward of Birr 30 is equivalent to US $3.5 (US$1=Birr 8.5).

[7] Households were confronted with choices of money that differ both in magnitude and time to calculate the implied subjective discount rate. For more insights on data collection and estimation of the individual subjective discount rates, see Yesuf (2003).

4. Descriptive analysis

We start our analysis by exploring the responses of the participants for each set of the experiment. Table 3 presents the distribution of preferences to different degrees of risk aversion for each level of the experiment.

Table 3: Distribution of preferences to risk[+].

Risk category	Gains-only games					Gains-and-losses games[++]				
	1	2	3	4	5	1	2	3	4	5
Extreme	15.3%	19.8%	24%	30.5%	36.6%					
Severe	13.4%	17.2%	21.4%	20.6%	19.1%	15.8%	13.2%	21.1%	25%	27.6%
Intermediate	19.5%	17.9%	21.8%	21.4%	18.3%	11.8%	23.7%	22.4%	23.7%	26.3%
Moderate	17.9%	17.9%	11.8%	12.2%	9.2%	19.7%	28.9%	22.4%	25%	21.1%
Slight to neutral	13.4%	13.7%	10.7%	8%	8.4%	19.7%	18.4%	19.7%	14.5%	13.2%
Neutral to preferring	20.6%	13.4%	10.3%	7.3%	8.4%	32.9%	15.8%	14.4%	11.8%	11.8%

+ Percentage shares are calculated for each game level, where 1 is the lowest and 5 is the highest game level. Percentages shares thus should be read as column percentages. A total of 262 households participated in the gains-only games. But only 76 participated in gains-and-loss games.

++ Distributions in the gain and loss games are conditional distributions (distributions given that a respondent played a gain and loss game).

In Table 3, we observe that a majority of the farm households revealed their preferences for prospects representing intermediate, severe, and extreme risk aversion alternatives. Even at the lowest level of the game, about 29% of the farm households chose the alternatives representing severe-to-extreme risk aversion. This proportion increases to about 56% at the highest level of the game. Considering the alternatives slight-to-neutral and neutral-to-risk preferring, the proportion declined from 34% in game 1 to 16.8% in game 5. This trend seems to coincide with the increasing partial risk aversion hypothesis, in which individual farm households are expected to be more risk averse as the size of the game increases. On the other hand, considering the share of responses falling into intermediate and moderate risk aversion categories, the proportions remain stable between 34% and 37% in games 1 to 4, but decline to 28% in game 5. This implies that for individuals who initially had moderate to intermediate levels of risk aversion, the level increases at a slower rate.

Comparing the distribution of risk preferences in Table 3 to other similar studies in developing countries, Binswanger (1980), and Wik and Holden (1998) found the proportion of respondents in the intermediate to moderate risk category to be 83% in India and 52% in Zambia, respectively, indicating that farm households in Ethiopia are more risk averse than those in India and Zambia.

Following the calibration theorem of Rabin and Thaler (2001), the fact that 29% of the respondents are severely to extremely risk averse for a 50-cent bet implies absurd risk aversion at relatively larger stake bets. Calculated at Birr 1000 as a monetary reward from a modest farming activity, an extreme or severe risk aversion to this group implies a relative risk aversion of around 15, given a lifetime wealth level of Birr 2000. This result is a bit absurd[8], and should be even more absurd at higher lifetime wealth levels. The empirical evidence based on choice under uncertainty suggests a relative risk aversion of around 2 or slightly larger (Dasgupta, 1998). Following the arguments of Rabin and Thaler (2001), this result shows that most of the households in this group are not expected utility maximizers.

A comparison of choices between games involving only gains and those involving gains and actual losses (in the sub sample of 76 respondents who participated in both sections of the experiment) shows an inclination of farm households to be more risk averse in the latter games than in the former (see Graph 1 in the Appendix, with frequency distribution of responses annexed). The null hypothesis of chi-square tests that the subjects' risk preferences are equivalent in both kinds of games is rejected for each pair of the experiment. The results of the chi-square tests are summarized in Table 4.

[8] Following the definition of risk aversion in Section 2, a CPRA coefficient of 7.48 to smaller stake (50 cent) implies an absolute risk aversion of 0.00748 at a monetary gain of Birr 1000. Assuming a lifetime wealth of Birr 2000, this implies a relative risk aversion of 15.

Table 4: Chi-square tests on the equivalence of risk preferences for gains-only and gain-and-loss games (a test of loss aversion or asset integration)

Hypothesis	**Statistics**[+]
Gain-only game in experiment 1 is equivalent to loss game in experiment 1	14.230 (0.0142)
Gain-only game in experiment 2 is equivalent to loss game in experiment 2	21.364 (0.0007)
Gain-only game in experiment 3 is equivalent to loss game in experiment 3	13.057 (0.023)
Gain-only game in experiment 4 is equivalent to loss game in experiment 4	16.197 (0.006)
Gain-only game in experiment 5 is equivalent to loss game in experiment 5	15.709 (0.008)

+ The chi-square statistics are calculated based on the distribution of risk preferences, given in the Appendix under Fig. 1. Numbers in parentheses are p-values. The degrees of freedom are calculated as *df* = (r-1)*(c-1), where r is the number of categories (6 in our case) and c is the number of columns to be compared (2 in our case).

The results of the tests show a significant difference in risk preference between gain-only and gain-and-loss games, confirming the conjuncture that the subjects' risk preferences are not in accordance with the predictions of expected utility theory. This is one piece of evidence of the absence of asset integration, and of the presence of loss aversion in the risk preferences of our farm households.

Our second focus in the analysis of the risk experiment data is on measuring the median levels of risk aversion for each level of the game. The results are given in Table 5. Note that the CPRA coefficient that corresponds to each risk category is stated at the bottom of the table.

Table 5: Median levels of risk aversion

Experiment sets	Gains-only games			Gains-and-losses games		
	East Gojjam	South Wollo	All	East Gojjam	South Wollo	All
Set 1	4	3	4	5	4	5
Set 2	4	2	3	4	3	4
Set 3	3	2	3	4	3	4
Set 4	3	2	3	4	3	4
Set 5	3	2	2	4	3	3

2= Severe (γ=2.00 to 7.47), 3=intermediate (γ=0.85 to 2.00), 4=moderate (γ=0.32 to 0.85), 5=slight to neutral (γ=0 to0.32)

The median levels of risk aversion increase from moderate in the lowest level of the game to severe in the highest level of the game for the entire sample in the gains-only games. The trend in the gains and losses game is from neutral to intermediate. This is partially because of sample selection bias, i.e. the median value in the latter case was taken only from those households participating in the gains and losses game, which are probably the better-off farm households.

5. Econometric analysis

In what follows, we use econometric techniques to investigate the variables that explain variations in the risk preferences of our sample of households.

5.1 The Econometric model

Our experimental data fits into an ordinal econometric model, i.e. an ordered probit (logit) model. An ordered probit (logit) model exploits the fact that the dependant variable outcomes, categories of risk aversion, have a natural (ordinal) ranking ranging from extreme risk aversion to risk loving behavior. This model has an advantage in that we need not assume a particular functional form of the utility function to analyze the risk aversion behavior of farm households. Therefore, we simply use the underlying latent variable model to analyze the observed choices. Using this model, the different hypotheses on risk aversion are tested and factors affecting risk aversion of farm households are analyzed.

Assume there is a latent variable y_i^* measuring the degree of risk aversion of the i^{th} decision maker as

$$y_i^* = x_i^{'}\beta + u_i, \tag{1}$$

for some *kx1* parameter vector β and stochastic disturbance term u_i, and a vector of regressors *x*.

The six outcomes for the observed variable y_i are assumed to be related to the latent variable through the following observability criterion:

$$y_i = m \text{ if } \alpha_{m-1} \le y_i^* \le \alpha_m \text{ for } m = 1,...,6 \tag{2}$$

for a set of threshold parameters α_0 to α_6, where $\alpha_0<\alpha_1<\alpha_2<\alpha_3<\alpha_4<\alpha_5<\alpha_6$, and $\alpha_0= -\infty$ and $\alpha_6=\infty$.

$$
y_i = \begin{cases} 1 \Rightarrow Extreme & if\ \alpha_0 = -\infty \le y_i^* < \alpha_1 \\ 2 \Rightarrow Severe & if\ \alpha_1 \le y_i^* < \alpha_2 \\ 3 \Rightarrow Intermediate & if\ \alpha_2 \le y_i^* < \alpha_3 \\ 4 \Rightarrow Moderate & if\ \alpha_3 \le y_i^* < \alpha_4 \\ 5 \Rightarrow Slight-to-neutral & if\ \alpha_4 \le y_i^* < \alpha_5 \\ 6 \Rightarrow Neutral-to-preferring & if\ \alpha_5 \le y_i^* < \alpha_6 = \infty \end{cases}
$$

We assume that the disturbance term has a standard normal distribution which yields the ordered probit model. There are at least two ways of interpreting the coefficients with respect to the observed outcome. These are to compute either the predicted conditional probabilities or the partial changes in predicted probabilities for each outcome. Since the marginal effects depend on the level of all other variables, we must decide which values of the variables to use when computing the effect. More commonly, the marginal effects are computed at the mean values of all other variables, as in our study.

5.2. Variables and expected signs

We have included several explanatory variables in our regression model. The independent variables that are included and their expected signs are discussed below.

Wealth indicators: From theory and a common assumption of DARA, we expect wealthier households to be less risk averse than poorer households. To capture the effect of wealth on risk aversion, we include several wealth indicators in the models, including the value of domestic animals, the number of oxen, current cash availability, household land size, and the number of cultivated plots. The major form of farm household wealth in rural Ethiopia is the stock of wealth kept in the form of livestock. We therefore include the market value of domestic animals as a wealth indicator in both models. On the other hand, in the studied region, farming households are cash constrained. Most of the farm and non-farm income is remunerated in kind. Therefore, to capture the effect of liquidity on risk aversion, we include another wealth indicator: the cash availability indicator, which is derived as the difference between total annual cash income and cash expenditure of a household. As another form of household wealth, we also include the total area of land for which the household has been granted user rights. In Ethiopia, land is a state property, and farm households are only granted user rights. As a result, there is no land market. This makes land a very constrained resource and therefore the key to various farming decisions. We therefore expect farm households with a relatively large farm size to have a greater opportunity of diversifying crops as one means of coping with risk. Hence, farm households with larger size farms are expected to be less risk averse than those with smaller land sizes. The number of oxen owned is also a form of wealth in rural Ethiopia, because apart from land, oxen are a vital means of production for a farming household. It has been suggested that asset market imperfections severely constrain substitution among these different forms of wealth (Reardon and Vosti, 1995; Holden et al., 1998). Under such a condition, each wealth category would have an independent effect on risk aversion.

Household (head) characteristics: We include several characteristics of the household head including age, gender, and educational level. We included these characteristics of the decision makers without any a priori expectations of the signs. As part of household characteristics, we also include household size and dependency ratios in our model. The effect of family size on risk aversion is ambiguous. On one hand, a large family size represents an increased labor force for the household, and has a negative effect on risk aversion. On the other hand, a larger family means more people to feed, which may increase risk aversion. This variable is therefore included without any a priori expectation of sign. To capture the latter effect separately, we include dependency ratio (the ratio of number of individuals younger than 15 years of age to that of individuals older than 15 years of age) as a separate variable.

Game characteristics: Several characteristics of the game were captured in our model. First, in order to test the hypothesis of Increasing Partial Risk Aversion (IPRA), we include the overall expected value of each game level as a scale variable. In Table 3, it seems that people are more risk averse when there are higher gains at stake, i.e. that their utility functions exhibit increasing partial risk aversion with respect to the possible incomes of the game. Therefore, we expect the sign of this coefficient to be positive for the hypothesis IPRA to be fulfilled. Second, in order to test differences in behavior between gains-only games and games involving losses, we include dummy variables for games involving real losses. As discussed earlier, this is one way of conducting a test on asset integration and loss aversion. If we find this coefficient to be statistically significant, then we reject the conjecture on the presence of asset integration in our experiment, and conclude that decision makers show different behaviors in the two types of games and people do not treat opportunity losses in the same way as real losses. We also include a dummy variable for game 5 in order to test for differences in behavior between real and hypothetical games. Third, in order to capture the effect of previous luck on current choice, we include a variable defined as ΣX_i, where i is an index of previous game numbers, and X takes a value of 1 if the person wins and –1 if he/she loses. Site dummies are also included to capture risk aversion differences across sites under investigation.

5.3. Results and Discussion

The results of the ordered probit model are given in Table 6. To correct for possible hetroscedasticity, the Huber/White/sandwich estimator of variances (White, 1980; StataCorp, 2001) is used, instead of the conventional MLE variance estimator. The reported standard errors are, therefore, robust standard errors.

Table 6: Ordered probit risk aversion estimates

Variable		Parameter Estimates		
		E. Gojjam	S. Wollo	All sites
Gender of the household head (Male=1)		0.716***	0.048**	0.247**
		(0.170)	(0.187)	(0.119)
Age of the household head		-0.017***	-0.010***	-0.012***
		(0.003)	(0.003)	(0.002)
Literacy (1=literate)		-0.150*	0.304***	-0.027
		(0.020)	(0.098)	(0.064)
Family Size		0.053*	-0.013	-0.018
		(0.029)	(0.019)	(0.015)
Dependency ratio		-0.407***	-0.018	-0.232***
		(0.070)	(0.064)	(0.045)
Land size (in hectares)		-0.099	1.107***	0.127*
		(0.090)	(0.087)	(0.079)
Number of plots		0.104***	-0.070*	0.084***
		(0.025)	(0.041)	(0.019)
Number of oxen		0.621***	0.297***	0.473***
		(0.054)	(0.087)	(0.048)
Value of capital stock (in '000 Birr)		0.314***	0.685***	0.385***
		(0.038)	(0.060)	(0.033)
Cash liquidity (in '000 Birr)		0.108*	0.032	0.063***
		(0.059)	(0.022)	(0.021)
Site dummy++ (1=Machakel *wereda*)		-0.566***		-0.572***
		(0.144)		(0.121)
Site dummy (1=Gozamin *wereda*)				-0.356***
				(0.101)
Site dummy (1=Enemay *wereda*)		0.319***		0.095
		(0.109)		(0.105)
Site dummy (1=Tehuldere *wereda*)			0.0002	-0.218**
			(0.114)	(0.109)
Expected payoff		-0.013***	-0.008***	-0.010***
		(0.001)	(0.002)	(0.001)
Dummy for loss games (1=loss games)		-1.055***	-0.183	-0.613***
		(0.105)	(0.151)	(0.089)
Dummy for hypothetical games (1=hypothetical games)		0.393***	0.236	0.299***
		(0.136)	(0.175)	(0.108)
Previous luck		0.105***	0.123***	0.119***
		(0.028)	(0.038)	(0.023)
Ancillary parameters (Threshold parameters)	Cut1 (α_1)	-0.948	-0.365	-0.896
		(0.239)	(0.269)	(0.188)
	Cut2(α_2)	0.287	0.513	0.062
		(0.234)	(0.272)	(0.186)
	Cut3(α_3)	1.282	1.557	1.009
		(0.228)	(0.285)	(0.186)
	Cut4(α_4)	2.159	2.325	1.803
		(0.229)	(0.303)	(0.192)
	Cut5(α_5)	3.099	2.909	2.596
		(0.235)	(0.316)	(0.198)
Log likelihood function		-1109.073	-799.105	-1998.583
Wald Chi-Squared (18)		676.13	404.11	725.97
Pseudo R2		0.2922	0.261	0.265
Number of observations		885	645	1530

Dependent variable: degrees of risk aversion (1=extreme,….6=Neutral to risk loving).
Figures in parentheses are robust standard errors.
***, **, * indicate significance levels at 1%, 5% , and 10% levels, respectively.
++ Kalu is the reference site for South Wollo as well as pooled data, whereas Gozamin is the reference site for East Gojjam.

In the ordered probit model, the dependent variable is an order (rank) of risk aversion where extreme risk aversion takes rank number one and risk-loving ranks number six. Therefore, a positive sign in the ordered probit model shows a reduction in the degree of risk aversion. In general, most variables have a significant effect and the coefficients have the expected signs. All the wealth indicators are significant and positive at the 1% level, indicating that more wealth is correlated with a lower degree of risk aversion. This result is consistent with the common assumption of DARA.

The results on the second group of variables that indicate the characteristics of the household and the household head are mixed. Parameter estimates on educational level of the decision makers, and family size of households are all statistically insignificant for the pooled data. More than 70 % of the sampled household heads are illiterate, and more than 95% have attended no more than 7 years of schooling. Therefore, an absence of significant variation in these variables in our sample might contribute to insignificant effects of schooling on risk aversion. The effect of the number of household dependents on the degree of risk aversion is captured by a separate variable and is found to be highly significant at the 1% level. Households with a higher number of children per adult are more risk averse than those with a low dependency ratio. We found age to be highly correlated with the degree of risk aversion. Older people are more risk averse than younger people. Males are the major decision makers in the vast majority of the population in the country. In our model, male heads are also found to be less risk averse than female heads.

All parameter estimates for the variables indicating the game characteristics are significant. There is a significant negative relationship between the expected payoff variable and the degree of risk aversion, implying that people are likely to take less risk when high gains are at stake. This result is consistent with the IPRA hypothesis discussed earlier in this paper. Second, people are more risk averse in games involving real losses than in gains-only games, as indicated by a statistically significant loss-game dummy variable, once again confirming the presence of loss aversion and the absence of asset integration in our experiment. Third, a statistically significant parameter estimate on dummy variable for the hypothetical game depicts the fact that people are less risk averse in hypothetical games than in real games, which is mere manifestation of the problems involved in hypothetical surveys, i.e. hypothetical bias. Fourth, there is a highly significant relationship between prior luck and degree of risk aversion, as indicated by a significant parameter estimate of the previous luck variable. This implies that people are correcting their subjective probabilities as the game level progresses. Similar behaviors could also be observed in actual farm investment decisions where farm households who had encountered series of droughts to be more reluctant to undertake other risky investment decisions, at least for a while, even when their wealth levels remained unchanged throughout those periods. Finally, a significant parameter estimate on site-dummies shows existing differences in the degree of risk aversion across study sites.

The estimated coefficients of the ordered probit model only portray the general direction of change not specific to each risk category. Changes in the predicted probabilities (marginal effects) of the observed outcomes of risk aversion are provided in Table 7, and simulation results on predicted probabilities are illustrated in Fig. 2 in the Appendix.

Table 7 provides an unambiguous and very substantive interpretation of our regression outputs. For example, holding all other variables at their means, a one year increment in age increases the probabilities of falling into extreme, severe, or intermediate risk categories by 0.001, 0.003, and 0.001 units respectively, but at the same time reduces the probabilities of falling into the moderate, neutral and risk preferring categories by 0.002, 0.002, and 0.008 units respectively. Similarly, holding all other variables at their means, a one hectare increment in land size, or a unit change in the number of plots, or the number of oxen, or in capital stock or cash liquidity, reduces the probabilities of falling into the extreme to intermediate risk aversion categories but at the same time increases the probabilities of ending up in the moderate, neutral, and risk aversion categories by the respective values provided in the table. The figures for dummies can be interpreted in a similar fashion but as discrete changes from 0 to 1. For example, women are more likely to fall into the extreme to intermediate categories, while men are likely to be found in the moderate to risk preferring categories. Similar interpretations can be made for other variables.

A similar conclusion supporting DARA and IPRA can also be drawn from Fig 2. Farm households are inclined to undertake relatively more risky decisions at higher than at lower levels of either of the wealth indicators.

Table 7: Changes in Predicted Probabilities (marginal effects) by Risk Categories

Variables	Changes in Predicted Probabilities (marginal effects)					
	Extreme	Severe	Intermediate	Moderate	Neutral	Preferring
Gender of the household head (male=1)	-0.032*	-0.053**	-0.006*	0.042*	0.035**	0.014**
	(0.019)	(0.026)	(0.003)	(0.022)	(0.016)	(0.006)
Age of the household head	0.001***	0.003***	0.0007***	-0.002***	-0.002***	-0.0008***
	(0.0003)	(0.0005)	(0.0002)	(0.0004)	(0.0004)	(0.0002)
Literacy (1=literate)	0.003	0.006	0.002	-0.004	-0.004	-0.002
	(0.007)	(0.014)	(0.004)	(0.011)	(0.01)	(0.004)
Family Size	0.002	0.004	0.001	-0.003	-0.003	-0.001
	(0.001)	(0.003)	(0.001)	(0.002)	(0.002)	(0.001)
Dependency ratio	0.026***	0.050***	0.013***	-0.038***	-0.035***	-0.016***
	(0.005)	(0.010)	(0.004)	(0.008)	(0.007)	(0.003)
Land size (in hectares)	-0.014***	-0.027***	-0.007	0.021	0.019	0.009
	(0.009)	(0.017)	(0.005)	(0.013)	(0.012)	(0.005)
Number of plots	-0.009***	-0.018***	-0.005***	0.014***	0.013***	0.006***
	(0.002)	(0.004)	(0.001)	(0.003)	(0.003)	(0.001)
Number of Oxen	-0.052***	-0.101***	-0.027***	0.077***	0.072***	0.032***
	(0.006)	(0.012)	(0.006)	(0.011)	(0.008)	(0.005)
Value of capital stock (in ‘000 Birr)	-0.042***	-0.082***	-0.022***	0.062***	0.058***	0.026***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Cash liquidity (in ‘000 Birr)	-0.007***	-0.013***	-0.004***	0.010***	0.010***	0.004***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Site dummy++ (1=Machakel *wereda*)	0.084***	0.119***	-0.002	-0.099***	-0.074***	-0.028***
	(0.022)	(0.024)	(0.009)	(0.022)	(0.014)	(0.006)
Site dummy (1=Gozamin *wereda*)	0.046***	0.076***	0.009**	-0.061***	-0.050***	-0.020***
	(0.015)	(0.021)	(0.004)	(0.018)	(0.013)	(0.006)
Site dummy (1=Enemay *wereda*)	-0.010	-0.020	-0.006	0.015	0.015	0.007
	(0.010)	(0.022)	(0.008)	(0.016)	(0.017)	(0.008)
Site dummy (1=Tehuldere *wereda*)	0.027*	0.047**	0.007***	-0.037*	-0.031**	-0.013**
	(0.015)	(0.023)	(0.003)	(0.019)	(0.014)	(0.006)
Expected payoff	0.001***	0.002***	0.001***	-0.002***	-0.002***	-0.0007***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)	(0.0002)	(0.0001)
Dummy for loss games (1=loss games)	0.088***	0.127***	0.003	-0.105***	-0.081***	-0.032***
	(0.016)	(0.019)	(0.008)	(0.018)	(0.011)	(0.005)
Dummy for hypothetical games (1=hypothetical games)	-0.029***	-0.062***	-0.025**	0.044***	0.048***	0.024**
	(0.009)	(0.022)	(0.013)	(0.015)	(0.018)	(0.011)
Previous luck	-0.013***	-0.025***	-0.007***	0.019***	0.018***	0.008***
	(0.003)	(0.005)	(0.002)	(0.004)	(0.004)	(0.002)

Dependent variable: degrees of risk aversion.
Figures in parentheses are standard errors.
***, **, * indicate significance levels at the 1%, 5%, and 10% levels respectively.
++ Kalu is the reference site.
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6. Conclusions and policy implications

Many development practitioners and researchers have long recognized that production and investment decisions of farm households in developing countries are affected by various kinds of risk including drought, pests, flooding, frost, livestock diseases, own illness, war and crime, which in one way or another affect their livelihood from agricultural activities. Because of poorly developed or absent credit and insurance markets, it is difficult to cover or pass any of these risks to a third party. As a result, they are usually reluctant to engage in any investment venture, such as adoption of new farm technologies, when it involves higher degree of risk in terms of loss in agricultural income. Despite its crucial role in farm investment decisions, however, there have been few efforts in the empirical literature to estimate the magnitude and nature of risk aversion of farm households in developing countries. This study is one attempt to reveal farmers' preferences towards risk in a developing country using an experimental approach with real payoffs. It uses a sample of 262 households in seven villages on the Ethiopian highlands. We found more than 50 percent of the households in the severe to extreme risk aversion categories, unlike similar studies in Asia where the vast majorities are found in the moderate to intermediate risk aversion categories. With careful construction of the experiment, the natures of absolute and partial risk aversion are examined. Our data supports the presence of decreasing absolute risk aversion (DARA), and increasing partial risk aversion (IPRA) behaviors. The presence of DARA indicates the existing significant difference in risk behavior between relatively poor and wealthy farm households, whereas IPRA indicates differences in risk behavior for investment activities resulting in smaller vis-à-vis larger pay-offs. We also find significant differences between real and hypothetical games, showing the problems involved in surveys that are launched in hypothetical settings.

Our findings are also consistent with economic theory which postulates that, in the absence of insurance markets, poor farm households tend to be highly risk averse and become more reluctant to participate in many farm investment activities that are uncertain and/or involve higher risk. In this study, in the absence of insurance and credit markets, household stock of wealth (including livestock and land) seems to govern household behavior towards risk. Households' dependency ratio also seems to have a significant impact on their risk behaviour. Hence, supplementary policy interventions that reduce poverty and asset scarcity, and households' dependency ratio would have an impact on risk behavior of farm households. In the long run, broad based economic development including the development of credit and insurance markets is the most certain way to correct the existing market imperfections and to reduce the levels of risk aversion among farmers.

This paper also tested the validity of some of the predictions of the standard expected utility model. The predictions of risk neutrality for smaller stakes, and of preferences that are similar for gains and losses, stemming from the major tenets of the theory (i.e. concavity and asset integration) are not supported by our experiment. Significant differences in risk preferences between gain and loss games verified the absence of asset integration in evaluating their utility functions. Useful concepts in modern research on choice under uncertainty such as loss aversion, myopic loss aversion, mental accounting and narrow bracketing may explain the foregoing anomalies in expected utility theory. The prospect theory of Kahneman and Tversky (1979) is one effort to incorporate loss aversion and other psychological aspects of decisions in choice theory.

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Appendix: Risk preference games

Set 1: 0.50 Birr

Gains-only			Risk aversion class	Gains and losses	
Choice	Bad harvest	Good harvest		Bad harvest	Good harvest
1	0.50	0.50	Extreme	0	0
2	0.45	0.90	Severe	-0.05	0.40
3	0.40	1.20	Intermediate	-0.10	0.70
4	0.30	1.50	Moderate	-0.20	1.00
5	0.10	1.90	Slight to neutral	-0.40	1.40
6	0	2.00	Neutral to preferring	-0.50	1.50

Set 2: Birr 2.50

Gains-only			Risk aversion class	Gains and losses	
Choice	Bad harvest	Good harvest		Bad harvest	Good harvest
1	2.50	2.50	Extreme	0	0
2	2.25	4.50	Severe	-0.25	2.00
3	2.00	6.00	Intermediate	-0.50	3.50
4	1.50	7.50	Moderate	-1.00	5.00
5	0.50	9.00	Slight to neutral	-2.00	7.00
6	0	10.00	Neutral to preferring	-2.50	7.50

Set 3: Birr 5

Gains-only			Risk aversion class	Gains and losses	
Choice	Bad harvest	Good harvest		Bad harvest	Good harvest
1	5.00	5.00	Extreme	0	0
2	4.50	9.00	Severe	-0.50	4.00
3	4.00	12.00	Intermediate	-1.00	7.00
4	3.00	15.00	Moderate	-2.00	10.00
5	1.00	19.00	Slight to neutral	-4.00	14.00
6	0	20.00	Neutral to preferring	-5.00	15.00

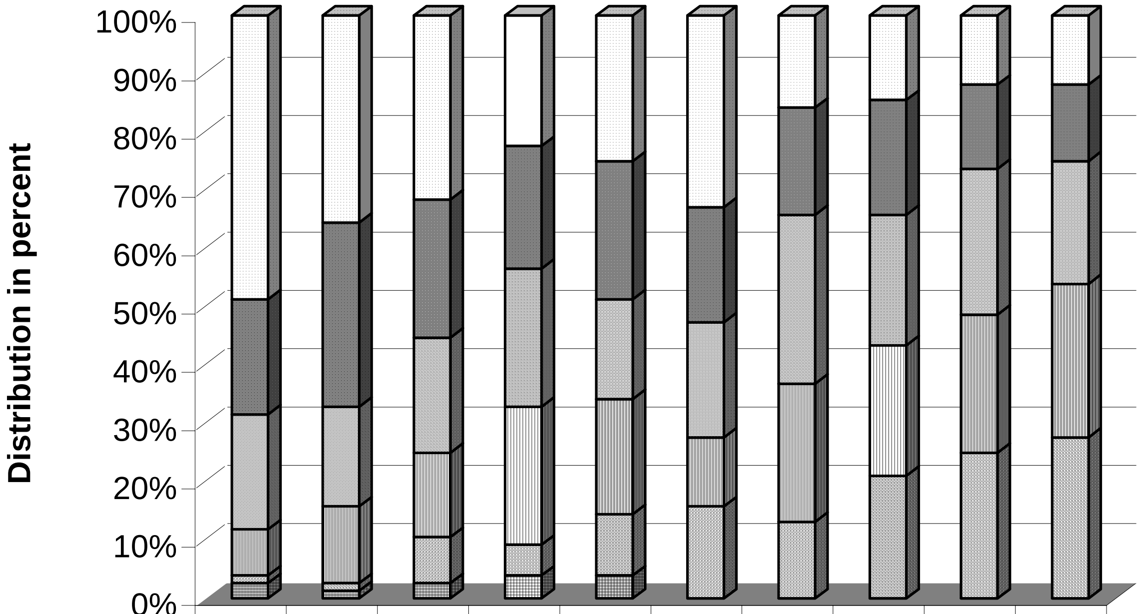
Set 4: Birr 10

Gains-only			Risk aversion class	Gains and losses	
Choice	Bad harvest	Good harvest		Bad harvest	Good harvest
1	10.00	10.00	Extreme	0	0
2	9.00	18.00	Severe	-1.00	8.00
3	8.00	24.00	Intermediate	-2.00	14.00
4	6.00	30.00	Moderate	-4.00	20.00
5	2.00	38.00	Slight to neutral	-8.00	28.00
6	0	40.00	Neutral to preferring	-10.00	30.00

Set 5: Birr 15 (hypothetical)

Gains-only			Risk aversion class	Gains and losses	
Choice	Bad harvest	Good harvest		Bad harvest	Good Harvest
1	15.00	15.00	Extreme	0	0
2	13.50	27.00	Severe	-1.50	12.00
3	12.00	36.00	Intermediate	-3.00	21.00
4	9.00	45.00	Moderate	-6.00	30.00
5	3.00	57.00	Slight to neutral	-12.00	42.00
6	0	60.00	Neutral to preferring	-15.00	45.00

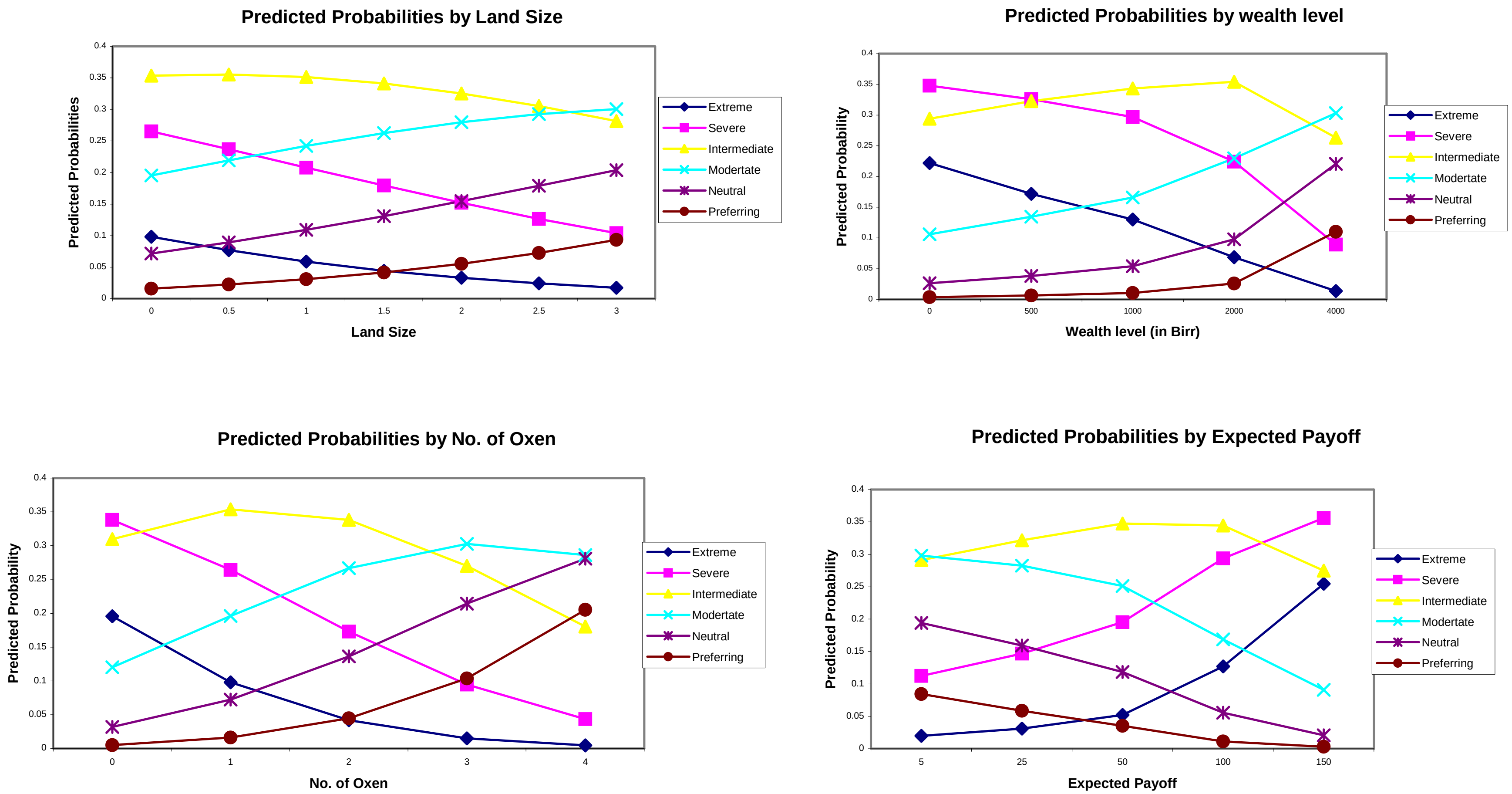
Fig. 1. Comparison of risk distribution between gains-only, and gains and losses games of the experiment (only those who played both)



	1	2	3	4	5	6	7	8	9	10
Preferring	37	27	24	17	19	25	12	11	9	9
Nuetral	15	24	18	16	18	15	14	15	11	10
Moderate	15	13	15	18	13	15	22	17	19	16
Intermediate	6	10	11	18	15	9	18	17	18	20
Severe	1	1	6	4	8	12	10	16	19	21
Extreme	2	1	2	3	3	0	0	0	0	0

Game levels (Nos. 6 to 10 are loss games)

Fig. 2. Predicted probabilities



Time Preferences of Farm Households in Ethiopia[+]

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Abstract
This study measures farmers' subjective discount rates using an experimental approach with monetary incentives for a sample of 262 farm households in the Ethiopian highlands. The median subjective discount rate is more than 43%, more than double the interest rate on the outstanding debt. Given imperfect credit markets, household wealth (physical asset) levels are found to be highly correlated to this attitude measure. The validity of some of the predictions of the discounted utility theory is tested and time frame effect, magnitude effect, and delay/speed up asymmetry are anomalies that are found in our single-parameter based discounting approach. High discount rate found in this study could explain why poor farm households with a binding credit constraint ignore or insufficiently internalise on-site user cost of soil erosion (even with complete information and property rights) and impose an intergenerational externality with little or no adoption of soil conservation technologies.

Key Words: discounting, Ethiopian farm households, experimental studies, interval regression, time preference

JEL Classification: C24; C93; D12; D91; Q12; Q21

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1. Introduction

In the literature, it has been argued that poverty may lead to short planning horizons in which people are forced to exploit resources to meet short-term needs, regardless of the long-term consequences. Poverty suggests a strong preference for income today rather than investments (such as soil conservation) for income tomorrow. These kinds of poverty induced environmental degradation arguments are clearly articulated in at least two important policy documents: the Brundtland commission report (WCED, 1987), and subsequently in a World Bank report (World Bank, 1996). It is also indicated in the environmental and resource economics literature that the higher the discount rate, the faster the optimal rate of depletion of non-renewable resources (Hotelling, 1931), the lower the optimal steady state stock of a renewable resource (Clark, 1976), and reduced incentives for cooperation in managing common property resources (Hardin, 1968). Therefore, in countries where poverty and environmental degradation are highly intertwined and credit and insurance markets are imperfect or completely absent, the extent to which people discount the future is believed to be strongly correlated to sustainability of resource use.

Despite its crucial role in policy-making, however, there have been few empirical studies estimating the farm households' subjective discount rates in developing countries. Frederick et al. (2002) tabulate over forty attempts at empirical estimations of discount rates, of which only two were done in farm villages of developing countries: Pender (1996) and Holden et al. (1998). This study is another attempt to reveal farmers' subjective discount rates in a developing country. It uses a sample of 262 households in seven villages on the Ethiopian highlands that are part of a larger land use survey.

In the empirical literature, two procedures have been used to estimate subjective discount rates: actual consumption surveys in which discount rates are inferred from economic decisions that people make in their ordinary life (see Hausman, 1979; Moore and Viscusi, 1990; Dreyfus and Viscusi, 1995), and experimental studies in which people are asked to evaluate stylized inter-temporal prospects involving real or hypothetical outcomes (see Frederick et al., 2002, for an overview). Because of difficulties in obtaining and interpreting actual consumption data for purposes of computing discount rates, using experimental studies is the most common method for eliciting discount rates. There are however some concerns regarding the use of experiments to elicit discount rates.

One such concern is a hypothetical bias if the experiment is launched on hypothetical payoffs. Since people might not be motivated to accurately reveal their true preferences in hypothetical choices, the use of real rewards is desirable. The current study is conducted using a real payoff setting, and hence possibilities of hypothetical bias are very unlikely.

Another basic concern with the use of an experimental approach is its inability to control for a host of different confounding factors (other than the pure time preference) that come into play at an individual level when making inter-temporal decisions. Frederik et al. (2002) enumerate inter-temporal arbitrage, inflation considerations, the collection of tendencies labeled as habit formation, and visceral influences as some of the factors affecting subjects' inter-temporal decisions. Given the fact that the current experiment is conducted in an economic setting where capital markets are thin and people have no excessive inflation experience in the past, the effects of inter-temporal arbitrage and considerations of inflation are minimal. Other confounding factors are less applicable to our experimental setting. The other concern with the experimental approach is the reliance on a single-parameter discounted utility model, which attaches a single exponential discount rate to explain subjects' inter-temporal choices. Frederick et al. (2002) enumerate a number of anomalous results that have induced a number of researchers to think about other representations of discounting behavior. Many researchers have now explored these anomalies (e.g. Loewenstein and Thaler, 1989; Loewenstein and Prelec, 1992). In our experiment, we test for the presence of the most common types of anomalies such as whether subjects reveal the same preference for relatively small and large rewards (magnitude effect), whether they reveal similar preferences for relatively short and long period rewards (time frame effect), and whether framing the experiment as a delay or speeding up of consumption from a certain reference point affects their preferences (delay/speed-up asymmetry or framing effect, or version effect).

The rest of the paper is organized as follows: Section 2 discusses the underlying economic theory behind the measure of time preferences and investigates the nature of the time preferences in two different credit market scenarios. In Section 3, both the methodological and measurement difficulties involved in the empirical stage of measurement of the time preferences are discussed. The design of the experiment and the characteristics of the respondents are described in Section 4. Descriptive and econometric outcomes of the experiment are presented in Section 5 and 6, respectively. Finally, Section 7 concludes the paper.

2. Theory

Individual Rate of Time Preference (RTP) is a measure of the inter-temporal rate of substitution of consumption at different points in time. In conventional neo-classical economics, this trade-off between outcomes occurring at different points in time has been explained by the discounted utility model. The RTP is the sum of two components as given in equation 1.[10] The first term, δ, captures the marginal rate of substitution for the same level of consumption and is a "pure" or "myopic" preference for consuming a good sooner rather than later. The second term, μ_g, describes the effect of the future change in the consumption level on the marginal rate of substitution between the two periods. μ is the negative of the elasticity of marginal utility of consumption , and g is the expected rate of growth in per capita consumption.

$$RTP = \delta + \mu g \, , \qquad (1)$$

It can be shown that in a well-functioning economy where credit constraints are not binding, the RTP is equal to one plus the fixed market interest rate. Thus, the pure rate of time preference is irrelevant in measuring RTP. On the other hand, in a very special case of poor countries where economic growth is stagnant implying that the rate of growth of income (consumption) is zero, and credit markets are imperfect or missing implying that credit supplies are binding, the RTP is equal to the pure rate of time preference and deviates sufficiently from the market rate of interest. These two extreme cases are illustrated below.

[10] See Markandya and Pearce (1988) for a lucid derivation of this equation.

Case1: RTP when access to borrowing is unlimited

Consider an individual household whose task is to find out the optimal level of borrowing (B^*) at a fixed interest rate r that maximizes its discounted utility function. To get important implications on risk, the objective function is set to incorporate uncertainties into future income earnings.

$$\underset{B}{Max}\, U(C_t) + EU(C_{t+1}) \tag{2}$$

where $C_t = W_t + B$, $C_{t+1} = W_{t+1} - (1+r)B$, and $W_{t+1} = Y + V$. W_t, and W_{t+1} are wealth (income) levels in the current and the future period, and the future income is composed of certain income (Y) and uncertain element (V). The usual restriction on utilities, $U^{'}(C) > 0$, $U^{''}(C) < 0$, is also assumed here.

Solving the first order condition of the borrower's problem, we find the following standard result:

$$1 + r = \frac{U_t^{'}(C_t)}{EU_{t+1}^{'}(C_{t+1})} = RTP\ . \tag{3}$$

Equation (3) has an important implication when measuring the RTP of a theoretical farm household facing unlimited borrowing access or possibilities. The RTP is exactly equal to one plus the fixed market rate of interest. No factor, except some exogenous factors affecting the market rate of interest, determines RTP. For such a farm household, neither wealth nor the shape of the utility function is relevant to its marginal rates of inter-temporal substitution.

Case2: RTP when access to borrowing is limited

Consider the same problem as in Equation (2), but now with a binding credit constraint. An individual household can't borrow more than a certain maximum level, say B_{max}. This is a common phenomenon in rural areas of many developing countries. Access to credit markets is constrained due to moral hazard and adverse selection problems in formal markets (Stigliz and Weiss, 1981) and due to lack of collateral and lenders' risk hypothesis in informal markets (Binswanger and Sillers, 1983). These are the two basic economic theory explanations to many empirical findings that farm households in many developing countries have little access to formal credit, or that they otherwise are charged with excessive interest rates by informal lenders. Now that the individual household in Equation (2) faces a binding credit constraint, $B \leq B_{\max}$, solving the first order condition for a constrained optimization problem would result in the following:

$$1 + r + \frac{\lambda}{EU'_{t+1}(C_{t+1})} = \frac{U'_t(C_t)}{EU'_{t+1}(C_{t+1})} = RTP\ , \tag{4}$$

where λ is the shadow value of a credit constraint. A simple comparison of Equations (3) and (4) shows that the RTP is higher when an individual faces a binding credit constraint. A positive shadow value on the credit constraint (λ) increases the inter-temporal marginal rate of substitution. Furthermore, factors affecting the expected marginal utilities of future consumption such as wealth, riskiness of future income and possibilities of insurance are important determinants of RTP. Therefore, following the predictions in Equation (4), we hypothesize that farm households with lower levels of wealth (cattle) have little access to credit and are more likely to have high RTPs. Furthermore, these households are more likely to become risk averse since they could not hedge any risk of crop failure with their cattle. This makes their RTPs even higher.

3. Methodological Issues

The most pervasive problem in the study of time preference is the measurement issue. One procedure for measuring time preference is by the use of experiments that determine a subject's indifference between two outcomes that vary in time and level. If we define the indirect utility function by $V(W_t, W_{t+1})$, then the subjective discount rate will be inferred from the rate that discounts the future reward such that an individual will be indifferent between that reward and the current reward (X). Mathematically, the subjective discount rate, *d*, is defined implicitly in Equation (5):

$$V(W_t + X, W_{t+1}) \equiv V(W_t, (1+d)X + W_{t+1}), \tag{5}$$

where $d = r + \dfrac{\lambda}{EU'_{t+1}(C_{t+1})}$.

During the empirical stage, the most insidious problem under such settings is hypothetical bias if the experiment is launched using hypothetical survey questions. Even with real pay-off experiments, if respondents lack confidence that a promised future reward will actually be paid (subjective risk consideration), they might tend to prefer a current reward irrespective of their actual discount rate. These two problems are specifically addressed in the design of the current study. The experiment was conducted using real-payoffs. Those households that chose future payments were given receivables from their respective peasant associations, which would enable them to collect their money at the specified time. These arrangements were communicated to the farm households before the experiment. Given such practicalities, we feel that there are real incentives for farm households to reveal their true preferences and hence the risk of hypothetical bias is minimized in our experiment.

A growing concern in the empirical studies of subjective discount rates is the findings of anomalous results, which are discussed extensively in the works of Loewenstein and Thaler (1989), and Loewenstein and Prelec (1992). The discounted utility model dictates a constant exponential discount rate irrespective of time frames, magnitudes and framing of the experiment. However, four kinds of anomalies are commonly identified in the literature: common difference effect, magnitude effect, delay/speed-up asymmetry, and gain/loss asymmetry. Following the example of Loewenstein and Prelec (1992), the common difference effect is said to happen, for example, when a person prefers one apple today to two apples tomorrow, but at the same time prefers two apples in 51 days to one apple in 50 days. This particular phenomenon is sometimes called hyperbolic discounting. Common difference effect also implies that discount rates should decrease as a function of time delay (time frame effect). Magnitude effect refers to the situation where larger sums of money suffer less proportional discounting than smaller ones. A closely related finding is that losses are discounted at a lower rate than gains. This latter finding is termed as gain/loss asymmetry. Finally, the findings that the amount required to compensate for delaying receipt of a reward by a given interval, from *t* to *t* + *s*, is significantly different from the amount subjects are willing to sacrifice to speed consumption up by the same interval, i.e. from *t* + *s* to *t* is referred to as delay/speed-up asymmetry. Loewenstein and Parlec (1992) found the former to be larger than the latter. Because the two pairs of choices are actually different representations of the same underlying pair of options, the results constitute a classic framing effect, which is inconsistent with the standard theory. In our study, three of the above anomalies (magnitude, timeframe and delay/speed-up asymmetry) are tested empirically.

4. Description of the experiment and households

Following Pender's simple experimental design, an experimental approach was employed on a random sample of households in seven villages on the highland of Ethiopia. The villages were located in two different zones (East Gojjam and South Wollo) on the highland of Ethiopia. East Gojjam is generally considered to have a good potential for agriculture, whereas South Wollo is considered to be seriously affected by soil erosion and subjected to recurrent drought.

Each farm household was subjected to four experiment sets, in which they were offered a number of choices between a specific amount of money to be received on a current date and an alternative amount to be received on an alternative future date. Each choice set was presented on a card, on which the respondent's preference was also recorded. After completing all 28 cards, the participant randomly selected one of the cards. The choice made on the selected card determined the reward payment made to the participant.

To test for the presence of magnitude and time frame effects, each set of the experiment was set to reflect different magnitudes of rewards (Birr 15 and 40)[11] and time frames (3,6, and 12 months). To test for the presence of delay/speed-up asymmetry, two versions of the experiment were dispatched: the first trying to delay current consumption and the second negotiating to speed up future consumption. In other words, in version one, all current rewards were set to be fixed, and only future rewards were changed in order to determine the point of indifference. In the second version, future rewards were fixed and only current rewards varied in order to determine

[11] These nominal payoffs are equivalent to US$1.76 and US$4.7 respectively (US$1=Birr 8.5), corresponding to 5% and 13% of monthly income of unskilled labor in the country, respectively.

the point of indifference. On average, each household won a sum of Birr 25, which is about 8 percent of the monthly income of unskilled labor in the country. This was felt to be a significant incentive for respondents to carefully consider the options and reveal their true preferences. The full format of the experiment is presented in the Appendix.

A total of 262 households participated in the main experiment. With the exception of six households, the entire experiment was done with the heads of the households. The experiment was conducted in February 2002. The basic descriptive statistics of our respondents are given in Table 1.

Table 1: Basic descriptive statistics of participating farm households, N=262

Variable	Mean	Std dev	Min	Max
Gender of the respondent (1=male)	0.85	0.34	0	1
Age of the respondent	46.73	15.77	15	90
Literacy (1=yes)	0.27	0.45	0	1
Family size	5.39	2.44	1	15
Household dependency ratio (the ratio of number of household members below age15 to age more than 15)	1.02	0.80	0	5
Household farm size	0.96	0.70	0.01	3.38
Number of plots	4.91	2.55	1	9
Number of oxen	1.38	1.15	0	4
Value of domestic animals in '000 Ethiopian Birr (Proxy for stock of wealth)	1.95	1.76	0.01	8.87
Annual liquid cash availability to a household in '000 Ethiopian Birr (Cash collected from all sources of cash revenue less cash expenditure in one year)	0.35	0.93	-2.37	9.57
Level of risk aversion (1 = extreme risk aversion, 6 = risk lover),[12]	2.94	1.55	1	6

5. Descriptive analysis

We start our analysis by exploring the responses of participants for each set of the experiment. For each choice set, the implicit discount rate can be inferred by taking the trade-off between the current and future rewards.[13] The discount rates are inferred only for consistent responses. The responses of a participant are considered to be consistent if he/she chooses either only the current rewards (right censored), or only the future rewards (left censored), or chooses part current and part future rewards but cross (changes preference) only once throughout the choice (an interval discount rate). A

12 Six levels were used to classify risk levels of farm households, where 1 for extreme risk aversion and 6 for risk loving behaviors. For more insights on data collection and estimation of the level of risk aversion, see Yesuf (2003).

13 Discount rates were calculated by the formula d=[ln (f/p)]/(s-t), where f is future reward at time s, and p current reward at time t, where s and t are expressed in years.

participant who crosses more than once is considered inconsistent and no discount rate is inferred from his/her choice, and hence the respondent is considered missing in the analysis.[14] Table 2 displays outcomes of the four sets in the two versions of the experiment.

In Table 2, we observe three important patterns. First, in all the experiments a good deal of the participants preferred the current vis-à-vis the future reward. The proportions of these ranges from 36-39% percent in Set 1 to 64-67% in Set 4. This shows that, using a simple majority rule, a large proportion of the farm households have high subjective discount rates.

[14] In the entire experiment, we encountered only 2 percent inconsistent responses.

Table 2: Structure of discount rate responses[+]

Experiment sets	Version one Reference date = current				Version two Reference date = future				All			
	Left censored	Right censored	Interval discount rates	Inconsistent responses	Left censored	Right censored	Interval discount rates	Inconsistent responses	Left censored	Right censored	Interval discount rates	Inconsistent responses
3 months, Birr 15	15%	39%	42%	4%	22%	36%	42%	0%	19%	37%	42%	2%
6 months, Birr 15	9%	54%	33%	4%	19%	58%	23%	0%	15%	56%	27%	2%
6 months, Birr 40	9%	28%	58%	5%	21%	36%	43%	0%	16%	32%	50%	2%
12 months, Birr 40	3%	67%	27%	3%	12%	64%	24%	0%	8%	65%	26%	1%
Total	9%	47%	40%	4%	19%	48%	33%	0%	14%	48%	36%	2%

+ Percentage shares should be read as row percentages for each version and each experiment set.

Second, there is both a time frame and a magnitude effect in the responses. The proportion of right-censored responses (preference for current reward) increases from 37 percent in the shorter period-smaller reward experiment (Set 1) to 65 percent in the longer period-larger reward experiment (Set 4) for the entire sample, whereas the proportion of left censored responses (preference for future reward) declines from 19 percent to 8 percent as we move from Set 1 to Set 4. Many left-censored observations in version 2 (19% in total) compared to in version 1 (9% in total) shows the presence of delay/speed-up asymmetry in the experiment. This conforms to the findings of Loewenstein and Prelec (1992) that subjects demand more to delay consumption than they are willing to sacrifice to speed up consumption. Formal chi-square tests for all observed anomalies are conducted later in the econometrics section.

Next we turn our attention to measuring the discount rates for each set of the experiment. The median discount rates for each set of experiments are presented in Table 3. In general, the median discount rates are very high and are far away from the reported interest rates on outstanding debt of the farm households, which are reported to be 20 percent on average.

Table 3: Median Discount Rates+

	Median Discount Rate (in %)		
Time frame	East Gojjam	South Wollo	All Households
3 months, Birr 15	106	105	105
6 months, Birr 15	81	58	58
6 months, Birr 40	50	72	63
12 months, Birr 40	43	56	43

+ We use mid-points for interval discount rates, and end points for left or right censored discount rates.

Comparing the median annual discount rates (last row in Table 3) to other similar studies, Pender (1996) reported a discount rate of 30-60 % for Indian villages, whereas Holden et al. (1998) found a mean discount rate of 93% for Indonesia, 104% for Zambia, and 53% for one village in Ethiopia, which are not too far from our findings.

6. Econometric Analysis

In the absence of a well-functioning credit market, time preferences of households are governed by their physical assets and other household characteristics. In what follows, we use econometric techniques to investigate the variables that explain variations in the subjective discount rates of our sample of households.

6.1 The Econometric model

In our experiment, the discount rates take either of three forms: right-censored if the participants choose only current rewards, left-censored if they only prefer to wait for the future rewards, or interval discount rates if they switch (cross) from current to future rewards at a certain level of the experiment. Thus the dependent variable is only observed to fall in a certain interval on a continuous scale - its actual value remains unobserved. Both end intervals are also assumed to be open-ended.

The interval regression model is an appropriate model for this type of data. The latent structure of the model to be considered is assumed to be given by

$$y^*_{ij} = x_{ij}\beta + u_{ij}\,;\; u_{ij} \sim iidN(0,\sigma^2) \qquad (6)$$

where y^* is the unobserved dependent variable, x is a vector of regressors, and β and σ are unknown parameters to be estimated. The indices i and j are used to indicate observation of the i^{th} individual in the j^{th} experiment. The observed information concerning the dependent variable is that it falls into a certain interval of the real line. The real line is divided into K intervals, the K^{th} being given by (A_{k-1}, A_k) and the K intervals exhausting the real line. Thus, $A_0 = -\infty$ and $A_k = +\infty$; i.e. the first and the K^{th} intervals are open ended

6.2 Results and discussion

We used the econometric model to determine factors explaining the variations in the subjective discount rates within each set of the experiment. We also used the same model to find an explanation to the variations in the subjective discount rates across the experiments. The explanatory variables are chosen based on the predictions of Equation 4 shown earlier in the theory section. We have used proxy variables to indicate the level of wealth (both current and overall stock). Household characteristics are also included with no a priori expectation of the signs.

Results of factors explaining variations in the RTP for each of the four experiment sets, and the pooled data, are given in Table 4. To correct for possible heteroscedasticity, the Huber/White/sandwich estimator of variances (White, 1980; StataCorp, 2001) is used instead of the conventional MLE variance estimator. The reported standard errors are, therefore, robust standard errors.

In the interval regressions none of the demographic variables such as gender, age, family size, and education are not significant in explaining variations in the discount rates across farm households, and hence are not reported in the table. However, parameter estimates on wealth indicators such as value of capital stock, number of oxen, and land size are highly significant for the pooled data. Farm households with a relatively better stock of capital, bigger farm sizes, and a large number of oxen are likely to have relatively low discount rates. This result conforms to the credit-rationing hypothesis which predicts that wealthier households face lower interest rates and hence borrow more in a rationed credit market than poorer households. Greater access to credit implies lower subjective discount rates. Furthermore, the degree of risk aversion in a farm household is a significant explanatory variable for discount rate variations across farm households. Risk averse farmers are more likely to have high discount rates as well. This might be because either risk averse households are myopic in their consumption decision (higher δ), or have lower elasticity of marginal utility of future consumption (lower μ), or they participate less in the existing formal credit market and hence are confronted with higher shadow prices (higher λ). There is no economic theory that clearly describes the relationship between risk and time preferences. We also include liquid cash availability in our regression to test whether cash income influences or is correlated with discount rates. Cash liquidity is calculated as the difference between all sources of cash revenue (such as crop sales, off-farm income, and remittance) and cash expenditure (such as crop purchase, household items purchase, and debt payment). However, the coefficient for this variable is insignificant for the pooled data.

Table 4: Interval Regression

Variable		Parameter estimates+						
		Exp. Set 1	Exp. Set 2	Exp. Set 3	Exp. Set 4	E. Gojjam	S. Wollo	Pooled
Constant		2.296 *** (0.452)	1.126*** (0.366)	1.372*** (0.308)	1.333*** (0.221)	2.391*** (0.302)	1.383 (0.253)	1.741*** (0.209)
Land size (in hectares)		-0.248** (0.117)	-0.385*** (0.103)	-0.188** (0.082)	-0.172*** (0.053)	-0.195*** (0.066)	-0.351*** (0.081)	-0.265*** (0.050)
Number of Oxen		-0.150 (0.107)	-0.105 (0.090)	-0.057 (0.061)	-0.099** (0.046)	-0.233*** (0.066)	-0.016 (0.054)	-0.119*** (0.042)
Value of capital stock (in '000 Birr)		-0.122* (0.067)	-0.108** (0.054)	-0.122*** (0.039)	-0.066** (0.026)	-0.127*** (0.033)	-0.077* (0.043)	-0.115*** (0.026)
Cash liquidity (in '000 Birr)		-0.133* (0.070)	-0.028 (0.045)	-0.049 (0.038)	0.055** (0.024)	-0.030 (0.053)	-0.037 (0.027)	-0.022 (0.026)
Risk aversion		-0.312*** (0.066)	-0.120** (0.058)	-0.153*** (0.041)	-0.096*** (0.035)	-0.1849*** (0.044)	-0.161*** (0.036)	-0.184*** (0.028)
Site dummy++ (1=Gozamin wereda)		0.117 (0.206)	0.274 (0.194)	0.0008 (0.130)	0.127 (0.091)	0.142 (0.100)		0.136 (0.089)
Site dummy (1=Enemay wereda)		-0.111 (0.219)	-0.499** (0.209)	-0.051 (0.152)	-0.316** (0.133)	0.086 (0.120)		-0.247** (0.102)
Site dummy (1=Tehuldere wereda)		0.142 (0.179)	0.115 (0.148)	-0.007 (0.115)	-0.006 (0.104)		0.124 (0.077)	0.032 (0.076)
Version dummy (1=Set 2)		0.755*** (0.172)	0.323** (0.135)	0.223** (0.110)	-0.050 (0.080			0.340*** (0.073)
Experiment dummy (1=Set 1)						0.093 (0.100)	0.053 (0.086)	0.075 (0.070)
Experiment dummy (1=Set 3)						-0.346*** (0.094)	-0.070 (0.080)	-0.220*** (0.064)
Experiment dummy (1=Set4)						0.044 (0.094)	0.227*** (0.086)	0.133** (0.068)
Number of observations: Uncensored	Overall	228	228	228	232	512	404	916
	Uncensored	0	0	0	0	0	0	0
	Left Censored	45	34	36	20	99	36	135
	Right censored	76	127	69	149	229	192	421
	Interval observations	107	67	123	63	184	176	360
Sigma (σ)		0.696 (0.053)	0.542 (0.053)	0.467 (0.033)	0.301 (0.033)	0.580 (0.038)	0.500 (0.029)	0.567 (0.024)
Log likelihood function		-318.58	-267.41	-396.95	-233.12	-652.81	-586.89	-1262.220
Chi-Squared		202.99	107.49	189.85	138.81	411.44	213.73	538.99

Figures in parentheses are robust standard errors.
***, **, * indicate significance levels at 1%, 5% and 10% levels, respectively.
+ Computed at mean of other regressors. All household demographic variables are found to be insignificant and hence are not reported in the table.
++ Kalu is the reference site for the South Wollo as well as pooled data, whereas Machakel is the reference site for East Gojjam.

Of particular interest in the pooled data regression is the inclusion of experimental dummies to conduct tests on magnitude, and time frame effects. The test for delay/speed-up asymmetry is conducted through the version dummy.

Experimental effects relative to Set 2 are shown by parameter estimates on experimental dummies. In general, discount rates from Set 2 are lower than those in Set 4, higher than those in Set 3, but are not statistically different from those in Set 1. This outcome is the result of a combination of factors such as magnitude and time frame effects.

In our design of the experiment, we set Sets 1 & 2, and 3 & 4 to reflect the same level of reward but different time frames. Therefore, the only conceivable explanation for differences in discount rates between Sets 1 & 2 (shorter time frame) and 3 & 4 (longer time frame) is a time frame effect. Similarly, Sets 2 & 3 are designed so as to capture the pure magnitude effects in the time preference experiment. Both experiment sets reflect the same time frames (6 months) but differ in the magnitude of the rewards. We also dispatched two versions of the experiments to capture the experimental design effect (framing effect or delay/speed-up asymmetry) on variations in the RTP.

The results of formal statistical tests on magnitude, time frame and version effects on all experiments are presented in Table 5.

Table 5: Chi Square and standardized t-tests for experimental effects for the pooled data

Effect	**Hypothesis:**	**Statistics**	**Result of the test**
Pure magnitude effects	Exp 2 = Exp 3	-3.44 (0.001)	Rejected at 1% level
Time frame effect	Exp 3 = Exp 4	30.21 (0.000)	Rejected at 1% level
	Exp 1 = Exp 2	1.08 (0.281)	Not Rejected
Combined effects (magnitude, and time frame effects)	Exp 1= Exp 3	23.02 (0.000)	Rejected at 1% level
	Exp 1 = Exp 4	0.69 (0.398)	Not Rejected
	Exp 2 = Exp 4	1.95 (0.051)	Rejected at 10% level
Version effect	Version 1= Version 2	4.67 (0.000)	Rejected at 1% level

Figures in parentheses are p-values.

From the results of the tests, we clearly observe the presence of pure magnitude effects in our experiment. Controlling for time frames, discount rates are a declining function of rewards offered. Furthermore, there exists a time frame effect in relatively longer waiting times (6 to 12 months) than in a shorter time frame (3 to 6 months). Apart from magnitude and time frame effects, we also observe significant differences in experiment outcomes in the two versions of the experiment.

7. Conclusions and policy implications

Rural credit markets in developing countries are often dominated by informal sources characterized by segmentation, rationing, and high rate of interest on small sums offered for short duration. In the literature, problems of moral hazard and adverse selection emanating from information asymmetries are often mentioned as major causes of credit market imperfections in these countries. In an ideal perfect capital market case, all farmers operate with the same discount rate, which is equal to the market interest rate. However, when capital is scarce and rates of interest are high, the high opportunity cost of capital, coupled with the cash liquidity constraints and consumption smoothing problems might drive the subjective discount rates far beyond the market interest rate.

This study measured farm households' subjective discount rates for a sample of 262 farm households in the Ethiopian highlands using a time preference experiment with real payoffs. In general, the median subjective discount rate was found to be very high: more than double the interest rate on the outstanding debt. The subjective discount rates varied systematically with wealth (physical asset) and risk preferences of farm households.

Our results have three important implications in understanding farm households' behavior in terms of their land management decisions. First, these farm households might fail to undertake investments with rates of return lower than their subjective rate of discount. Second, such excessive rate of discount might lead farmers to ignore on-site user cost of soil erosion (even with complete information and property rights) and impose an intergenerational externality. Third, when future returns tend to be more uncertain (e.g. fear of expropriation), risk-averse decision maker will favour projects with short payback periods, and will be less motivated to invest in investment in projects with long-term benefits.

In the short run, policy intervention that would reduce poverty and asset scarcity would be imperative to reduce the subjective discount rate of the rural poor farm households. In the long run, broad based economic development, including the development of credit and insurance markets seem are vital to correct the existing market imperfections and reduce the farmers' subjective rate of discount.

This paper also tested for the presence of some of the anomalies in the theoretical predictions of the standard single-parameter discounted utility model and confirmed the presence of magnitude effect, time frame effect, and delay/speed-up asymmetry in the time preference experiment. All of this points to a need for a new technique to elicit context specific discount rates. In response to the anomalies just enumerated, there is a growing trend to develop a variety of alternative theoretical models. Some models attempt to achieve greater descriptive realism by relaxing the assumption of constant discounting; others incorporate additional considerations into the instantaneous utility function; and still others depart from the discounted utility model more radically and try to develop a version of prospect theory to the issue of discounting.

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Appendix. Choice Sets

Version 1: Reference date=current

Set 1: Time frame=3 months, reference date= February 2002, nominal size=15.

Current time offers	Birr 15					
Future time offers	Birr 15	Birr 16	Birr 17	Birr 18	Birr 19	Birr 20
Implied discount rate	0%	26%	50%	73%	95%	115%

Set 2: Same as 1 but longer time frame (6 months)

Current time offers	Birr 15					
Future time offers	Birr 15	Birr 16	Birr 17	Birr 18	Birr 19	Birr 20
Implied discount rate	0%	13%	25%	36%	47%	58%

Set 3: Time frame=6 months, reference date= February 2002, nominal size=40

Current time offers	Birr 40							
Future time offers	Birr 40	Birr 42	Birr 44	Birr 47	Birr 50	Birr 55	Birr 60	Birr 70
Implied discount rate	0%	10%	19%	32%	45%	64%	81%	112%

Set 4: Same as 3 but longer time frame (12 months)

Current time offers	Birr 40							
Future time offers	Birr 40	Birr 42	Birr 44	Birr 47	Birr 50	Birr 55	Birr 60	Birr 70
Implied discount rate	0%	5%	10%	16%	22%	32%	41%	56%

Version 2: Reference date=future

Set 5: Time frame=3 months, reference date= May 2002, nominal size=15.

Current time offers	Birr 10	Birr 11	Birr 12	Birr 13	Birr 14	Birr 15
Future time offers	Birr 15					
Implied discount rate	162%	124%	89%	57%	26%	0%

Set 6: Same as 5 but longer time frame (6 months)

Current time offers	Birr 10	Birr 11	Birr 12	Birr 13	Birr 14	Birr 15
Future time offers	Birr 15					
Implied discount rate	81%	62%	45%	28%	13%	0%

Set 7: Time frame=6 months, reference date= August 2002, nominal size=40

Current time offers	Birr 26	Birr 28	Birr 30	Birr 32	Birr 34	Birr 36	Birr 38	Birr 40
Future time offers	Birr 40							
Implied discount rate	86%	71%	56%	45%	33%	21%	10%	0%

Set 8: Same as 7 but longer time frame (12 months)

Current time offers	Birr 26	Birr 28	Birr 30	Birr 32	Birr 34	Birr 36	Birr 38	Birr 40
Future time offers	Birr 40							
Implied discount rate	43%	36%	28%	23%	17%	11%	5%	0%

Market Imperfections and Farm Technology Adoption Decisions: An Empirical Analysis[+]

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Abstract
In this paper, we investigate the impacts of market and institutional imperfections on technology adoptions in a model that considers fertilizer and soil conservation adoptions as joint decisions. Controlling for plot characteristics and other factors, we find that a household's decision to adopt fertilizers does significantly and negatively depend on whether the same household adopts soil conservation. The reverse causality, however, is insignificant. We also find outcomes of market imperfections such as limited access to credit, plot size, risk considerations, and rates of time preference as significant factors explaining variations in farm technology adoption decisions. Relieving the existing market imperfections will more likely increase the adoption rate of farm technologies.

Key Words: Bivariate probit, credit access, Ethiopian farm households, fertilizer adoption, market imperfections, risk aversion, time preferences, soil conservation.

JEL Classification: C35; D43; Q12, Q24

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1. Introduction

Sustainable agricultural development is widely acknowledged as a critical component in a strategy to combat both poverty and environmental degradation. Yet sustainable agricultural development remains an elusive goal, particularly in many of the poorest regions of the world. In many of these countries, degradation of agricultural land continues to pose a serious threat to future production potential and current livelihood of the peasant households (Scherr et al., 1996; IFPRI, 1999). Ethiopia is one of the poorest countries on earth and the country is heavily dependent on peasant agriculture and is affected by extensive degradation of agricultural lands. The problem of degradation of agricultural land is most notable in the highlands where human and livestock pressure is the highest. According to a study by the World Bank, the rate of annual on-site soil losses from soil degradation is estimated to be about 5% of the agricultural GDP (Bojö and Cassells, 1995). In the last two decades, per capita food production has been lagging behind the rates of population growth, and food shortage and rural poverty have become chronic problems in the country. The challenge that Ethiopia is currently facing is to meet food security using dissemination of yield-enhancing technology, and at the same time to slow or reverse the trend in agricultural land degradation to maintain sustainability of future agricultural production. Recognizing the seriousness of the soil fertility problems in Ethiopia and the necessity of improving agricultural productivity and food security, there have been large efforts by the Ethiopian government and donors to promote yield enhancing and soil conserving technologies. Past efforts and programs to intensify agricultural production through dissemination of fertilizers, improved seeds, and adoption of soil conservation structures have in most cases failed; the adoption and dissemination rates are low even by African standards. The average technology adoption rate of modern fertilizers, for example, is estimated to be less than 33% of the cultivated lands and the average level of use of modern fertilizer is only 11 kg per hectare, compared to 48 kg per hectare in Kenya, and 97 kg per hectare worldwide (Mulat et al., 1997; FAO, 1998). The figures are even much lower for soil conservation adoption.

Many factors contribute to the failure of past efforts and programs. Among others, first, these programs were conducted based on superficially perceived causes of land degradation and deterioration of soil productivity. In these programs, the factors often blamed for causing this apparently excessive deterioration of soil productivity were physical processes like over-cultivation, over-grazing, over-population, deforestation, climatic factors, etc. (Bojö and Cassells, 1995). However, there is a growing consensus in recent literature that these factors tend to be physical manifestations of underlying market and institutional failures (Bojö and Cassells, 1995). Second, many of the programs failed because they did not integrate the efforts to disseminate yield-enhancing inputs (such as fertilizers) with efforts on soil and water conservation. Many of these efforts were conducted by separate programs with different objectives, resulting in poor coordination of efforts (Hurni, 1993). This is unfortunate, since the complementarities between soil and water conserving and yield enhancing technologies can be substantial. For example, the returns to soil conservation would be much higher if farmers adopt fertilizers as well and vice versa since the structures could help conserving soil moisture and reduce losses of other inputs through runoff.

In many of the previous studies on soil conservation and fertilizer adoption decisions, several factors that reflect personal, physical, economic, and institutional elements were identified on an ad-hoc basis, and analyzed 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 is detected and/or unobserved heterogeneities are correlated for these decisions (Greene, 2000; Maddala, 1983). It also obscures the possible inter-linkages and synergies that might possibly exist between the different forms of technology adoption decisions. In the context of simultaneous estimation of several adoption decisions, it becomes possible to uncover interactions that can be extremely useful in attempts to manipulate the adoption process (Feder et al., 1985). For example, it might be the case that a farmer is more likely to adopt fertilizers if soil conservation is adopted, but not necessarily vice versa. These results, if forthcoming, would suggest that extension work might concentrate more on soil conservation adoption, since fertilizer use is more likely to follow. It might also be possible that a farmer would abandon one of the technologies in decision in favor of the other even if adopting both at the same time could be more beneficial in production. This could happen when the farmer faces a binding resource or liquidity constraint in his/her investment decisions (Feder et al., 1985). These results, if forthcoming, would suggest that resources and efforts should be geared towards relieving some of the constraints so as to reap potential gains from complementarities. Any effort to provide incentive in one of the technologies would retard the adoption of the other, and the potential gains would be lost.

In this study, we investigate the market and institutional constraints behind low adoption rate of farm technologies in a simultaneous equation model that considers soil conservation and fertilizer decisions as related decisions. The rest of the paper is organized as follows. In Section two, we discuss the conceptual framework and hypotheses. Section three deals with the econometric approach. In Section four, we discuss the data and econometric results. Section five concludes the paper.

2. The conceptual framework and hypotheses

In the literature, we find several theoretical approaches in modeling farm technology adoption decisions, depending on the specific objective of the study (see Feder et al, 1985 for a survey). Many of the existing approaches are constructed under the assumption of a perfectly competitive market structure and clearly defined property rights (perfectly working institutions). However, in many developing countries, decisions are made under an imperfect market structure, and 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 insecure 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 of the farmer 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 perception of farm households. Farm profit is a function of the farmer’s choice of a mix of technologies such as chemical fertilizer 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 use 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[15] 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 the 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 the observed factors that might determine the level of awareness of the household including soil and plot characteristics (PC_p) such as plot size, slope, and soil quality, human capital of the household (HC_h) such as gender, age, education, and village level factors (X_v) such as agro-ecological factors including rainfall variability. Since we have not been able to measure perception of erosion at the plot level in our study, we substitute PC_p, HC_h , and X_v into $perc_{hp}$ and get the following expression for fertilizer use and soil conservation adoption decisions respectively:

[15] Although measures of soil conservation vary in the literature, our definition of soil conservation is restricted to the construction of any physical structures in a plot to reduce run-off and soil loss. The most common structures in the Ethiopian highlands include stone bunds, soil bunds, cut-off drainage, and grass strips. Our definition of modern fertilizer is also restricted to any use of chemical fertilizers. The most common types in the Ethiopian highlands include Diammonium Phosphate (DAP) and Urea fertilizers.

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

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

Beginning with profitability, we use the proximity to markets and roads as proxies to measure profitability. 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 involved in accessing credit and labor markets. However, better access to markets and roads may also increase non-farming opportunities and hence takes labor away from agricultural activities and hence discourages 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, high 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, existing credit institutions in rural Ethiopia provide short-term credit for productive activities (mainly for the purchase of modern fertilizers and improved seeds), and consumption smoothing purposes, while there exist a serious credit failure for long term investments like soil conservation. Formal credit institutions in rural Ethiopia currently require that loans for agricultural inputs are repaid immediately after harvest, forcing farmers to sell their harvest when prices are low, rather than storing and selling when prices are higher and food is scarcer. According to a recent study, failure to repay this commodity-specific credit mainly due to crop failure has increased indebtedness among the peasantry (IDR, 2000). This is likely to prevent particularly risk averse households from taking credit, which subsequently affects their decision in adopting 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 hypothesize that households with better access to credit or other sources of cash liquidity are more willing to adopt farm technologies than credit or liquidity-constrained households. On the other hand, as long as credit is available only for the short term farm activities but not for long term investments like soil conservation, greater provision of credit might take 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 one important deterrent of long-term land investment decisions (see Alemu, 1999; Gebremedehin and Swinton, 2003). Apart from its direct effect of providing incentives to undertake 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 through the provision of 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, shared cropped in or shared cropped 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 the right of peasants and pastorialists to free access to land, it is not clear how this right is being assured in practice, given the scarcity of land and the ever exploding population pressure. Under the current land tenure arrangements, this right to free access of land is being 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 his/her consent (Sjaastad and Bromley, 1997; Alemu, 1999). Thus, given the land tenure structure in Ethiopia, we hypothesize that households with insecure tenure perceptions are 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 that hinges on land redistribution has an adverse effect on farm technology adoption decisions through its impact on reducing and fragmenting individual plots following the overriding population pressure. There is an on-going debate in the literature on the impact of population pressure and deteriorating farm sizes on agricultural intensification or technology adoptions. One group (the Boserupians) argues that population pressure that leads to smaller plots will induce intensive use of the land through the adoption of new farm technologies, while the other group (the neo-Malthusians) argues that population pressure doesn't lead to intensive use of the land; instead it 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 affect 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 are subjected to high consumption smoothing problems and thereby high subjective discount rates which in turn discourage land investment decisions that entail 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 reduced substantially when outcomes from the adoption of such technologies are conditioned by other stochastic 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 in a situation where insurance markets are poorly functioning or completely missing so 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 a rain fed agriculture (which is the main form in Ethiopia), returns from fertilizer use are highly conditional on many stochastic events, mainly on weather. Under such farming condition, 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 is to identify determinants of soil conservation and fertilizer adoptions decisions, in a situation where institutions and factor markets are imperfect. We assume that all non-technology variables that affect the adoption decisions are exogenous. In order to deal with the simultaneity of the technology adoption decisions we adopt 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:

$$fa^{*}_{hp} = \gamma_1 sc^{*}_{hp} + \beta'_1 X_1 + \varepsilon_f , \qquad fa_{hp} = 1(if \quad fa^{*}_{hp} > 0) \tag{3}$$

$$sc^{*}_{hp} = \gamma_2 fa^{*}_{hp} + \beta'_2 X_2 + \varepsilon_c , \qquad sc_{hp} = 1(if \quad sc^{*}_{hp} > 0) \tag{4}$$

$$\left[\varepsilon_f , \varepsilon_c\right] \sim BVN\left[(0,0), \ \sigma^2_f , \sigma^2_c , \rho\right],$$

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

$$\left.\begin{aligned} fa_{hp} &= \pi'_1 X + v_f , \\ sc_{hp} &= \pi'_2 X + v_c , \\ \left[v_f , v_c\right] &\sim BVN\left[(0,0), \theta^2_f , \theta^2_c , \tau\right], \end{aligned}\right\} \tag{5}$$

where τ is the correlation, θ_j is the standard deviation, and where X is the union of exogenous variables in the system. The predicted values of fa_{hp} and sc_{hp} from the reduced form are used to estimate the structural bivariate model. Maddala (1983) derives a way to recover consistent estimates of the structural form of coefficients from the reduced form coefficients that takes into account the cross equation relationships and is therefore asymptotically more efficient than a single equation estimation. Since the consistent parameter estimates, and not actual values of fa_{hp} and

sc_{hp}, are used in the estimation of the structural equations, the estimated asymptotic covariance matrix must be corrected.[16]

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 on how to calculate marginal effects in a bivariate probit model is illustrated in Greene (1996). In our model, ρ is not statistically different from zero (i.e. the two equations are independent). In this case, the marginal effects are easier to calculate since the joint probability will be the simple product of marginal probabilities. The unconditional expected value of *sc* and *fa* are given by Equation (6) and (7) respectively.

$$E[sc \mid X_1, X_2] = E_{fa}E[sc \mid X_1, X_2, fa] = prob[fa=1]E[sc \mid X_1, X_2, fa=1] + prob[fa=0]E[sc \mid X_1, X_{2,} fa=0]$$

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

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

4. Results and discussion

The above models are estimated using survey data collected from 847 plots of 206 randomly selected households from seven villages of highland Ethiopia. The households are located in five *weredas* of two different *zones*, one with high agricultural potential and the other with a history of recurrent drought and famine.[17] These households are part of a larger land use survey that was conducted in 2000 and 2002. A separate experiment was administered in 2002 aiming at estimating risk and time preferences among the farmers. In the risk experiment, households were confronted with six farming alternatives that differed both in their expected outcomes and spreads (risk levels) of good and bad outcomes. These six alternatives represented six levels of risk, where 1 for extreme risk aversion and 6 for risk loving behaviors,

[16] See Maddala, 1983, p.246-247; LIMDEP, 2002, on the identification of consistent parameter estimates and derivation of the asymptotic covariance matrix.

[17] *Wereda* and *zone* are the second and third lowest administrative hierarchies respectively in Ethiopia. *Kebele* is the lowest administrative hierarchy, a *wereda* is a collection of contiguous *kebeles,* and *zone* a collection of contiguous weredas.

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 implied subjective discount rate (rate of time preference) was calculated for each farm household.[18] The basic descriptive statistics of the sampled households are provided in Table 1.

Table 1: Basic descriptive statistics (n=847)

Variable	Description	Mean	Standard deviation
Technology adoption			
Conserve	A dummy whether the household has adopted any soil conservation structure in the plot	0.26	0.44
Fert	A dummy whether the household has used any modern fertilizer in the plot	0.43	0.50
Consfert1	A dummy whether the household has adopted both soil conservation and fertilizer at the same time in the same plot	0.09	0.28
Consfert2	A dummy whether the household has adopted both soil conservation and fertilizer at the same time in the same plot, given he/she 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	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 source	0.45	0.50
Plot and soil characteristics			
Steepslope	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 hectare	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* (a group of contiguous villages or kebeles) dummy	0.29	0.45
Gozamin	*Wereda2* (a group of contiguous villages) dummy	0.24	0.43
Enemay	*Wereda3* (a group of contiguous villages) dummy	0.19	0.40
Tehuldere	*Wereda4* (a group of contiguous villages) dummy	0.12	0.32
Kalu	*Wereda5* (a group of contiguous villages) dummy	0.16	0.36

The results of a two-stage bivariate probit model of Equation (3) and (4) that estimates soil conservation and fertilizer adoption decisions are provided 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 is tested and found not to be a serious problem (with variance inflation factors less

[18] 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).

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.[19] In all the cases, standard errors for marginal effects are calculated using the delta method (Greene, 2000).

[19] 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

Variable	Soil conservation adoption		Fertilizer adoption	
	Univariate probit	Two-stage bivariate	Univariate Probit	Two-stage bivariate
Technology Adoption				
Fertilizer Adoption	0.196	0.009		
	(0.135)	(0.492)		
Soil Conservation Adoption			0.117	-0.277*
			(0.129)	(0.165)
Tenure Insecurity				
Tenure Perception	-0.143	-0.147	-0.065	-0.095
	(0.117)	(0.127)	(0.113)	(0.116)
Factor-Market Participation				
Formal Credit	0.040	0.082	0.651***	0.697***
	(0.138)	(0.382)	(0.109)	(0.116)
Plot and Soil Characteristics				
Steep Slope	0.624***	0.614***		
	(0.113)	(0.123)		
Poor Soil			0.088	0.196
			(0.111)	(0.139)
Plot Size	0.616**	0.686	1.264***	1.444***
	(0.298)	(0.689)	(0.273)	(0.289)
Human Capital				
Gender	0.950**	0.920	-0.638**	-0.376
	(0.480)	(0.584)	(0.283)	(0.350)
Age	-0.014***	-0.014***	-0.006	-0.009**
	(0.004)	(0.005)	(0.004)	(0.004)
Literate	0.170	0.165	-0.133	-0.072
	(0.128)	(0.148)	(0.122)	(0.130)
Family Labor	0.038	0.038		
	(0.025)	(0.026)		
Behavioral Measures				
Risk Aversion			-0.025	-0.041*
			(0.021)	(0.024)
Time Preference	-0.421**	-0.428**		
	(0.199)	(0.203)		
Access to Market and Road				
Distance to Town	0.006***	0.006***	-0.002	-0.0001
	(0.002)	(0.002)	(0.002)	(0.002)
Village Dummies+				
Machakel	-1.830***	-1.760***	1.095***	0.493
	(0.245)	(0.559)	(0.188)	(0.379)
Gozamin	-1.228***	-1.196***	0.472***	0.025
	(0.185)	(0.287)	(0.189)	(0.304)
Enemay	-0.228	-0.229	-0.052	-0.193
	(0.166)	(0.175)	(0.185)	(0.202)
Tehuldere	-0.186	-0.177	0.151	0.061
	(0.196)	(0.202)	(0.198)	(0.224)
Intercept	-1.128**	-1.055*	-0.226	-0.408*
	(0.580)	(0.602)	(0.412)	(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

Figures in parentheses are standard errors.
***, **,* 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

Variable	Direct	Indirect	Total	(Type of variable, Mean)
Soil Conservation Adoption Decision				
Tenure Insecurity	-0.020	-0.014	-0.034	Binary, 0.30
	(0.023)	(0.013)	(0.029)	
Formal Credit	-0.032	0.046**	0.014	Binary, 0.45
	(0.072)	(0.019)	(0.065)	
Subjective Discount Rate	-0.104**		-0.104**	Continuous, 0.42
	(0.053)		(0.053)	
Plot Size	0.167	0.177*	0.344***	Continuous, 0.27
	(0.137)	(0.094)	(0.089)	
Steep Slope	0.124***		0.124***	Binary, 0.28
	(0.033)		(0.033)	
Distance to Town	0.001**	-0.00001	0.001**	Continuous, 60.81
	(0.001)	(0.0003)	(0.001)	
Literate	0.036	0.006	0.042	Binary, 0.2574
	(0.033)	(0.013)	(0.041)	
Gender	0.112***	0.031	0.142**	Binary, 0.97
	(0.033)	(0.035)	(0.071)	
Age	-0.001	-0.003**	-0.005***	Continuous, 46.49
	(0.001)	(0.002)	(0.002)	
Family Labor	0.009		0.009	Continuous, 5.88
	(0.007)		(0.007)	
Fertilizer Adoption	0.002		0.002	Endogenous, 0.43
	(0.033)		(0.033)	
Fertilizer Adoption Decision				
Tenure Insecurity	-0.015	-0.014	-0.029	Binary, 0.30
	(0.035)	(0.013)	(0.040)	
Formal Credit	0.195***	0.046**	0.241***	Binary, 0.45
	(0.045)	(0.019)	(0.057)	
Risk Aversion Rate	-0.014*		-0.014*	Continuous, 2.31
	(0.008)		(0.008)	
Plot Size	0.502***	0.101	0.603***	Continuous, 0.27
	(0.111)	(0.082)	(0.112)	
Poor Soil Quality	0.058		0.058	Binary, 0.24
	(0.041)		(0.041)	
Distance to town	-0.0001	0.001	0.001	Continuous, 60.81
	(0.001)	(0.001)	(0.001)	
Literate	-0.035	0.006	-0.029	Binary, 0.26
	(0.039)	(0.013)	(0.044)	
Gender	-0.187	0.031	-0.156	Binary, 0.97
	(0.142)	(0.035)	(0.139)	
Age	0.0004	-0.003**	-0.003	Continuous, 46.49
	(0.002)	(0.002)	(0.002)	
Soil Conservation Adoption	-0.163**		-0.163**	Endogenous, 0.26
	(0.081)		(0.081)	

Figures in parentheses are standard errors.
***, **,* indicate significance levels at 1%, 5% and 10% levels, respectively.
+ Kalu is the reference village

The p-value of 0.224 for the test of ρ equals zero shows that the unobserved heterogeneities of both decisions are uncorrelated. This result however doesn't lead us to the conclusion that the two decisions are uncorrelated. Instead, a significant parameter estimate of the endogenous soil conservation variable in the fertilizer adoption equation shows that one of the important determinants (though negative) of whether a household adopts fertilizer is whether the same household has adopted soil conservation on that plot. The reverse causality, however, is insignificant. That is, household's decision to adopt soil conservation does not depend on whether the same household has adopted fertilizers. On the margin, controlling for other factors, households that adopt a soil conservation structure are 16 percentage units less likely to adopt modern fertilizers as well. 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, like in many other developing countries, the farm households in the Ethiopian highlands are working under severe cash liquidity and other resource constraints, which might force households 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., 19985). In that case policies that enhance the adoption of one component may 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 do 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 does not seem to deter farm technology adoption decisions. The current land tenure policy that advocates for continuous redistribution, however, has a strong indirect effect on technology adoption decision through its effect on plot size and land fragmentation which, in our model, is captured by a separate variable called plot size. Farm households with bigger plot sizes are more likely to adopt new farm technologies than others. In the literature this result is 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 has 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 the ever-increasing population pressure doesn't lead to more intensification of farming.

Market access to a formal credit market is found to be one of the strong and major determinants of fertilizer adoption decisions, though it does not have a direct strong impact on the soil conservation adoption decision. Households with access to formal credit are 24 percentage units more likely to adopt fertilizer than those without access. Access to the credit market gives opportunities to farm households to get the necessary resources for the adoption of technologies. Given the fact that credit institutions in rural Ethiopia provide short-term credit only for productive activities (mainly for the purchase of modern fertilizers and improved seeds), and consumption smoothing purposes, but not to long term investments like soil conservation, our result that shows a positive and significant effect on fertilizer adoption but not on soil conservation adoption decision is not surprising. However, there are two other indirect channels through which better access to credit and cash liquidity affects both types of technology adoption decisions. First, better access to credit even for productive, consumption, and other purposes will reduce consumption smoothing problems and the subjective rates of time preference of farm households, which is a very significant factor explaining variations in farm technology adoption decisions in our study. This effect is captured by a separate variable called discount rate. Second, a better access to credit and cash liquidity will enhance technology adoption decisions by encouraging farmers to take risks. This effect is also captured in our model by a separate variable called risk aversion. In countries where credit and insurance markets are poorly functioning or completely missing and 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 is consistent with our findings that variations in farm households' rates of time preferences and degree of risk aversion explain a significant portion of variations in soil conservation and fertilizer adoption decisions, respectively.

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

Finally, proximity to town seems to affect the soil conservation adoption decision but not the fertilizer adoption decision. The direction of relationship, however, seems counter-intuitive in that the probability of adoption decreases with proximity to town. This is perhaps because households who live with closer proximity to town have higher opportunity costs of labor than distant households, which makes decisions to participate in labor-intensive soil conservation tasks more expensive to them. Significant parameter estimates for many of the village dummies also depict 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 counties. 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 as the adoption rates are low and adoption is limited to certain villages and groups of farm households.

Although there is a growing literature that looks 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 despite the fact that understanding the synergies across the different forms of technology adoption decisions could perhaps help policy makers and development agents to exert more effective and coordinated efforts to address the problem.

In this paper, we investigate the impacts of market and institutional imperfections on technology adoptions in a model that considers fertilizer and soil conservation adoptions as related decisions. In our case study, controlling for soil characteristics and other factors, we find that a household's decision to adopt fertilizers does significantly and negatively depend on whether the same household adopts soil conservation. The reverse causality, however, is insignificant. On the margin, controlling for other factors, households that adopt soil conservation structures are 16% less likely to adopt modern fertilizers as well. For our sample households, these two technologies are found to be substitutes. This is consistent with decision theory in economics where factor markets are imperfect. The returns to fertilizers will be much higher if farmers adopt soil conservation as well since the structures help to conserve soil moisture and reduce losses of such inputs through runoff. However, if the decision maker faces a binding cash liquidity or credit constraints, the decision maker could neglect one in favor of the other and hence any incentive that promotes the adoption of one might retard the adoption of the other. Under such circumstances, efforts should be geared towards relieving some of the constraints or searching for the least cost technologies that suit the resource base of the farm households so as to enable them to adopt the technologies and reap benefits from potential complementarities of farm technologies.

Most of the other factors that significantly affect either of the technology adoption decisions are 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 are 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 highly inter-twined, 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 investments decisions (WECD, 1987; World Bank, 1996). In an imperfect credit and insurance market environment, variations across households in these two behavioral measures are mainly explained by differences in households' physical and financial endowments.

Limited access to the formal credit market is another outcome of factor market imperfection. This variable is found to strongly explain variation in fertilizer adoption decision, but not in soil conservation adoption decision. Households with better access to formal credit are 24% 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 do not find tenure insecurity as one of the significant determinants of either of the technology adoption decisions. Instead, we find that plot size and land fragmentation, which are direct results of land redistribution in the current land policy in Ethiopia, significantly and positively explain variations in both of the technology adoption decisions. This result seems to support the neo-Malthusian argument on population pressure, land size and agricultural intensification.

This study generally shows the importance of investigating factor market imperfections in 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 to reduce a farm household’s subjective discount rate and degree of risk aversion, 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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