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Technology Adoption, Land Rental Contracts and Agricultural Productivity

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Introduction

Low and declining agricultural productivity, increasing food insecurity and poverty are major problems facing the Ethiopian agricultural sector. These problems are aggravated by land degradation, low quality and quantity of livestock feed, population pressure, low adoption of land saving and productivity enhancing technologies and institutional imperfections (Kruseman et al., 2002; Tangka et al., 2002; Holden et al., 2001; Gebre-Selassie, 2003). In order to reverse the declining agricultural productivity, improve food security and sustainability of resources, the Ethiopian government has been promoting adoption of technologies such as improved seeds, fertilizer, soil conservation practices and improved fodder production. The government has initiated green revolution type extension programs to increase the uptake of these technologies by farmers. In addition, the government liberalized both agricultural output and input markets since the early 1990s to attain fast economic development.

Recently, the government relaxed the land policy by allowing longer duration of land tenancy contracts and issuing land certification although this does not include land sale and mortgage. Farmers engage in land rental contractual arrangements as one of the strategies to address food insecurity and reduce poverty. These arrangements have an important role to play for efficient allocation of resources to promote agricultural development in most countries in Sub-Saharan Africa, including Ethiopia, where formal land sale and mortgage is prohibited and markets for other inputs are imperfect or missing (Benin et al., 2005; Sadoulet et al., 2001). To study the efficiency of land rental contracts in Ethiopia has become an interest of researchers and policy makers following the lifting of the ban on land rental contracts in 1991.

This dissertation explores the impact of soil conservation on agricultural productivity, forage legumes-cereals intercropping adoption impact on income and soil conservation, factors that determine the adoption of forage legumes-cereals intercropping and how share tenancy arrangements affect agricultural productivity and input use in the Ethiopian highlands. Specifically, the dissertation aims at providing empirical evidence to the following research questions:

- Does investment on soil conservation improve land productivity in high rainfall areas of the Ethiopian highlands?

- Do sharecropping contracts with kin or non-kin partners lead to Marshallian inefficiency?
- Does intercropping forage legumes with cereals improve household income and enhance environmental protection?
- What socio-economic and institutional factors determine adoption of forage legumes-cereal intercropping?

These questions are addressed as separate thematic topics in this dissertation where various econometrics and mathematical programming methods have been applied on household, plot level survey and experimental data from Ethiopian highlands.

Except few empirical studies in the past that have directly examined the impact of soil conservation on land productivity and forage legumes-cereals intercropping adoption on income and soil conservation, studies on sharecropping impact on land productivity in reverse share tenancy contracts (poor landlord and rich tenants) are limited. In addition where attempts to study the effect of soil conservation and sharecropping contracts on productivity have been made, such studies have suffered from methodological and data problems. This dissertation seeks to find remedies for these problems.

Theoretical framework

This section provides theoretical framework for analysing the agricultural productivity and income effects of technology adoption and land rental contracts. Production and technology adoption decisions depend on a wide variety of factors, many of which are specific to a particular village, household, or plot (See Figure 1 below for the summary of variables that influence technology adoption and production decisions). Many of these, such as agro-climatic conditions[1] have effects on the costs, returns and risks of investments (Pender and Kerr, 1998). Difference in land characteristics, for example, can lead to variations in returns (Pagiola, 1996). Similarly, factor market distortions may cause benefits and costs of investments to vary among households depending on their initial factor endowments.

Market imperfections are widespread in rural economies of developing countries, characterised by high transaction costs arising from high transportation costs, high search,

[1] It includes soil type & characteristics, soil depth, slope, rainfall, crops, etc.

recruitment, monitoring and enforcement costs and limited access to information (Hoff and Stiglitz, 1990; Hoff et al., 1993; Sadoulet et al., 1996; Pender and Kerr, 1998; Holden et al., 2001). The effects of these imperfections spill-over to farmers adversely affecting their production and investment decisions and participation in the market (Sadoulet and de Janvry, 1995; Pender and Kerr, 1998; Holden et al., 2001, Yesuf, 2004). In such circumstances, households' initial resource endowments and household characteristics may play a role in investment and production decisions besides farm characteristics and exogenous prices of inputs and outputs. For example, when a technology and farming practice is labour intensive and labour markets are fully or partially missing, it becomes less attractive for households with low initial labour endowments to adopt such technologies than those with abundant labour. Market constrained households would be forced to allocate farm labour sub-optimally as compared to households facing perfectly working labour market conditions. Holden et al. (2001) found that imperfect labour market was one major factor for the differences in farm profitability among farmers in Ethiopia. Pender and Kerr (1998) found that imperfections in labour markets lead to differences in soil and water conservation investments among farmers in India (Aurepalle village), where investment is greater among households having more adult males, fewer adult females and who farm less land.

It has been a long-held belief among policy makers that poor households in developing countries lack access to adequate credit, which is believed to have significant negative consequences on various aggregate and household-level outcomes, including technology adoption, agricultural productivity, food security, nutrition, health and overall household welfare (Diagne et al., 2000). Credit market imperfections exist in all economies although these imperfections seem to have particularly important implications for developing countries. Collateral requirement, high covariate risk of agricultural production, asymmetric information, underdeveloped complementary institutions, high transaction costs and lack of proper enforcement of loan contracts and government interference in the credit markets are causes of credit market imperfections in developing countries (Stiglitz and Weiss, 1981; Binswanger and Rosenweig, 1986; Carter; 1990; Hoff and Stiglitz, 1990; Timothy, 1994; Sadouelt and de Janvry, 1995). These and other features of rural credit market in developing countries limit the development of formal financial institutions; lead to credit rationing and rationed out poor farmers. In such situation, farmers with more capital assets are likely to invest more on technologies (Pender and Kerr, 1998).

In most developing countries where agriculture still remain a risky activity, better credit facilities can help farmers smooth out consumption and, therefore, increase the willingness of risk-averse farmers to take risks and make agricultural investments (Rosenweig and Binswanger, 1993). Better access to rural credit markets may lead to high volume of agricultural output and consequently employment and wages than would be attainable with a less developed or less efficient credit system (Binswanger and Khandker, 1995). Due to liquidity constraints, personal rate of discount is often higher and individual farmers fail to undertake investments decisions (Holden et al., 1998; Yesuf, 2003). In India, Pender and Kerr (1998) found strong evidence that credit market imperfections were affecting conservation investment, where investment is greater among households having more debt and a high percentage of off-farm income.

A special feature of agriculture, which provides the income of most rural residents, is the risk of income shocks. These include weather fluctuations that affect whole regions as well as changes in commodity prices that affect all the producers of a particular commodity. Some researchers have argued that production, price and technology risks, and risk aversion behaviour of households play a central role in explaining farm household technology adoption and production decisions in developing countries (Sandmo, 1971; Finkelshatain and Chalfant, 1991; Fafchamps, 1992; Feder, 1980; Wik, 1998, Yesuf, 2004). Risks problems constrain the development of the market for credit. Many poor farmers in developing countries possess few assets that would be acceptable to lenders as loan collateral, whilst the lack of crop insurance reduces the value of end-of-season harvest as a guarantee of loan repayment. The variables risk, risk aversion behaviour and discount rates can be parameterized as a function of a vector of household socio-economic characteristics in the absence of direct measure of these variables (Holden et al., 1998; Wik and Holden, 1998; Hagos and Holden, 2003; Yesuf, 2004).

Adoption of a technology can be governed by its specific characteristics. Farmers have subjective preferences for technology characteristics that play a major role in technology adoption (Ashby and Sperling, 1992 as cited in Adesina and Zinnah, 1993). For instance farmers in high and secure rainfall areas of Ethiopia (e.g. our study area) expressed concerns over physical conservation bunds that include the following: reducing the available area for planting; water accumulation behind the bund causing waterlogging; providing fertile ground for weeds and pests to reproduce; difficulty to turn the ox-drawn plough due to narrow terrace spacing; and in some areas aggravating soil erosion due to poor construction of bunds (Tegene, 1992; 1997; Bewket and Sterk, 2002). Krüger (1994) observed that about 10 to 15% of the total crop area might be affected by waterlogging due to conservation bunds. These problems can hinder adoption. On the other hand, soil conservation bunds that are properly designed and fit the local conditions can help to mitigate production risks, for instance by conserving moisture in moisture stressed areas.

Poverty can also affect household's production and investment decisions. Conventional wisdom suggests that poorer households lack the financial capacity to undertake investment in resources conservation. Based on experimental data from three developing countries, Holden et al. (1998) found that poverty and liquidity constraints tend to increase rates of time preference and thereby reducing the incentives for sustainable managements of natural resources. Feder and O'Mara (1981), and Rosenzweig and Binswanger (1993) argue that adoption rates for risky technologies typically will be higher on large farms than on small farms. Similarly, Just and Zilberman (1988) reported that new technologies might favour large farms when capital market is imperfect and risk preferences are heterogeneous. Holden et al. (1998), Hagos and Holden (2003) and Yesuf (2004) found that poorer farm households tend to have higher discount rates than relatively richer households. Holden and Yohannes (2001) found that investment in perennials is affected significantly by poverty as measured by wealth indicator variables (livestock and farm size).

The characteristics of land market and tenure insecurity may also affect investment decisions and productivity. Various researchers indicated that land rental contracts and tenure insecurity do not provide sufficient time for the tenants and land owners to reap the benefits of their investment (Feder and Feeney, 1991; Pender and Kerr, 1998; Deininger and Binswanger, 2001). However, Bardhan (1984), Banerjee et al. (2002) and Banerjee and Ghatak (2004) developed theoretical models showing that threat of eviction may induce tenants to carry out long-term investments and increase land productivity on rented in plot. Sadoulet et al. (1997) have also showed that kinship networks induce cooperative and efficient behaviour by acting as a powerful enforcement mechanism. Land rental contracts help circumvent problems of imperfect or missing markets for other inputs, playing an important role for efficient allocation of resources to promote agricultural development (Benin et al., 2005; Sadoulet, et al., 2001). Land rental contracts allow land to be used by farmers who are more capable to earn the highest return from it through the mobility of scarce factors of production such as labour, draft power, implements, purchased inputs and management ability (Pender and Kerr, 1999).

Active land sale market can increase incentives to invest because it enables farmers to recover land improvement investment through sales (Pender and Kerr, 1998). Apart from its direct effect of providing incentives to undertake long-term investments, properly secured tenure increases land-improving investments by relaxing the credit constraints through the provision of collateral in the credit market (Feder et al., 1998; Feder and Feeney, 1991; Besley, 1995). More secured tenure also implies lower discount rates due to a better access to credit, which further motivates more investment.

Properly designed policies can play a facilitating role in speeding up economic development by circumventing market imperfections and other farmers' problems. Policy support for land reform, credit, agricultural marketing and extension can enhance adoption of natural resources conservation technologies. In Ethiopia, the government has initiated green revolution type extension programs to increase the uptake of agricultural technologies by farmers. In addition, the government liberalized both agricultural output and input markets since the early 1990s to attain fast economic development. Recently, the government relaxed the land policy by allowing longer duration of land tenancy contracts and issuing land certification although this does not include land sale and mortgage.

Production and consumption decisions are non-separable in rural poor economies where conditions such as risk and risk aversion, market imperfections and preference for self-sufficiency are common (Singh et al., 1986; de Janvry et al., 1991; Sadoulet and de Janvry, 1995; Holden et al., 2001). A farm household in developing countries is generally considered both a producer and a consumer of a set of production-consumption goods; i.e., goods that are both supplied and demanded by the same household at some point. Where market imperfections are common and goals other than profit maximization are likely to affect production decisions, the relevance of the separable approach is questionable (de Janvry et al., 1991; Delforce, 1994). Thus, a pure profit-maximizing framework often fails to reflect real patterns of cropping and resource use in farm household farming (Singh and Janakiram, 1986; Delforce, 1994). This is mainly because production and resource use decisions are likely to be affected by non-profit considerations such as preference for home production of staple food, culture and other goals. Livestock feed demand also governs crop production as farm households rarely depend on external feed sources due to high transaction costs such as high transportation costs and asymmetric information. This dissertation follows the non-separability approach.

Figure 1 summarizes the foregoing discussions by illustrating the interrelationships of variables that influence technology adoption and production decisions.

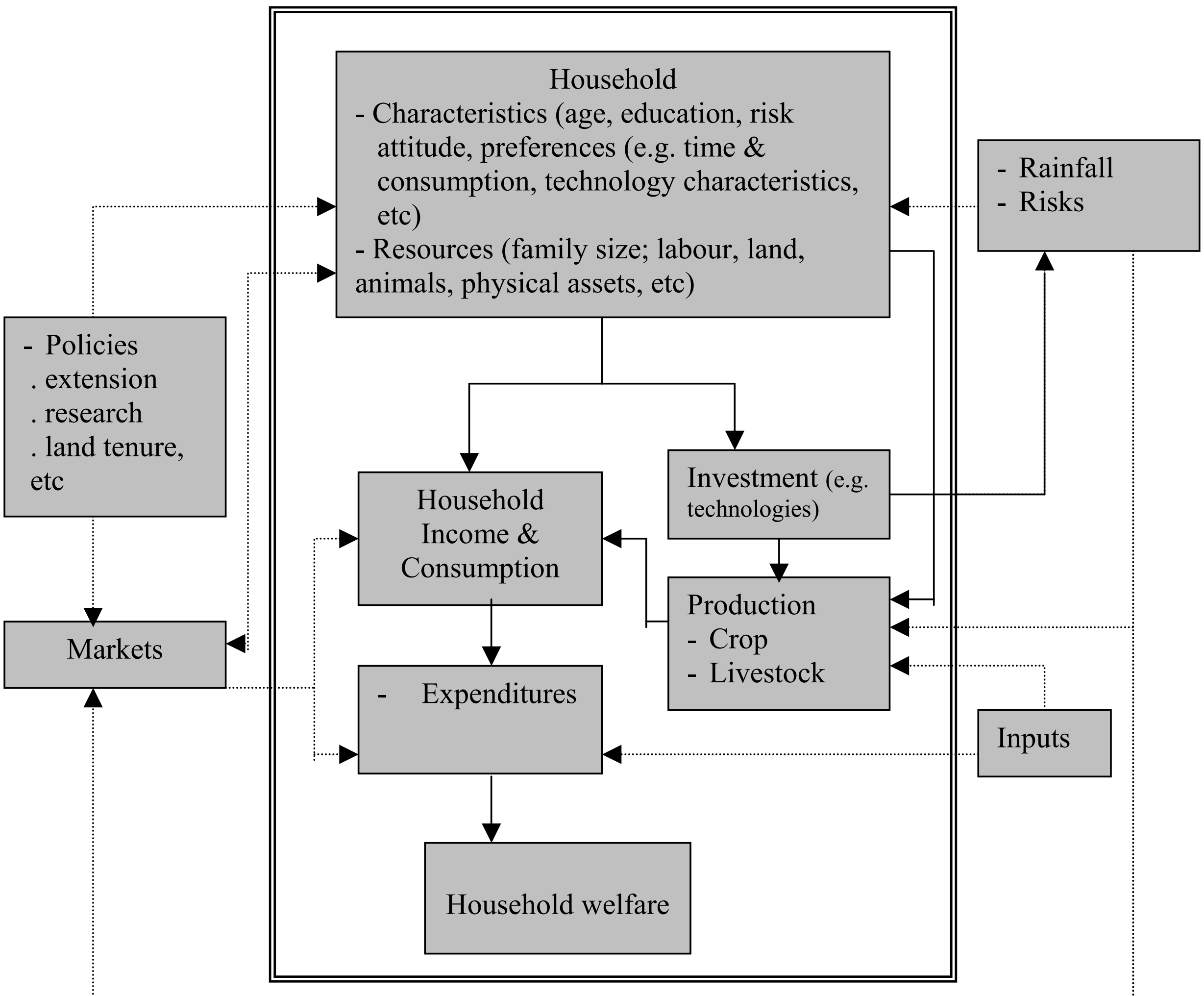

Figure 1. Theoretical framework: Factors that influence household technology adoption and production decisions.

Summary and contribution of each paper

In this section, we present the summary of the papers highlighting the objectives, data types, methods, empirical findings and contribution of the papers.

Paper I: Parametric and Non-parametric Estimation of Soil Conservation Adoption Impact on Yield in the Ethiopian Highlands

Land degradation presents a threat to food security and sustainability of agricultural production in many developing countries. Governments and development agencies have invested substantial resources to promote adoption practices to reduce land degradation, and there is growing literature on soil erosion and water conservation programs. However, there remains little understanding of soil conservation impact on land productivity. This paper assesses the land productivity impacts of a top-down approach to introducing physical soil conservation technology in a high rainfall area in the Ethiopian highlands. The paper also investigates the sources of yield gap and their contributions between conserved and non-conserved plots using Oaxaca-Blinder wage decomposition method. Sensitivity analysis is also conducted to check if some technical changes on the conservation bunds can result in higher yields. We apply parametric and non-parametric estimation methods based on multiple plot observations per household.

The results from fixed and random effects models, stochastic dominance analysis and matching methods indicate that yield from conserved plots was lower than yield form non-conserved plots for the household considered. The Oaxaca-Blinder yield decomposition results show that there is little difference in endowments between conserved and non-conserved plots, however the returns to these endowments are higher for non-conserved plots. The findings imply that the technology may be inappropriate to the local conditions under its existing condition given that the study area is characterized by high rainfall regime and deep soil. In fact, farmers in the study area reported that conservation structures create waterlogging conditions just above the bunds, serving as a harbouring area for pests and weeds.

Further, we assess whether increasing the production of natural grass on bunds could reduce the yield gap between conserved and non-conserved plots. Overall, the sensitivity analysis results suggest that there are possibilities to make conserved plots more productive or as productive as non-conserved plots. For instance, the matching estimator results show that an increase in natural fodder grass production on bunds eliminate the statistically significant yield gap difference between conserved and non-conserved plots in the case of the barley sub-sample plots. The yield gap reduces also for the entire sample plots but mean yield difference is still statistically significant.

In short, these results yields important lessons for future design of technologies, and in particular, the need for a bottom-up approach in technology research and development in order to develop technologies that are socially acceptable and best suited to the local conditions.

The paper contributes methodologically and empirically to the body of research literature on land degradation and soil conservation. First, the applications of switching regression analysis and matching methods to assess the impact of conservation on conditional mean yield are new elements of this paper. Second, the panel nature of the data, cross section with multiple plots per household, is unique such that it allows us to control for unobserved household and plot (partly) heterogeneity that have impact on technology adoption and production decisions. Third, the applications of Oaxaca-Blinder decomposition method to identify the sources of yield differences and their contributions between conserved and non-conserved plots are new in this kind of study. Fourth, the nature of the problem is also different; we are addressing physical conservation measures (*fanya juu*) unlike biological measures addressed by the previous studies.

Paper II: Sharecropping Efficiency in Ethiopia: The Role of Kinship and Contract Insecurity

Land is a key asset to generate income for rural households in developing countries. When land sizes declines as a result of population pressure, households use different means such as land sale and land rental contracts to access more land. In Ethiopia, formal land sale and mortgage is prohibited. Since 1991, land redistribution was abandoned in many rural areas. Land rental contracts have remained the dominant form of access to farmland among land deficient households. These contracts are aimed at generating income while at the same time helping to circumvent the problem of missing or imperfect markets. The land rental contracts impact on income to both parties (landlord and tenants) depends on the productivity of the rented-in lands. This paper examines the impact of land rental contracts (kin and non-kin sharecrop) on land productivity and input use in the Ethiopian highlands.

We review the relevant literature on land contract efficiency and develop a theoretical model that combines the Marshallian hypothesis, threat of eviction hypothesis and other two hypotheses, which state that kinship may reduce or eliminate the effects of the Marshallian and the threat of eviction hypotheses. We apply parametric and non-parametric estimation methods based on multiple plot observations per household.

The parametric regressions results suggest that conditional on plot quality variables and household fixed effects, kin and non-kin sharecrop plots are more productive than share tenants' own plots. The stochastic dominance analysis support this result where the yield from kin and non-kin sharecrop plots unambiguously dominate the yield from share tenants own plots. This is in line with the threat of eviction (contract insecurity) hypothesis that tenants may work harder to increase output on sharecropped plots to qualify for contract renewal. This result contradicts with the Marshallian inefficiency hypothesis where productivity is expected to be lower on sharecropped plots than on share tenants' own plots due to the disincentive effects of sharing the output under sharecropping contracts. Contrary to the findings of Sadoulet et al. (1997), we find that non-kin sharecrop plots receive more fertilizer and have more output than kin sharecrop plots. The non-kin sharecrop plots yield distribution unambiguously dominate the kin sharecrop plots yield distribution. These findings are consistent with the hypothesis that the threat of eviction is stronger among non-kin than among kin partners. This is confirmed by our data set where the duration of contracts is relatively shorter for non-kin tenants than for kin tenants.

In short, our findings indicate that the threat of eviction effect is dominating over the Marshallian inefficiency effect and kinship reducing the threat of eviction effect. In rural societies where social network and ties are extremely important it is more difficult to evict kin tenants than non-kin tenants. This implies that non-kin tenants feel less secure about their tenure and therefore are more productive on their sharecropped plots to increase the probability of contract renewal.

The contribution of the paper is as follows. First, it addresses issues that have not been properly addressed in previous empirical work such as plot quality and household unobserved heterogeneity impact on sharecropping contracts efficiency and contract choices (self-selection bias). Estimations carried out without controlling for these factors may lead to wrong conclusion and inconsistent estimates of the impact of tenancy on productivity and input use. Second, unlike previous studies where sharecropping contracts are assumed to be homogenous (exception is Sadoulet et al., 1997), we differentiate sharecrop contracts into kin and non-kin sharecrop contracts. Third, although this is not the first paper to compare productivity and input use on tenanted and owned plots, as far as we know it is the first paper to use stochastic dominance assessment in the analysis of sharecropping efficiency. Fourth, unlike previous studies (e.g. Sadoulet et al., 1997; Okbasillassie and Holden, 2004), we estimate the impact of tenancy on fertilizer use sequentially where the decision to or not to use and how much to use are estimated separately. Estimating these decisions simultaneously while the decisions are separate may lead to inconsistent estimates and wrong conclusion on tenancy impact on input use. Finally, the paper contributes to the limited literature available on reverse share tenancy and kinship sharecropping contracts impact on productivity and input use.

Paper III: The Economic Potential of Forage Legumes Adoption in the Ethiopian Highlands

Fodder and land degradation are major constraints for livestock and crop production in the Ethiopian highlands. These constraints are contributing to low and declining agricultural productivity and food insecurity. There is growing evidence that forage legumes can offer a ray of hope by increasing the quality and quantity of fodder production, enhancing land productivity, generating extra income to farmers and reducing soil erosion when they are intercropped with cereals. Forage legumes are scale neutral technology as they can be used by poor and rich farmers equally without affecting the existing farming system. These technologies can reduce the risk of farmers by increasing crop and livestock productivity using internally (home) produced inputs (e.g. high quantity and quality of fodder and nitrogen). Despite these benefits, few empirical evidences exist to show the effects of intercropping forage legumes with cereals on agricultural productivity and soil conservation.

This paper therefore assess the impact of forage legumes-cereals intercropping adoption on household income and soil conservation. We develop a farm household utility model that captures the role of forage legumes in improving livestock productivity through better feed and crop productivity through better soil fertility management. We apply a bio-economic linear programming model combining household survey and on-farm experimental data.

The results indicate that forage legumes-cereals intercropping significantly increase household income (per capita income) while at the same time reducing pressure on the land resources. We find that the per capita income of the household increase by 51.7% (from Birr 1149 to 1743)[2] over the base scenario only by introducing forage legumes into the farming system to use it as feed for existing livestock and for soil fertility management. This was accompanied by a 9.4% decline in soil loss (from 11.7 to10.6 ton/ha/year) compared to the base scenario. The farm income is further increased when forage legumes are combined with crossbred cows for milk production (from Birr 1149 to 2006). The results further suggest that the marginal value productivity of grazing lands decrease after forage legumes are introduced in the model. This is a result of an increase in feed dry matter availability form intercropping. Increased high quality and quantity of feed dry matter from intercropping may have reduced the problem of overgrazing and hence soil erosion and compaction of farmland by livestock. Overall, the results imply that development interventions that consider forage legumes will achieve a double advantage of enhancing the livelihood of rural households while checking land degradation.

The contribution of the paper is threefold. First, to our knowledge, it is the first empirical paper to assess the link between annual legumes-cereals intercropping and soil conservation benefits while examining the economics of legumes. Second, an attempt has been made to estimate the marginal benefit of soil fertility to account for nitrogen fixation by legumes. Finally, as there exists limited study in this area, the results of this paper will inform development practitioners and policy makers the role of forage legumes to combat poverty and land degradation.

Paper IV: Adoption of forage legumes-cereals intercropping in the Ethiopian highlands

Considerable research has been directed to the issues of technological adoption in agriculture during the last decades. However, empirical studies to examine the adoption of intercropping forage legumes with cereals are very limited. This paper uses household survey data and a probit model to investigate determinants of forage legume-cereal intercropping adoption in the North-Western Ethiopian highlands. The paper uses the innovation-diffusion, economic

[2] Birr is the Ethiopian currency valued @ US$ 1.00 = 8.65 Birr in 2005.

constraint and adopter perception paradigm and previous technology adoption studies to develop both a theoretical and empirical framework for our study. The empirical results show that access to information through extension and radio, farmer's education level, access to crossbred cows and problem of livestock feed shortage in the household influenced positively the vetch-maize intercropping decision behaviour of households. Implications for policy of these findings include education of farm households, strengthening extension services and information flow and increasing the dissemination of complementary inputs such as improved livestock breeds.

The results from the paper may help development practitioners and policy makers to identify constraints to adoption and to speed up the adoption of forage legumes.

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Conservation Bunds

Farmers dismantling conservation bunds for more land

I

Parametric and non-parametric estimation of soil conservation adoption impact on yield in the Ethiopian Highlands[3]

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Abstract
This paper applies a series of econometric tests to assess the land productivity impacts of physical soil conservation technology in a high rainfall area in the Ethiopian highlands. The analysis is based on data from a cross section household survey with multiple plot observations per household. The results from fixed and random effects models, stochastic dominance analysis and matching methods indicated that yield from conserved plots was lower than yield from non-conserved plots for the household considered. For example, the Oaxaca-Blinder yield decomposition results showed that there was little difference in endowments between conserved and non-conserved plots, however the returns to these endowments were higher for non-conserved plots. The findings imply that the technology may be inappropriate to the local conditions under its existing condition given that the study area is characterized by high rainfall regime and deep soil. In fact, farmers in the study area reported that conservation structures create waterlogging conditions just above the bunds due to poor construction, create difficulty to turn oxen drawn plough due to narrow spacings between structures, serving as a harbouring area for pests and weeds. Overall, these results yields important lessons for future design of technologies, and in particular, the need for a bottom-up approach in technology research and development in order to develop technologies that are socially acceptable and best suited to the local conditions.

Key words: Yield; Yield decomposition; Soil conservation; Switching regression analysis; Stochastic dominance analysis; Matching methods

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1. Introduction

Land degradation problem, soil erosion and nutrient depletion, is one of the basic problems facing the Ethiopian highlands to increase production and reduce poverty and food insecurity. In response, considerable efforts and resources have been mobilized to develop and promote soil conservation measures since mid 1970s. In spite of these efforts and resources, soil conservation measures have not been widely adopted in smallholders farming environment and soil erosion continues to be a problem (Herweg, 1993; Shiferaw and Holden, 1998; Tadesse and Belay, 2004). In some places adopted conservation measures have been either partially or fully removed (Shiferaw and Holden, 1998; Tadesse and Belay, 2004).

The limited success of all these efforts necessitates the investigation of the factors that influence farmers' willingness to invest (or not to invest) in conservation activities. It is imperative to create favourable conditions so that a greater number of farmers can take advantage of conservation measures. One of the most important steps towards this goal is to identify factors that encourage the adoption of conservation measures. The overriding questions that this paper addresses are: 1) Are there any yield[4] differences between conserved and non-conserved plots in high rainfall areas of the Ethiopian highlands, if so what are the sources of yield differences? 2) Does age of conservation structures matter to obtain higher yield? 3) Will conservation measures with some technical changes that involve enhancing productivity of bunds through fodder production result in higher yields?

The paper deviates from similar previous econometric studies (e.g. Shively, 1999; 2001) that assess the impact of conservation on yield in the following points. First, the applications of matching methods and switching regression analysis to assess the impact of conservation on yield are new elements of this paper. Second, the panel nature of the data, cross section with multiple plots per household, is unique such that it allows us to control for unobserved plot and household heterogeneities that have impact on technology adoption and production decisions. Third, the applications of Oaxaca-Blinder wage decomposition method to determine the sources of yield difference between conserved and non-conserved plots are new in this kind of study. Fourth, the nature of the problem is also different; we are addressing

[4] Yield refers to output values per ha obtained on a plot. We used values instead of physical output since more than one crop is grown on a plot and farmers cultivate many crops simultaneously.

physical conservation measures (*fanya juu*[5]) unlike biological measures addressed by Shively (1999; 2001).

The study was based on data from a cross section household survey with multiple plot observations per household collected in high rainfall area in the Ethiopian highlands. The results from parametric and non-parametric analysis (matching methods & first order stochastic dominance analysis) indicated that yield with conservation was statistically lower than yield without conservation. A sensitivity analysis showed that investments in conservation with fodder grass production on the bunds could make conservation productive.

The remainder of the paper is organized as follows. Brief reviews of the determinants of soil conservation adoption and previous empirical works are presented in sections two and three, respectively. The conceptual model is discussed and the econometric framework outlined in sections four and five, respectively. The study area and data type are described in section six. The estimation procedure is presented in section seven. Section eight presents empirical results followed by conclusion in the final section.

2. Determinants of soil conservation adoption: A literature review

Numerous factors underlie soil conservation adoption decisions. These are market and institutional imperfections, availability of inputs (e.g. land); long payback periods, short planning horizons, land tenure, high discount rates, borrowing constraints, profitability of the technology, non-participatory nature of the conservation program (top-down approach) and inappropriateness of the technology to local conditions (Feder et al., 1985; Azene, 1997; Shiferaw and Holden, 2001; Holden et al., 2001; Bewket and Sterk, 2002). Farmers in developing countries are confronted with imperfect markets. These imperfections may have an impact on their production and investment decisions (Pender and Kerr, 1998; Holden et al., 2001). In such circumstances, households' initial resource endowments and household characteristics may play a role in investment and production decisions. For example, if capital and labour markets work poorly, farmers with more capital assets and household labour endowments are likely to invest more. In the absence of better access to credit and cash liquidity, poor households are subject to high consumption smoothing problems and thereby high subjective discount rates which in turn discourages land investment decisions that

[5] *Fanya juu* bund is a soil bund type in which a ditch is dug along the contour, with soil being thrown up to form a ridge above it; a natural bench terrace will then form over the course of the following few years.

involve short term costs but long run benefits (Holden et al., 1998). The characteristics of land markets and tenure insecurity may also affect investment decisions and productivity as rental contracts and tenure insecurity may not provide sufficient time for tenants and land owners to reap the benefits of their investment (Feder and Feeney, 1991; Pender and Kerr, 1998; Deininger and Binswanger, 2001). We refer to Pender and Kerr (1998) and Holden et al. (2001) for detailed discussion of the market imperfection implications on production and investment decisions of farm households. Farm size and plot characteristics also determine adoption. When soil depth is deep, farmers have little incentive to prevent soil loss and are unwilling to adopt conservation technologies, as there is little benefit from soil conservation (Pender and Kerr, 1998; Mbaga-Semgalawe and Folmer, 2000; Shively, 2001).

The most important factors influencing adoption of technology is the profitability of the technology. Farmers often reject conservation because the economic returns are too low or negative. The returns are negative in the short run due to high initial investment costs and space occupied by conservation structures (Shiferaw and Holden, 1998; Shively, 1999). Whether conservation technologies have, in general, increased yield appears to depend on the local conditions and the technology in question. The initial benefits may be higher in low rainfall areas due to an immediate moisture conservation effect. For example, Sutcliffe (1993) in comparing economic benefits of different physical conservation measures in Ethiopia concluded that in an area where water stress is less frequent (e.g. our study area) investments in conservation are only profitable if bunds themselves can be used in a productive manner as cultivation area for producing fodder grass or trees. He further concluded that conservation activities are only justifiable in moisture stressed areas, where water conservation plays an important role in increasing yield. These results have two implications. First, moisture conservation may not be important in high rainfall areas, but placing appropriate conservation measures could help soil protection during extreme rainfall. Second, blanket recommendation of technologies across the country without accounting for the local conditions is inappropriate[6].

Adoption (rejection) of technologies by farmers depends on farmers' perceptions of the appropriateness (inappropriateness) of the technologies under investigation. For instance, farmers in high and reliable rainfall areas of Ethiopia (e.g. our study area) expressed concerns

[6] Like other technologies (e.g. fertilizer, seeds) blanket recommendation of soil conservation measure is common in the country.

over physical conservation bunds that include the following: reducing the available area for planting; water accumulation behind the bund causing waterlogging; providing fertile ground for weeds and pests to reproduce; difficulty to turn the ox-drawn plough due to narrow terrace spacing; and in some areas aggravating soil erosion due to poor construction of bunds (Tegene, 1992; Bewket and Sterk, 2002)[7]. Krüger (1994) observed that crop production on about 15% of the total crop area is affected during the first year of bund construction and an additional 10 to 15% of the production area may be affected by waterlogging. In addition, the construction of conservation structures did not consider important factors that affect the construction of structures. The development agents (DAs) simply followed guidelines of manuals prepared in reference to slope inclinations ignoring other factors such the intensity of rainfall. Without such basic data to estimate how much runoff will be generated in the fields, it is practically impossible to determine dimensions and spacing of conservation structures.

Another important consideration, which affects adoption, is the top-down approach pursued in the planning and implementation of conservation activities without consulting farmers and full diagnosis of the local conditions. This ignores local knowledge and practices and thus reduces farmers' willingness to participate in conservation activities underway in their communities. If they participate, it is not because they are convinced with the benefit of the technology but simply persuaded by the village administration and the development agents (Azene, 1997; Yeraswork, 2000; Bewket and Sterk, 2002). The conservation measures were in most cases physical measures and undertaken through campaign using Food-for-Work or constructions of social services (e.g. health clinic) as an instrument to motivate farmers to putting up the conservation structures both on communal holdings as well as on their own plots. These measures are often not integrated with soil fertility management practices.

3. Impact of conservation on Crop yield: Previous econometrics works

Few empirical studies have examined directly the impact of conservation on crop yield using econometric and cross-sectional data (e.g. Shively, 1998a; 1998b; 1999; Byiringrio and Reardon, 1996; Kaliba and Rabele, 2004). Byiringiro and Reardon (1996) using on farm level data in Rwanda, found that farms with greater investments in soil conservation have much better land productivity than other farms. However, the type of conservation was not clearly specified in the article. Shively (1998a; 1998b; 1999) using cross sectional data in the

[7] This implies that the quality of bunds is poor and implementation of bunds does not considere the existing farming system (oxen-plough).

Philippines found that the presence of hedgerows was associated with an increase in corn yields whereas the intensity of hedgerows was negatively correlated with corn yield. In Lesotho, Kaliba and Rabele (2004) found statistically significant positive association between wheat yield and short (e.g. fallow and crop rotation) and long-term soil conservation measures (e.g. terraces and water ways).

The previous studies, however, suffered from two major problems: methodological and inadequate data problems. First, all studies assumed single equation model where technology has only intercept effects and the same set of variables equally affect both technology adopters and non-adopters. Second, except Shively (1998b; 1999), the remaining studies did not account for the endogeneity of the technology and self-selection problem. Third, all studies did not account for the unobserved heterogeneity that might have impact on their findings. Kaliba and Rabele's (2004), study suffered from small sample size (50 households) problem and did not control for plot characteristics variables. If there is asymmetric distribution in plot quality across plots and households, and a correlation between conservation and plot quality, estimation of conservation impact on yield without controlling for these factors may lead to inconsistent estimates.

4. Conceptual model

Following Shively (1997) the concepts outlined in section 2 can be summarized using the following model. We use a model of household utility maximization to explain farm households' investment and production decisions. Since farm households in developing countries undertake agricultural production under production uncertainty (e.g. erosion risk) and multifaceted market imperfection, we use an expected utility maximization framework to represent investment and production decisions made under uncertainty. Conservation effort (C) is assumed to be an essential input in the production process. Farm household's problem is defined as:

1) $\max\limits_{C,X} E[U(\pi)] = \int_0^T [E[U(\pi)]]e^{-\rho t}\,dt$

s.t $\pi_t = [\theta f(C, X, Z^p, Z^h) - q(C, X)]$,

Where ρ is a per-period discount factor, π is the per-period return from farming, X is the vector of all conventional inputs except conservation effort, Z^h denotes household socio-economic characteristics such as labour, age, experience, extension contact, tenure status, livestock wealth, physical assets, Z^p represents plot characteristics such as plot size, soil fertility and depth, slope and plot location, rented in plots , $\theta f(C, X, Z^p, Z^h)$ is a stochastic production function that relates inputs with output, and $q(C, X)$ is a cost function. Output and input price is normalized to one for ease of exposition. We assumed multiplicative stochastic production function, where θ is the stochastic variable with mean one and variance σ^2 (Newbery and Stiglitz, 1981).

The objective function of the farmer after inserting the definition of π into (1) is given as:

2) Max $H = E\left[U\left[\theta f(C, X, Z^p, Z^h) - q(C, X)\right]\right]$

The first order condition (FOC) for conservation input C is:

3) $\dfrac{\partial H}{\partial C} = E\left[U^{'}\left(\theta \dfrac{\partial f}{\partial C} - \dfrac{\partial q}{\partial C}\right)\right] = 0.$

Similar procedure can be followed to derive the FOCs of other inputs.

Considering a first order Taylor series approximation of $U^{'}$ about expected income, $\bar{\pi}$

4) $U^{'}(\pi) = \overline{U}^{'} + \overline{U}^{"}(\pi - \bar{\pi})$

where $\overline{U}^{'}$ and $\overline{U}^{"}$ are $U^{'}$ and $U^{"}$ evaluated at mean income, respectively. Further, let the Arrow-Pratt measure of absolute risk aversion be denoted by $p(\pi) = -U^{"}(\pi)/U^{'}(\pi)$ so that at mean income $\bar{p} = -\overline{U}^{"}/\overline{U}^{'}$. Then using (4) in (3) and after some manipulation, the FOC is approximated by

5) $\dfrac{\partial f}{\partial C} - \dfrac{\partial q}{\partial C} - \left[\bar{p}\sigma^2 f(C, X)\left(\dfrac{\partial f}{\partial C} - \dfrac{\partial q}{\partial C}\right)\right] = 0$

Equation (5) is the marginal benefit-marginal cost condition for adoption. For risk-neutral farmers the term in the square bracket of (5) will disappear and adoption of technology will depend on the classical marginal conditions. For risk-averse farmers this term is different from zero. For this farmers technology adoption will be governed by production risk and attitude towards risk besides the adoption costs and other factors. Farm specific attributes such as plot quality and slope may influence adoption decision by influencing technology performance or adoption costs. A vector of household socio-economic characteristics can parameterize risk and risk aversion behaviour of the households (Holden et al., 1998). The reduced form of soil conservation investment demand function at plot level will take the following forms

6) $C = \phi(Z^p, Z^h)$

Then, the output value function $f(C, X, Z^p, Z^h)$ can be defined as follow[8]:

7) $Y = f(X, Z^p, Z^h)$

5. Econometric framework

Assessment of the productivity gain of conservation based on non-experimental observations is not trivial because the counterfactual of interest (yield) is not observed. That is, we do not observe the outcome of plots with conservation had they not had conservation structures (or the converse). Ex-post assessment of the gains to conservation over without conservation is also difficult using observational data because the unobserved household and plot attributes are likely to influence technology adoption, input application choices and observed output. The failure to account for household and plot heterogeneity can lead to inconsistent estimates of the impact of the technology. Conservation measures may be introduced externally through projects and DAs. If project experts and DAs select households and plots based on some unobserved factors for the econometricians (selection bias), the impact of technology on yield will not be estimated consistently without controlling for the selection criteria. The estimation methods most suitable to solve these problems and achieve our objectives with the available data are the switching regression models, stochastic dominance analysis and matching methods. We discuss each method below.

5.1. Switching regression models

Consider the following pooled cross section two regression equations and a switching equation C_{ip} that determines, which regime the plots faces. The analysis is done at plot level.

8) $C_{ip} = 1(z_{ip}\gamma + u_{ip} > 0)$,

9) $Y_{1ip} = x_{ip}\beta_1 + \varepsilon_{1ip}$ if $C_{ip} = 1$

10) $Y_{0ip} = x_{ip}\beta_0 + \varepsilon_{0ip}$ if $C_{ip} = 0$

where i indexes household $(i = 1,...,N)$, p indexes plots within a household $(p = 1,...,P)$, $C_{ip} =$ 1 if household i use conservation on a plot p and zero otherwise, x_{ip} is a vector of covariates, z_{ip} is a vector of explanatory variables assumed to explain the probability of adoption, Y_{1ip} and Y_{0ip} are yield with and without conservation, respectively, γ, β_1 and β_0 are vector of unknown parameters to be estimated, $1(.)$ is binary selection indicator function

[8] See section 7 how the issue of endogeneity of input choices are addressed.

and ε_{1ip}, ε_{oip} and u_{ip} are idiosyncratic error terms assumed to be trivariate normally distributed with mean zero and with covariance matrix,

$$\begin{bmatrix} \sigma_1^2 & \sigma_{10} & \sigma_{1u} \\ & \sigma_0^2 & \sigma_{0u} \\ & & 1 \end{bmatrix}.$$

The conditional expectation of the yield equations (9 & 10) assuming that $E(u_{ip}^2) = 1$ are defined as

11) $E(Y_{1ip} \mid x_{ip}, C_{ip} = 1) = x_{ip}\beta_1 + \sigma_{1u}\lambda_1(z_{ip}\gamma)$

12) $E(Y_{0ip} \mid x_{ip}, C_{ip} = 0) = x_{ip}\beta_0 + \sigma_{0u}\lambda_0(z_{ip}\gamma)$

where $\lambda(.)$ is the inverse mill's ratio defined as $\lambda_1 = \dfrac{\phi(z_{ip}\gamma)}{\Phi(z_{ip}\gamma)}$ for positive observations $(C_{ip} = 1)$ and $\lambda_0 = -\dfrac{\phi(z_{ip}\gamma)}{1-\Phi(z_{ip}\gamma)}$ for the zero observations $(C_{ip} = 0)$.

where ϕ and Φ are, respectively, the pdf and cdf of the standard normal distribution. Equation (11) and (12) are defined to be endogenous switching regime model and when $\sigma_{1u} = \sigma_{0u} = 0$ theses equations simplify to exogenous switching regime model. The residuals from (11) and (12) cannot be used to determine the variance-covariance matrix of the two-stage estimates since λ_1 and λ_0 are generated regressors. Standard errors in the second stage are corrected by bootstrapping both equations (switching as well as yield equations) simultaneously.

The mean yield difference between conservation adoption and non-adoption can be estimated as:

13) $E(Y_{1ip} \mid x_{ip}, C_{ip} = 1) - E(Y_{0ip} \mid x_{ip}, C_{ip} = 1) = x_{ip}(\beta_1 - \beta_0) + \vartheta_1\lambda_1 - \vartheta_0\lambda_0$.

The second term in the left-hand side of (13) is the expected value of Y if the plot had not adopted the soil conservation (Counterfactual outcome)[9]. Examples of previous studies using this approach include Lee (1978), Fugile and Boch (1995) and Khanna (2001).

The parametric procedure described above might have some drawbacks. First, the yield gap between plots with and without conservation measured at the mean; potentially ignoring

[9] Equation 13 is similar to average treatment effects on the reated. That is the mean effect for those, which actually conserved (see section 5.3).

important differences in the form of the entire yields distribution. Second, the resulting estimates in the case of endogenous switching regression model are contingent on the underlying trivariate normal distribution of the errors in the adoption and yield equations. The identification condition is also a problem if one does not get good identification variable in the first stage regression in the case of endogenous switching regression model. Third, the yield equation assumes functional form, which is usually linear. Thus, results obtained from parametric regressions need to be checked for robustness.

In this study we implement a non-parametric procedure, stochastic dominance analysis (SDA) and matching methods. They are appealing methods because of their free distributional and flexible functional form assumption. In SDA instead of focusing on mean yields, we examine the entire density of yields.

5.2. Stochastic Dominance Analysis

The stochastic dominance analysis has been developed to compare and rank the outcome of alternative risky investments. The comparison and ranking is based on cumulative density functions (CDFs). The two dominance rules discussed below are first order stochastic dominance (FSD) and second order stochastic dominance (SSD) analysis. Assume that a farmer decide whether to invest in conservation or to continue farming without conservation with cumulative distribution functions of their return given by $F(y)$ and $G(y)$, respectively. Conservation dominates without conservation in the sense of the FSD *iff*

14) $G(y) - F(y) \geq 0, \forall_{y} \in \Re,$

with strict inequality for some $y \in \Re$. This implies that if the CDF of yields without conservation $G(y)$ is greater than the CDF of yields with conservation $F(y)$ for all levels of yields, then the distribution with the higher density function is dominated by the distribution with the lower density function. In terms of graph, if the yields in the cumulative distribution graph without conservation are to the left of the yields in the cumulative distribution graph with conservation for all levels of yields, then $G(y)$ is dominated by $F(y)$ (Mas-Colell et al., 1995). The assumption behind the FSD criterion is that the households maximize expected utility and they usually prefer more to less yields, regardless of their attitude towards risk. However, if CDFs intersect, FSD cannot discriminate between the two alternatives.

If the CDFs under FSD intersect and farmers are risk averse in addition to preferring more to less, a choice between distributions could be made by SSD criterion (Hien et al., 1997). Formally, conservation dominates the without conservation in the SSD sense *iff*

15) $\int_{-\infty}^{y} \left(G(y) - F(y)\right) dy \geq 0, \forall_y \in \Re,$

with strict inequality for some $y \in \Re$

The test for SSD requires a comparison of the area under CDFs. In words, SSD requires that the area under the cumulative density function for conservation is always smaller than the area under the cumulative density function for the without conservation.

In empirical analysis, the probability distribution of G and F are usually unknown, and must be estimated from data. We used the standard normal kernel density function to derive the CDFs (Greene, 2003, pp 454-455).

Previous studies on stochastic dominance analysis using non-experimental farm level data include Shively (1999). Shively (1999) compared observed crop yields with and without contour hedgerow in the Philippines. He found that the hedgerow technology did not constitute an unambiguously dominant production strategy compared to plots without hedgerows.

5.3. Matching methods[10]

Matching is widely used in the estimation of the average treatment effect of a binary treatment on a continuous scalar outcome. It uses non-parametric regression methods to construct the counterfactual under an assumption of selection on observables. We think of conservation as a binary treatment, output value per ha as an outcome, and conserved plots as treatment group and non-conserved plots as control group variables. Matching estimators aim to combine (match) treated and control group plots that are similar in terms of their observable characteristics in order to estimate the effect of conservation as the difference in the mean value of an outcome variable.

[10] We did not come across previous studies applying these methods on agriculture.

Following the literature of program evaluation, let Y_1 be the value of yield when plot i is subject to treatment $(C = 1)$ and Y_0 the same variable when a plot is exposed to the control $(C = 0)$. The observed outcome is then[11]

16) $Y = CY_1 + (1 - C)Y_0$.

When $C = 1$ we observe Y_1; when $C = 0$ we observe Y_0. Our goal is to identify the average effect of treatment (ATT) (conservation investment) on the treated (those plots that received soil conservation investment). That is the mean effect for those plots, which actually conserved. It is defined as

17) $ATT = E(Y_1 - Y_0 | C = 1) = E(Y_1 | C = 1) - E(Y_0 | C = 1)$,

The evaluation problem is that we can only observe $E(Y_1 | C = 1)$; however, $E(Y_0 | C = 1)$ does not exist in the data, since it is not observed. A solution to this problem is to create the counterfactual $E(Y_0 | C = 1)$ (what would have been the yield of plots with conservation had they not had conservation (or the converse)), by matching treatment and control plots. As discussed by Heckman (1998) a critical assumption in the evaluation literature is that the no-treatment state approximates the no program state[12]. For matching to be valid certain assumptions must hold. The primary assumption underlying matching estimators is the Conditional Independence Assumption (CIA). CIA states that the decision to adopt is random conditional on observed covariates X (Wooldridge, 2002). In notation,

18) $(Y_1, Y_0) \perp C | X$

This assumption implies that the counterfactual outcome in the treated group is the same as the observed outcomes for non-treated group

19) $E(Y_0 | X, C = 1) = E(Y_0 | X, C = 0) = E(Y_o | X)$

This assumption rules out selection into the program on the basis of unobservables gains from conservations. The CIA requires that the set of X's should contain all the variables that jointly influence the outcome with no-treatment as well as the selection into treatment. Under the CIA, ATT can be computed as follow:

20) $ATT = E(Y_1 - Y_0 | X, C = 1) = E(Y_1 | X, C = 1) - E(Y_0 | X, C = 1)$

Matching plots based on observed covariates might not be desirable or even feasible when the dimensions of the covariates are many. To overcome the curse of dimensionality, Rosenbaum

[11] We dropped the subscript i and p to make the notation easy.

[12] Here the assumption of no contamination bias or general equilibrium effect is important.

and Rubin (1983) show that instead of matching along X, one can match along $P(X)$, a single index variable that summarizes covariates. This index is known as propensity score (response probability). It is the conditional probability that plot i adopts conservation given covariates:

21) $p(X) = pr(C = 1)|X$

The ATT in equation (18) can then be written as

22) ATT= $E(Y_1|P(X), C = 1) - E(Y_0|P(X), C = 1)$

The intuition is that two plots with the same probability of adoption will show up in the treated and untreated samples in equal proportions. The propensity score (pscore) estimated by a simple binary choice model, in this paper a binary probit model is used[13]. Once the pscore is estimated, the data is split into equally spaced intervals of the pscore. Within each of these intervals the mean pscore and of each covariate do not differ between treated and control plots. This is called the balancing property. For details on the algorithm of pscore matching see Dehejia and Wahba (2002). If the balancing property is not satisfied higher order and interaction terms of covariates can be considered until it is satisfied. Since pscore is a continuous variable exact matches will rarely be achieved and a certain distance between treated and untreated plots has to be accepted. To solve this problem treated and control plots are matched on the basis of their scores using nearest neighbour, kernel methods and stratification matching estimators. These methods identify for each plot the closest propensity score in the opposite technological status; then it computes conservation effect as the mean difference of plot's yield between each pair of matched plots. For details of these methods we refer to Becker and Ichino (2002) who also provide the STATA software code we use in this paper.

5.4. Yield decomposition[14]

To identify and quantify the sources of yield gap and their contributions we used the Oaxaca (1973) and Blinder (1973) wage decomposition method. The Oaxaca-Blinder decomposition separates the portion of the gap resulting from differing characteristics of conserved and non-conserved plots from the portion that is resulted from the returns to those characteristics. The method is easy to apply and only requires coefficient estimates from yield regressions and

[13] Under this condition the matching methods can be considered as semi-parametric method since parametric results (probit model results) are used as input for non-parametric methods in the second stage of matching. However, since the second stage is fully non-parametric we still stick on the name non-parametric.

[14] We did not come across previous studies applying this method on agriculture.

sample means of the independent variables used in the regressions. The yield equation, which we estimate for conserved and non-conserved plots can be written as:

23) $Y_{1ip} = X_{1ip}\beta + \varepsilon_{1ip}$

24) $Y_{0ip} = X_{0ip}\beta_0 + \varepsilon_{0ip}$

The Y's are the yields of conserved and non-conserved plots, the X's are vectors of household and plot level characteristics (endowments), the β's are vectors of rewards or payments for the characteristics and the $\varepsilon's$ are random error terms. These equations tell us that yields (those of conserved and non-conserved plots) are determined by characteristics, X, rewards, β and some random component, ε. Once we have estimated the equations using ordinary least squares regressions, the standard Oaxaca-Blinder decomposition of the yield gap can be expressed as:

25) $\hat{Y}_{1ip} - \hat{Y}_{0ip} = \sum \hat{\beta}_1 (\overline{X}_{1ip} - \overline{X}_{0ip}) + \sum \overline{X}_{0ip} (\hat{\beta}_1 - \hat{\beta}_0)$

where $\overline{X}_{ip}$ is a vector of average values of the characteristics (endowments) and the other variables are as defined above.

The yield differential (the left hand side) can be split into two parts:
(a) differences in average characteristics (the first component of the right hand side) and
(b) differences in rewards for those characteristics (the second component on the right hand side).

The existence of $\sum \overline{X}_{0ip} (\hat{\beta}_1 - \hat{\beta}_0)$ can be explained in different ways. Conservation may increase the productivity of inputs and/or waterlogging and pests may affect endowment productivity of plots with conservation. Framers might have invested on degraded plots so that return to endowments due to conservation may be low on these plots compared to plots without conservation. On the other hand, plots without conservation may be more degraded than plots with conservation due to erosion risk. As a result, returns to endowments may be lower on these plots than on plots with conservation.

6. Study area, Data and soil conservation technology

The study village is located in Dembecha district, West Gojjam zone of Northwestern Ethiopian highlands. Soil Conservation Research Project (SCRP) established in the village in 1984. This project was collaboration between the Ethiopian and Swiss governments to identify suitable conservation technologies for different areas. The study area is characterised by high rainfall (1690 mm per annum) regime and good to medium soil depth.

The econometric evaluation is based on cross section household survey with multiple plot observations per household collected with experienced enumerators under close supervision of the first author. The data are drawn from sample of 148 farm households, operating 1290 plots, collected in 2001. Household and plot level variables were collected for the 2000 production year. Among the variables collected, plot size, plot slope and space occupied by conservation structures were measured using measuring tapes and inclinometer.

Table 1 provides the characteristics of the sample we used for conserved and non-conserved plots for the entire sample and for the sub-sample of barley plots. Barley is the major crop in the study area and the number of plots planted to barley were relatively bigger than those planted to other crops. Because the ability of conservation to increase yield may change over time, we differentiated conservation structures into old and relatively new. Old conservation structures were located within SCRP site. They were built with the help of well-trained personnel and established well (i.e. they do not need much maintenance) compared to new conservation structures located outside SCRP site. During the time of the survey these conservation structures were about 15 years old. The new conservation structures were built with the help of less trained personnel (development agents). Some of these might have the same age as the old conservation structures but the majority of them were less than 15 years old. About 32.7% of the sample plots had conservation, and sixty-one percent of these had conservation structures of 15 years old at the time of the survey. Project experts and DAs mobilized community labour for constructing the structures on 78% of the total conserved plots. Initially, the SCRP built a health clinic for the village as an instrument to motivate farmers to construct and maintain the conservation structures on their own plots.

The predominant conservation strategy used in the village was *fanya juu* bunds introduced by the SCRP, traditional ditch (furrow) being one of alternative indigenous conservation measures being practiced in the area. The *fanya juu* bunds are not integrated with soil fertility management practices.

Even if physical conservation measures do not directly increase crop yields, they can be used for producing natural fodder grass on the bunds, besides arresting the soil loss. During the rainy season when grazing is restricted, grass from conservation structures is fed to the oxen. Framers reported that the grass on the bunds covered 9.5% of the total livestock feed requirements[15]. The estimated grass yield on the bunds ranges from 0-180 kg dry matter per plot (1995 kg per hectare). This benefit is considered as an output of the system, in addition to the crop output. Since there are no markets for grass or hay, the value of the grass from bunds is expressed in terms of the animal feed for oxen. The average price of an ox during the survey period was Birr 800 and the annual dry matter feed requirement is about 1831 kg, assuming the daily dry matter intake is 2.2% of the livestock body weight (Nicholson et al., 1994).

7. Econometric Estimation procedure

Some methods have been developed to correct for selectivity bias in panel data context (e.g. Vella and Verbeek, 1999; Wooldridge, 1995). However, it is not clear to what extent these methods can be extended to the data structure we have, cross section multiple observations per household. We tried the Wooldridge (1995) method where he assumed a linear correlation between the unobserved effects and the means of time (in our case plot) varying explanatory variables to estimate fixed effects model. However, this method did not fit our data, the covariance matrix was singular, and the coefficients as well as the predicted values were inflated. We thus switched to cross section endogenous switching regression model (pooled OLS).

The selectivity issue may be captured using the panel nature of our data without including inverse Mills ratio in the equation of interest. If self-selection is a function of plot invariant unobserved factors (household heterogeneity), the availability of multiple observations for a given household may allow to account for these factors in the estimation (Wooldridge, 2002; Hsiao, 2003). We focused on this approach for the following reasons. First, the results of the endogenous regression model are contingent on the specification of the first stage regression (e.g. identification condition) and on the assumption we made about the error terms. Second, the panel nature of the data allows us to solve the problem of endogeneity and/or selection bias due to omitted variables and measurement errors (Ibid). By applying household fixed effects to our multiple plots per household type of panel data, we have been able to eliminate plot invariant household and partially plot specific effects that may otherwise have created

[15] The contribution of communal pasture land, private pasture land, crop residues, stubbles and weeds to the total feed requirement is 30.8, 11.2, 23.7, 15 and 9.8%, respectively.

such biases. Third, the adoption of conservation for about 61% and 17% of the conserved plots was driven externally through projects (SCRP) and DAs, respectively, through community labour mobilization. If there are no systematic selection of plots and households by project experts and DAs, exogenous switching regression model is appropriate for estimating conservation impact on yield.

Household fixed and random effects models are traditionally used when there is cross-sectional time series data. These models can also be applied for single cross-sectional observations by assuming each plot observation within a household as a time variable.
The general yield regression model to be estimated is:

26) $y_{hp} = x_{hp}\beta + c_h + e_{hp}$,

where y_{hp} is output value per ha obtained by household h on plot p depending on the conservation status of the plot, c_h is the unobserved household heterogeneity that captures unreported household characteristics such as farm management ability, average land fertility, households' risk preferences and time preferences that affects productivity, e_{hp} is the random variable which summarizes the plot specific component other than the ones reported in the survey such as unobserved variation in plot quality and plot specific production shocks (e.g. plot level variation in rainfall, hail, frost, floods, pest & weed infestation), x_{hp} include both plot-invariant and variant observed explanatory variables, and β is a vector of parameters to be estimated. Equation 26 can be considered as exogenous switching regression model.

The fixed effects estimators may suffer from efficiency problem if we have small number of observations per household. Mundlak (1978) indicated that the variance of the fixed effects estimators declines with the size of the sample as determined by increasing the number of observations per households. In our case besides high standard errors the estimates were inflated for barley sub-sample plots, especially for plots with conservation. For entire and barley sub-sample plots we relied on fixed and random effects models, respectively.

8. Results and Discussion

Stata econometric software version 9 used to estimate parametric models and matching methods. Stochastic dominant analysis was done using spreadsheets, Excel.

8.1. Adoption of conservation

The results of the probit estimates are presented in Table 2. The model was estimated with and without household level variables. The probit model was estimated to serve as an input for yield regression models. Therefore, we briefly described the results based on the entire sample plots. For the barley sub-sample plots we did not find as many significant variables as the entire sample. Results indicated that rented-in plots, plot slope (quadratic), female labour supply (linear) and a dummy variable for households that lost land during 1997 redistribution were all negatively correlated with adoption probability. Adoption probability was positively correlated with plot size, plot distance, plot slope (linear), farmer's contact with extension workers, and female labour supply (quadratic).

8.2. Conservation impact on yield

In this section we discuss the results obtained from parametric and non-parametric models.

8.2.1. Parametric model

Yield regression results are reported in Tables 3, 4 & 5. The Chow test rejected the hypothesis that coefficients from conservation and non-conservation yield regressions were the same. So separate yield estimation was important to get consistent estimates of the impact of conservation technology on yield. However, for comparison purpose we reported also the pooled (pooling conserved and non-conserved plots together) model results where conservation intensity variable was used as one of the regressors in the model (Table 5).

The results indicated that factor inputs were associated with increases in yield at statistically significant levels. Rented in plots were more productive than owner-operated plots (Table 3 and 5). Plot and household level variables also affected yield for some of the specifications.

To determine the effects of conservation adoption on yield, we compared the predicted mean yield obtained from plots with and without conservation using equation (13). The mean predicted yield was determined for four different plot slope categories: a) holding all the explanatory variables at their means except the variable plot slope in order to get variation for statistical testing purpose (pooled slope); b) mean plot slope between 0 and 12 degrees (Slope A); c) mean plot slope between >12 and ≤ 20 degrees (Slope B); and d) mean plot slope greater than 20 degrees (Slope C). We hold all the explanatory variables at their means, except labour input for ploughing, for scenarios b, c and d.

We found significant statistical evidence that mean yield with conservation was lower than mean yield without conservation for each specification (Table 6)[16]. Similar results obtained from pooled model estimation (Table 5). The increase in yield with plot slope may be associated with recent expansion of cultivation to steeper areas and with waterlogging problem where it can decrease as slope increases. The age of conservation structures did not change the overall results; we used barley plots to examine conservation age effect on yield. These results were in line with those from non-parametric analysis discussed in section 8.2.2.

8.2.2. Non-parametric models

We check the robustness of our parametric estimation results using non-parametric techniques.

8.2.2.1. Stochastic Dominance Analysis

The stochastic dominance analysis was estimated for the four categories of plot slopes. These include: slope between 0 and 12 degrees (Slope A), slope between >12 and ≤ 20 degrees (Slope B), slope > 20 degrees (Slope C) and for all plot slopes (pooled slope)[17]. Figures 1 and 2 for the pooled slopes showed that the CDF for yield with conservation is always to the left of that without conservation, indicating that yield without conservation first order stochastically dominated the yield distribution with conservation. This directly implies SSD dominance as well. The results imply that the chance of getting higher yield was higher for plots without conservation than plots with conservation, given the same probability.

For the entire sample, the results remained the same before and after disaggregating plots by slope types (fig 5). For the barley plots, slope B and C non-conserved plots still dominated all slopes categories of conserved plots (fig 6).

Comparing the yield distribution of old and new conservation structures, we did not see clear pattern for the entire sample plots (fig 1). For the barley plots, however, those with old conservation structures seem to dominate except for some yield ranges to the right of the yield distributions (fig 2).

[16] The results were robust to exclusion of inputs and are available upon request. We tried also the random effects models for the entire sample, however, the conclusion remained the same as in the fixed effects models.
[17] The number of observations for each slope category for the entire sample was 199, 498, 171, & 868 for plots without conservation and 90, 244, 88 & 422 for plots with conservation. For the barley sub-sample plots 62, 132, 69, & 263 for plots without conservation and 38, 77, 24 & 139 for the case with conservation.

8.2.2.2. Matching Methods

The results of the matching estimators are presented in Table 7. The matching estimates showed a significant negative effect of conservation on mean yield (Column E).

In the following section the causes of yield gap and methods to reduce the gap are explored. This may help us to identify possible problems causing the yield gap and to recommend possible solutions to minimize yield gap.

8.2.3. Yield gap decomposition

Table 8 outlines the decomposition results. The Oaxaca-Blinder decompositions results showed that there was little difference in endowments between conserved and non-conserved plots, however the returns to those endowments were higher for non-conserved plots. Considering barley plots, conserved plots had higher total endowment differences than non-conserved plots. However, the returns to these endowments were lower on conserved plots than on non-conserved plots. Specific results for endowments of soil fertility and soil depth between plots with and without conservation indicated little differences although the returns to these variables were higher for plots without conservation. This finding has the following implications. One is that conserved plots are not more degraded than non-conserved plots. Second, the technology may be inappropriate to the local conditions under its existing condition. In fact, farmers in the study area reported that conservation structures create waterlogging conditions just above the bunds due to poor construction, reduce frequency and proper ploughing of plots due to narrow structure spacings, and serving as a harbouring area for pests and weeds.

8.2.4. Sensitivity analysis (SA)

The economic performance of conservation structures could be improved if bunds themselves can be used in a productive manner by planting fodder grass with an economic value. We tested this hypothesis by increasing the grass production on bunds from the current level of production (1995 kg per ha) to 5986 kg per ha; the estimated native pasture productivity from communal grazing land in Ethiopia ranges between 3000–6000 kg per ha (Mengistu, 1987). The grass from bunds is expressed in terms of the animal feed for oxen since there are no markets for grass or hay. The average price of an ox during the survey period was Birr 800 and the annual dry matter feed requirement is about 1831 kg assuming the daily dry matter intake is 2.2% of the body weight (Nicholson et al., 1994). The SA was done using non-parametric methods.

The SDA results indicated that the yield distribution of plots without conservation had no dominance on those with old conservation structures in the case of the barley plots (Fig 4). The gap between CDFs decreased for the entire sample plots, but the CDF's of non-conserved plots was still first order stochastically dominated (fig 3). However, the yield distribution of plots without conservation still dominated the yield distribution of those with new conservation. This difference could be due to old conservation occupied more space (0.02 ha) than new conservation (0.01 ha) and grass productivity may be lower on new bunds than on old bunds.

There was no statistically significant mean yield difference between conserved and non-conserved plots when we tested using matching estimators for the barley plots (Table 7). However, for the entire sample plots the difference was statistically significant, but the magnitude of the mean yield difference decreased[18]. The response of some crops to conservation may be strongly negative compared to barley crop. Overall, the result suggested that there are possibilities to make conserved plots more productive or as productive as non-conserved plots. However, these results are not conclusive. Detailed studies regarding grass and other improved forage fodders and their impact on livestock could add to these findings.

9. Conclusions

We have analysed the impact of soil conservation on yield in a high rainfall area in the Ethiopian highlands. The results from both parametric and non-parametric analyses indicated that yield on conserved plots was statistically lower than yields on non-conserved plots for the households considered. The Oaxaca-Blinder yield decomposition results showed that there was little difference in endowments between conserved and non-conserved plots, however the overall returns to these endowments were higher for non-conserved plots. The findings imply that the technology may be inappropriate to the local conditions under its existing condition given that the study area is characterized by high rainfall regime and deep soil. In fact, farmers in the study area reported that conservation structures create waterlogging conditions

[18] Such technical changes along with properly constructed bunds can further increase productivity.

just above the bunds. This result may explain the low adoption rates for the soil conservation technology.

Further, we assessed whether increasing the production of natural grass on bunds could reduce the yield gap between conserved and non-conserved plots. Overall, the sensitivity analysis results suggested that there are possibilities to make conserved plots as productive as non-conserved plots. For instance, the matching estimator results show that an increase in natural fodder grass production on bunds eliminated the statistically significant yield gap difference between conserved and non-conserved plots in the case of the barley sub-sample plots. The yield gap reduced also for the entire sample plots but the mean yield difference was still statistically significant.

The results imply that there is a need for efforts to increase the economic performance of conservation bunds through proper construction of bunds and some technical changes such as natural grass production or planting some other better fodders (e.g. forage legumes) on the conservation bunds. This can also alleviate the severe livestock feed problems in the Ethiopian highlands. Finally, we note that Ethiopia has diverse agro-ecological conditions, which has implications on technology performance. Further studies are therefore necessary to assess the effects of soil conservation on productivity in moisture stressed areas and its influence on production risk. This may help to understand the role of soil conservation for the diverse agro-ecological conditions and to design better soil conservation strategies that fit the local conditions.

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Table 1. Descriptive statistics

Variables	Entire sample				Barley sub-sample plots							
					Entire barley plots				Old conservation		New conservation	
	With conservation		Without conservation		With conservation		Without conservation					
	mean	sd	mean	sd	mean	sd	Mean	sd	mean	sd	mean	sd
Hectares devoted to conservation (continuous)	0.02	0.01	0.00	0.00	0.02	0.01	0.00	0.00	0.02	0.02	0.01	0.01
plots with good fertile soil (dummy)	0.17	0.38	0.20	0.40	0.22	0.41	0.21	0.41	0.23	0.42	0.19	0.39
plots with medium fertile soil (dummy)	0.48	0.50	0.52	0.50	0.47	0.50	0.54	0.50	0.47	0.50	0.49	0.50
plots with poor fertile soil (dummy)	0.35	0.48	0.28	0.45	0.31	0.46	0.25	0.43	0.30	0.46	0.32	0.47
plots with shallow soil depth (dummy)	0.29	0.45	0.23	0.42	0.27	0.44	0.19	0.40	0.22	0.42	0.34	0.48
plots with good soil depth (dummy)	0.39	0.49	0.44	0.50	0.42	0.49	0.47	0.50	0.41	0.49	0.43	0.50
plots with medium soil depth (dummy)	0.32	0.47	0.33	0.47	0.32	0.47	0.34	0.47	0.37	0.49	0.23	0.42
plot slope in degree (continuous)	17.06	6.63	17.53	10.22	16.64	7.41	19.01	12.95	15.84	5.21	17.92	9.92
intercropped plots (dummy)	0.24	0.43	0.23	0.42	0.20	0.40	0.08	0.27	0.22	0.42	0.17	0.38
Plot distance in minutes (continuous)	14	16	18	32	14	16	14	18	13	16	15	16
plot size in ha (continuous)	0.26	0.14	0.24	0.14	0.30	0.13	0.28	0.14	0.30	0.14	0.30	0.13
rented in plots (dummy)	0.09	0.28	0.18	0.38	0.12	0.32	0.12	0.33	0.14	0.35	0.08	0.27
output value per ha (continuous)	696.86	577.34	888.47	742.20	520.94	331.50	615.96	417.12	542.66	330.14	485.70	333.80
fertilizer value per ha (continuous)	128.91	175.93	91.81	190.61	82.55	107.34	41.05	102.55	88.72	116.66	72.54	90.36
seed value per ha (continuous)	106.81	104.78	132.34	148.44	138.77	77.18	143.15	94.08	137.10	70.13	141.48	88.07
Ploughing labour per ha (continuous)	14.79	19.14	18.00	24.04	9.84	6.12	12.24	9.37	9.86	6.46	9.81	5.57
weeding labour per ha (continuous)	13.89	20.74	20.90	34.49	0.69	2.76	1.34	4.27	0.61	2.44	0.81	3.22
Households lost land during 1997 redistribution	0.27	0.45	0.28	0.45	0.26	0.44	0.31	0.46	0.28	0.45	0.26	0.44
Household gained land during redistribution	0.44	0.50	0.44	0.50	0.45	0.50	0.42	0.50	0.43	0.50	0.46	0.51
Household neither gained nor lost land	0.29	0.45	0.28	0.45	0.29	0.45	0.27	0.45	0.28	0.45	0.29	0.46
oxen power supply per ha (continuous)	0.84	0.54	0.92	0.63	0.85	0.58	0.90	0.63	0.86	0.60	0.83	0.48
Other Livestock in TLU per ha (continuous)	1.46	0.90	1.45	0.94	1.50	1.01	1.48	0.95	1.42	1.00	1.69	1.02
Extension contact (dummy)	0.62	0.49	0.59	0.49	0.64	0.48	0.59	0.49	0.70	0.46	0.57	0.50
household head age in years (continuous)	39.58	11.92	39.19	11.59	41.10	12.23	39.06	11.21	42.11	12.32	39.89	11.95
Male labour supply per ha (continuous)	1.42	0.74	1.52	0.74	1.56	0.71	1.53	0.76	1.59	0.76	1.55	0.70
Female labour supply per ha (continuous)	1.41	0.67	1.38	0.64	1.51	0.73	1.40	0.63	1.57	0.82	1.38	0.52
farm size per capita (continuous)	0.36	0.11	0.35	0.11	0.36	0.11	0.36	0.12	0.35	0.11	0.35	0.09
off farm activity participation (dummy)	0.16	0.37	0.18	0.38	0.16	0.37	0.18	0.38	0.15	0.36	0.11	0.32
Number of observations	422(124)		868(147)		139(77)		263(118)		86(53)		53(35)	

Note: (A) Figure in parentheses household number

Table 2. Pooled probit model for soil conservation adoption (Dependent variable =1 for plots with conservation & Zero otherwise)

Independent variables	Entire sample plots		Barley plots	
	With household level variables	Without household level variables	With household level variables	Without household level variables
Plot characteristics				
plots with good fertile soil	-0.136(0.155)	-0.113(0.161)	0.081(0.225)	0.092(0.210)
plots with medium fertile soil	-0.082(0.116)	-0.083(0.123)	-0.091(0.181)	-0.098(0.171)
plots with good soil depth	-0.091(0.127)	-0.122(0.131)	-0.289(0.194)	-0.259(0.192)
plots with medium soil depth	-0.089(0.132)	-0.112(0.144)	-0.189(0.199)	-0.156(0.195)
plot slope	0.036(0.016)**	0.036(0.016)**	-0.004(0.019)	-0.002(0.019)
Plot slope square	-0.001(0.000)**	-0.001(0.000)**	-0.000(0.000)	-0.000(0.000)
ln(plot distance from residence)	0.055(0.045)	0.057(0.045)	0.107(0.056)*	0.113(0.053)**
ln(plot size)	0.182(0.067)***	0.164(0.062)***	0.234(0.132)*	0.225(0.121)*
rented in plots	-0.464(0.175)***	-0.590(0.175)***	-0.067(0.213)	-0.119(0.208)
Household level variables				
ln(oxen power supply per ha)	-0.468(0.277)*		-0.351(0.373)	
ln(other livestock in TLU per ha)	0.025(0.150)		0.063(0.206)	
female labour supply per ha	-0.714(0.361)**		-0.803(0.518)	
quadratic female labour supply per ha	0.274(0.114)**		0.286(0.133)**	
quadratic male labour supply per ha	-0.096(0.104)		-0.080(0.106)	
male labour supply per ha	0.433(0.445)		0.521(0.500)	
extension visit	0.263(0.118)**		0.147(0.140)	
ln(household head age in years)	-0.082(0.234)		0.431(0.354)	
off farm activity participation	-0.078(0.141)		0.070(0.185)	
households lost land	-0.314(0.160)**		-0.661(0.223)***	
households neither lost nor gained land	-0.097(0.137)		-0.153(0.192)	
ln (farm size per capita)	0.084(0.319)		-0.089(0.437)	
Constant	0.148(0.952)	-0.443(0.260)*	-1.371(1.346)	0.027(0.370)
Observations	1290	1290	402	402
Percent correctly predicted	68	67	68	66
Model test	Waldchi2(21)= 93.02(0.000)***	Wald chi2(10) = 82.15(0.000)***	Wald chi2(21) = 38.45(0.011)**	Wald chi2(9) = 16.07(0.066)*
Robust standard errors in parentheses				
* significant at 10%; ** significant at 5%; ***significant at1%				

Table 3. The determinants of plot level output value for the entire sample plots (Dependent variable = logarithm of output value per ha)

Independent variables	Exogenous switching regression (fixed effects)		Endogenous regression (Pooled OLS)			
	With conservation	Without conservation	With conservation		Without conservation	
			With household level variables	Without household level variables	With household level variables	Without household level variables
Input variables						
ln (ploughing labour per ha)	0.129(0.091)	0.314(0.047)***	0.138(0.080)*	0.152(0.080)*	0.279(0.044)***	0.293(0.045)***
ln (weeding labour per ha)	0.114(0.037)***	0.112(0.018)***	0.115(0.031)***	0.111(0.030)***	0.113(0.017)***	0.110(0.017)***
ln (fertilizer value per ha)	0.043(0.018)**	0.020(0.009)**	0.042(0.016)***	0.046(0.015)***	0.017(0.009)*	0.019(0.009)**
ln (seed value per ha)	0.161(0.052)**	0.225(0.021)***	0.163(0.043)***	0.165(0.044)***	0.226(0.023)***	0.232(0.023)***
Plot characteristics						
ln(plot slope)	0.062(0.113)	0.081(0.042)*	0.019(0.075)	0.019(0.077)	0.059(0.047)	0.075(0.052)
plot distance from residence	0.018(0.046)	0.032(0.019)*	-0.003(0.028)	-0.011(0.029)	0.022(0.017)	0.026(0.016)
rented in plots	0.191(0.153)	0.208(0.068)***	0.114(0.098)	0.156(0.098)	0.152(0.060)**	0.215(0.063)***
plots with good fertile soil	-0.005(0.166)	0.149(0.084)*	0.137(0.101)	0.187(0.097)*	0.146(0.071)**	0.163(0.070)**
plots with medium fertile soil	-0.093(0.120)	0.119(0.061)*	-0.035(0.075)	-0.008(0.074)	0.079(0.054)	0.084(0.053)
plots with good soil depth	0.045(0.128)	0.111(0.076)	-0.049(0.084)	-0.017(0.084)	0.062(0.068)	0.065(0.070)
plots with medium soil depth	-0.067(0.142)	-0.000(0.075)	-0.079(0.086)	-0.051(0.087)	-0.031(0.064)	-0.028(0.064)
intercropped plots	0.419(0.103)***	0.258(0.059)***	0.472(0.076)***	0.467(0.077)***	0.228(0.063)***	0.232(0.065)***
Household level variables						
ln(oxen power supply per ha)			-0.237(0.149)		0.096(0.122)	
ln(other livestock in TLU per ha)			0.088(0.077)		0.177(0.065)***	
extension visit			0.203(0.067)***		0.138(0.049)***	
ln(household head age in years)			-0.163(0.103)		-0.359(0.090)***	
off farm activity participation			0.041(0.071)		-0.013(0.056)	
ln (farm size per capita)			-0.187(0.098)*		-0.043(0.083)	
Mills ratio			0.265(0.166)	-0.046(0.139)	0.246(0.153)	0.138(0.149)
Constant	4.707(0.406)***	3.905(0.186)***	4.859(0.533)***	4.789(0.311)***	5.252(0.444)***	4.082(0.262)***
Observations	422	868	422	422	868	868
R-squared	0.48	0.56	0.34	0.33	0.44	0.41
Model test	F(12, 284) = 7.51(0.000)***	F(12, 709) = 37.62(0.000)***	F(19,125) = 13.72 (0.000)***	F(13, 125) = 14.49(0.000)***	F(19, 146) = 23.59(0.000)***	F(13, 146) = 29.79(0.000)***
Figure in parentheses bootstrapped standard errors adjusted for clustering effect						
* significant at 10%; ** significant at 5%; *** significant at 1%						

Table 4. The determinants of plot level output value for the Barley plots (Dependent variable = logarithm of output value per ha)

Independent variables	Exogenous switching regression (Random effects estimation)				Endogenous switching regression (Pooled OLS)			
	With conservation		Without conservation		With conservation		Without conservation	
	With household level variables	Without household level variables	With household level variables	Without household level variables	With household level variables	Without household level variables	With household level variables	Without household level variables
Input variables								
ln (ploughing labour per ha)	0.055(0.105)	0.080(0.109)	0.207(0.097)**	0.204(0.099)**	0.055(0.106)	0.083(0.112)	0.194(0.096)**	0.211(0.100)**
ln (weeding labour per ha)	0.120(0.084)	0.092(0.071)	0.025(0.049)	0.040(0.048)	0.119(0.084)	0.094(0.070)	0.004(0.051)	0.017(0.051)
ln (fertilizer value per ha)	0.033(0.025)	0.040(0.022)*	0.035(0.015)**	0.046(0.015)***	0.032(0.025)	0.042(0.022)*	0.030(0.014)**	0.037(0.017)**
ln (seed value per ha)	0.429(0.142)***	0.354(0.130)***	0.406(0.107)***	0.406(0.110)***	0.428(0.142)***	0.368(0.133)***	0.391(0.105)***	0.402(0.112)***
Plot characteristics								
ln(plot slope)	0.111(0.108)	0.080(0.125)	0.082(0.052)	0.119(0.057)**	0.106(0.113)	0.117(0.127)	0.026(0.058)	0.090(0.068)
ln(plot distance)	0.049(0.052)	0.034(0.055)	0.010(0.025)	-0.003(0.027)	0.045(0.056)	0.028(0.055)	0.017(0.025)	0.005(0.027)
rented in plots	0.195(0.167)	0.096(0.151)	-0.042(0.099)	0.012(0.105)	0.191(0.172)	0.087(0.151)	-0.039(0.093)	0.054(0.101)
plots with good fertile soil	0.143(0.170)	0.163(0.171)	0.130(0.135)	0.117(0.147)	0.144(0.169)	0.175(0.169)	0.100(0.130)	0.079(0.146)
plots with medium fertile soil	-0.053(0.108)	-0.079(0.115)	0.153(0.093)	0.156(0.102)	-0.050(0.113)	-0.051(0.121)	0.100 (0.092)	0.120(0.103)
plots with good soil depth	-0.119(0.133)	-0.070(0.129)	0.074(0.116)	0.061(0.121)	-0.125(0.132)	-0.045(0.134)	0.062(0.117)	0.087(0.127)
plots with medium soil depth	-0.043(0.162)	-0.055(0.161)	-0.047(0.103)	-0.075(0.105)	-0.046(0.157)	-0.014(0.161)	-0.042(0.102)	-0.059(0.105)
intercropped plots	0.267(0.148)*	0.304(0.131)**	0.437(0.101)***	0.450(0.109)***	0.270(0.147)*	0.290(0.130)**	0.386(0.105)***	0.391(0.116)***
Household level variables								
ln(oxen power supply per ha)	-0.033(0.235)		0.197(0.151)		-0.028(0.254)		0.130(0.171)	
ln (other livestock in TLU per ha	0.185(0.139)		0.181(0.106)*		0.192(0.146)		0.190(0.103)*	
Extension visit	0.333(0.096)***		0.287(0.071)***		0.332(0.099)***		0.314(0.068)***	
ln(household head age)	0.073(0.171)		-0.332(0.134)**		0.068(0.180)		-0.363(0.139)**	
off farm activity participation	0.035(0.156)		-0.020(0.097)		0.033(0.159)		-0.035(0.097)	
ln (farm size per capita)	0.016(0.157)		-0.191(0.129)		0.020(0.162)		-0.267(0.143)*	
Mills ratio					-0.007(0.212)	-0.208(0.176)	0.299(0.219)	0.089(0.233)
Constant	2.765(0.959)***	3.771(0.727)***	3.893(0.684)***	3.253(0.433)***	2.820(0.987)***	3.779(0.724)***	4.403(0.745)***	3.392(0.546)***
Observations	139	139	263	263	139	139	263	263
R-squared					0.29	0.22	0.41	0.32
Model test	Wald chi2(18)= 75.85(0.000)***	Wald chi2(12)= 34.37 (0.001)***	Wald chi2(18) = 149.07(0.000)***	Wald chi2(12)= 90.19(0.000)***	F(19, 76)= 4.12(0.000)***	F(13, 76) = 2.79(0.003)***	F(19, 117) = 7.39(0.000)***	F(13, 117) = 5.68(0.000)***
Figure in parentheses robust standard errors adjusted for clustering effect								
* significant at 10%; ** significant at 5%; *** significant at 1%								

Table. 4 (cont'd)

Independent variables	Old conservation		New conservation	
	With household level variables	Without household level variables	With household level variables	Without household level variables
Input variables				
ln (ploughing labour per ha)	0.304(0.167)*	0.323(0.162)**	-0.231(0.115)**	-0.221(0.113)*
ln (weeding labour per ha)	0.052(0.115)	0.036(0.097)	0.310(0.129)**	0.177(0.110)
ln (fertilizer value per ha)	0.055(0.029)*	0.066(0.022)***	0.048(0.057)	0.050(0.054)
ln (seed value per ha)	0.259(0.196)	0.233(0.190)	0.706(0.158)***	0.587(0.148)***
Plot charcateristics				
ln(plot slope in degree)	0.116(0.203)	0.030(0.201)	0.039(0.286)	0.211(0.209)
ln(plot distance form homestead)	0.021(0.066)	0.013(0.067)	0.140(0.113)	0.083(0.103)
rented in plots	0.250(0.196)	0.189(0.135)	0.028(0.381)	-0.032(0.369)
plots with good fertile soil	0.007(0.200)	-0.025(0.173)	0.245(0.346)	0.343(0.361)
plots with medium fertile soil	-0.142(0.120)	-0.184(0.116)	-0.077(0.289)	-0.081(0.283)
plots with good soil depth	-0.174(0.157)	-0.162(0.150)	-0.094(0.300)	0.003(0.209)
plots with medium soil depth	0.021(0.194)	0.007(0.183)	-0.200(0.223)	-0.284(0.268)
intercropped plots	0.510(0.193)***	0.518(0.149)***	-0.297(0.367)	-0.192(0.319)
Houesehold level variables				
ln(oxen power supply per ha)	-0.094(0.238)		0.062(0.535)	
ln(other livestock in TLU per ha)	0.212(0.144)		0.395(0.268)	
Extension visit	0.171(0.114)		0.464(0.218)**	
ln(household head age in years)	0.047(0.175)		0.083(0.422)	
Off farm activity participation	-0.069(0.210)		0.199(0.221)	
ln(farm size per capita)	-0.033(0.141)		0.253(0.524)	
Constant	3.256(1.283)**	4.028(0.960)***	2.179(2.075)	2.842(1.094)***
Observations	86	86	53	53
Model test	Wald chi2(18) = 78.09(0.000)***	Wald chi2(12) = 41.33(0.000)***	Wald chi2(18) = 84.90(0.000)***	Wald chi2(12) = 42.78(0.000)***
Figure in parentheses robust standard errors adjusted for clustering effect				
* significant at 10%; ** significant at 5%; *** significant at 1%				

Table. 5. Pooled fixed effects estimates of the determinants of output value (dependent variable: logarithm of output value per ha)

Explanatory variables	Entire sample		Sub-sample barley plots	
	With inputs	Without inputs	With inputs	Without inputs
Inputs				
ln (ploughing labour per ha)	0.250(0.048)***		0.220(0.130)*	
ln (weeding labour per ha)	0.109(0.018)***		0.092(0.081)	
ln (fertilizer value per ha)	0.026(0.009)***		0.049(0.021)**	
ln (seed value per ha)	0.210(0.025)***		0.355(0.172)**	
Plot characteristics				
ln(plot slope in degree)	0.064(0.040)	0.088(0.049)*	0.123(0.082)	0.145(0.097)
ln(plot distance from residence)	0.016(0.016)	-0.040(0.018)**	0.024(0.034)	0.072(0.047)
rented in plots	0.220(0.057)***	0.328(0.064)***	0.114(0.133)	0.116(0.161)
plots with good fertile soil	0.148(0.072)**	0.152(0.095)	0.259(0.194)	0.164(0.214)
plots with medium fertile soil	0.076(0.055)	0.091(0.069)	0.149(0.144)	0.020(0.180)
plots with good soil depth	0.069(0.064)	0.126(0.079)	-0.162(0.131)	-0.097(0.149)
plots with medium soil depth	-0.016(0.063)	0.030(0.073)	-0.054(0.128)	-0.036(0.144)
intercropped plots	0.324(0.053)***	0.403(0.054)***	0.357(0.146)**	0.305(0.155)*
hectares devoted to conservation	-3.260(1.760)*	-7.642(2.041)***	-8.833(4.574)*	-10.666(5.321)**
Constant	4.226(0.180)***	6.035(0.150)***	3.419(0.702)***	5.644(0.291)***
Observations	1290	1290	402	402
R-squared	0.49	0.24	0.59	0.48
Model test	F(13, 147) = 41.23(0.000)***	F(9, 147) = 19.05(0.000)***	F(13, 139) = 3.60(0.000)***	F(9, 139) = 1.30(0.109)
Figure in parentheses robust standard errors				
* significant at 10%; ** significant at 5%; *** significant at 1%				

Table. 6. Parametric estimation results

Regression types	Exogenous switching regression		Endogenous switching regression		Mean yield difference due to adoption	
	Predicted mean yield with conservation	Predicted mean yield without conservation	Predicted mean yield with conservation	Predicted mean yield without conservation		
	A	B	C	D	E= A-B	F=C-D
Entire sample plots						
Pooled slope	6.283	6.515	6.088	6.639	-0.232(0.004)***	-0.551(0.001)***
Slope A	6.247	6.470	6.078	6.605	-0.223(0.010)***	-0.527(0.009)***
Slope B	6.272	6.502	6.085	6.629	-0.231(0.010)***	-0.544(0.009)***
Slope C	6.317	6.562	6.097	6.673	-0.245(0.010)***	-0.575 (0.009)***
Barley sub-sample plots						
Entire barley plots						
Pooled slope	6.081	6.221	6.124	6.379	-0.140(0.008)***	-0.255(0.004)***
Slope A	6.018	6.167	6.061	6.363	-0.149(0.009)***	-0.302(0.009)***
Slope B	6.063	6.200	6.106	6.374	-0.137(0.009)***	-0.268(0.009)***
Slope C	6.146	6.261	6.188	6.393	-0.115(0.009)***	-0.205(0.009)***
Old conservations						
Pooled slope	6.134	6.221			-0.087(0.005)***	
Slope A	6.072	6.167			-0.095(0.016)***	
Slope B	6.118	6.200			-0.082(0.016)***	
Slope C	6.205	6.261			-0.057(0.016)***	
New conservations						
Pooled slope	6.015	6.221			-0.206(0.005)***[-0.119(0.016)]***	
Slope A	6.028	6.167			-0.139(0.018)***[-0.044(0.025)]*	
Slope B	6.012	6.200			-0.188(0.018)***[-0.107(0.025)]***	
Slope C	6.127	6.261			-0.134(0.018)***[-0.078(0.025]***	

Notes: (A) the square bracket in the row's of new conservation indicates the difference between the new and old conservation yield; (B) Robust standard errors adjusted for clustering in parenthesis; (C) *** significant at 1%; * significant at 10% (C) For endogenous regressions the results were based on plot level variables. The conclusion is the same using both household and plot level variables, and (D) the entire sample and entire barely plots compared plots with and without conservation before disaggregating them into old and new conservation.

Table. 7. Non-parametric estimation results (matching methods)

Matching methods and types of plots	Number of treated group (conserved plots)		Number of control group (non-conserved plots)		Treatment effect (differences in means)	
	Before increasing grass production on bunds	After increasing grass production on bunds	Before increasing grass production on bunds	After increasing grass production on bunds	Before increasing grass production on bunds	After increasing grass production on bunds
	A	B	C	D	E= A-C	F= B-D
Entire sample plots						
Kernel Matching	422	422	807	811	-154.6(35)****	-81(35)***
Nearest neighbour	422	422	303	303	-192.3(66)***	-123.5(65)*
Stratification	422	422	808	808	-135.8(35)***	-66.9(36)*
Entire barley plots						
Kernel Matching	139	139	245	245	-85.5(31)***	-23.6(33)
Nearest neighbour	139	139	110	110	-78.8(64)	-16.9(65)
Stratification	139	139	246	247	-76.3(36)***	-13.9(36)

Notes: (A) The propensity score is estimated using a probit of treatment status on: plots with good fertile soil, plots with medium fertile soil, plots with good soil depth, plots with medium soil depth, plot distance, plot size, plot slope, plot slope square, rented in plots; (B) figures in parenthesis are bootstrapped standard errors with 200 replications; (C) balancing property satisfied.

Table. 8. Yield decomposition for the entire sample and barley plots

Explanatory variables (endowments)	Decompositions results for variables (as %s)							
	Entire sample plots		Old conservation versus without conservation plots (entire sample)		Entire barley sub-sample plots		Old conservation versus without conservation (barley sub-sample)	
	Endowments	Coefficients	Endowments	Coefficients	Endowments	Coefficients	Endowments	Coefficients
ln (ploughing labour per ha)	-2.6	-49.5	-4.1	-35.3	-1.3	-30.0	-5.6	29.6
ln (weeding labour per ha)	-4.8	0.3	-4.5	-4.9	-1.1	1.5	-0.5	-0.3
ln (fertilizer value per ha)	3.2	5.1	3.2	7.9	5.3	-0.6	9.2	2.0
ln (seed value per ha)	-2.6	-28.1	-3.5	-23.0	0.7	-24.8	0.6	-82.6
ln(plot slope)	0.2	-5.2	-0.0	-26.3	-0.3	-10.7	-0.2	-24.4
ln(Plot distance)	0.1	-2.8	-0.2	4.3	0.8	7.2	0.2	-1.2
rented in plots	-1.7	-0.3	-0.0	-3.6	-0.1	1.0	0.3	2.1
plots with good fertile soil	**0.0**	**-3.1**	**0.0**	**-4.2**	**0.1**	**1.0**	**-0.1**	**-2.9**
plots with medium fertile soil	**0.3**	**-10.9**	**-0.1**	**-4.4**	**0.5**	**-12.7**	**1.4**	**-18.6**
plots with good soil depth	**-0.2**	**-3.0**	**0.1**	**-5.4**	**0.4**	**-6.1**	**1.0**	**-10.0**
plots with medium soil depth	**0.1**	**-2.2**	**-1.3**	**-10.4**	**0.1**	**-0.7**	**0.0**	**2.5**
intercropped plots	0.3	3.8	0.6	4.9	3.7	-1.2	7.3	0.5
subtotal	**-7.6**	**-95.9**	**-9.9**	**-100.2**	**8.8**	**-74.5**	**13.5**	**-99.7**
Yield gap	**Summary of decomposition results (as%)**							
-due to endowments (E)	-7.6		-9.9		8.8		13.5	
-due to coefficients (C)	-95.9		-100.2		-74.5		-99.7	

Note: (A) positive & negative number indicates advantage to plots with & without conservation, respectively; (B) the results for the entire sample & the barley sub-sample is based on fixed and random effects, respectively.

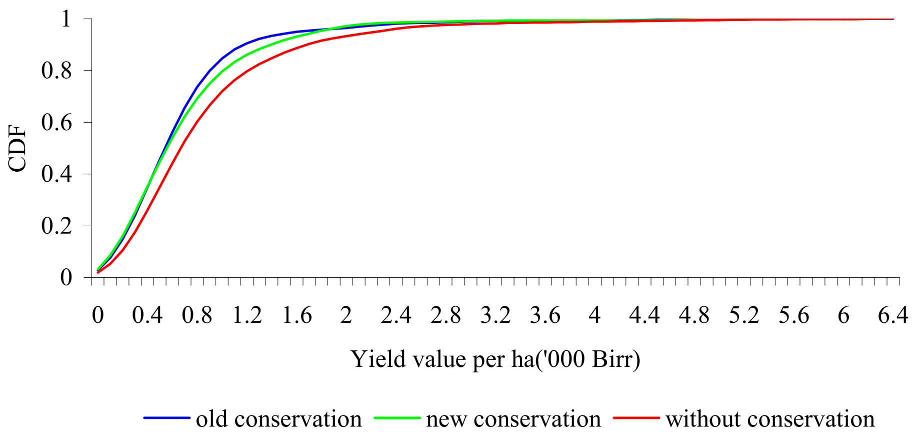

Figure 1. CDF for entrie the sample plots before increasing fodder grass production on bunds (pooled slope)

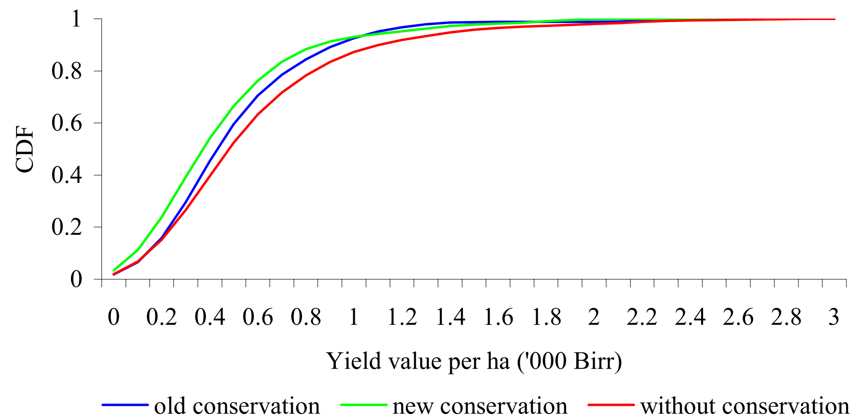

Figure 2. CDF for the Barley plots beofre increasing fodder grass production on bunds

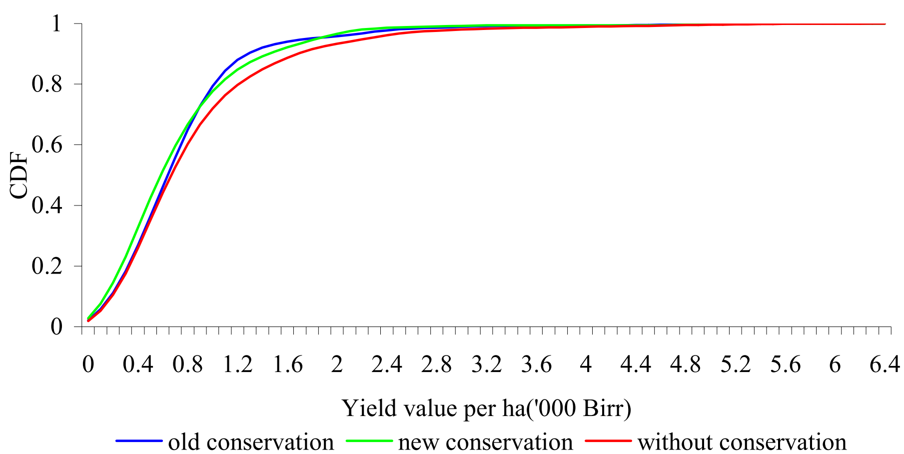

Figure 3. CDF for the entire sample plots after increasing fodder grass production on bunds (pooled slope)

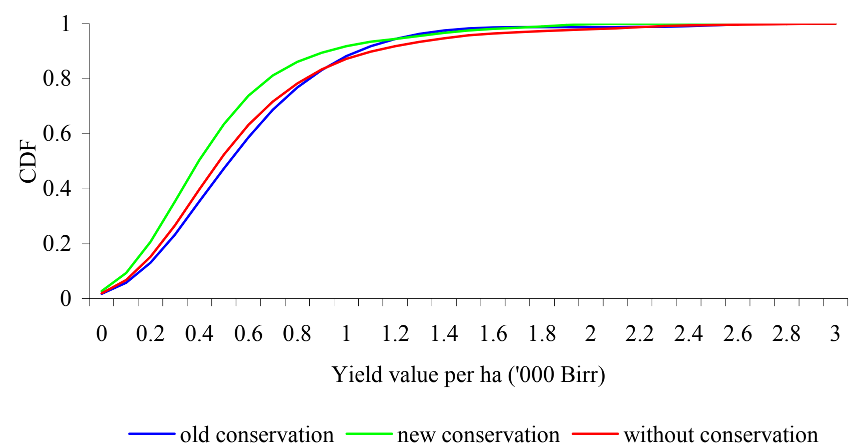

Figure 4. CDF for the Barley plots after increasing gras production on bunds

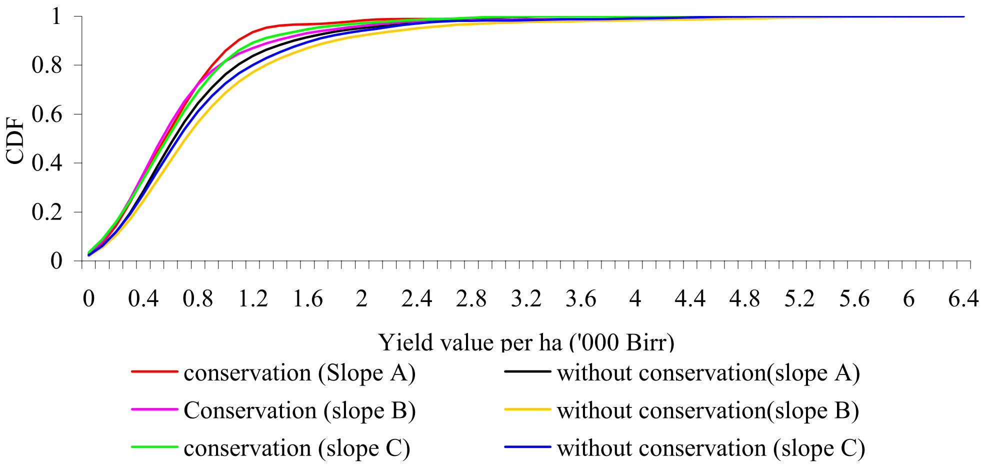

Figure 5. CDF for the entire sample plots before increasing fodder grass production on the bunds

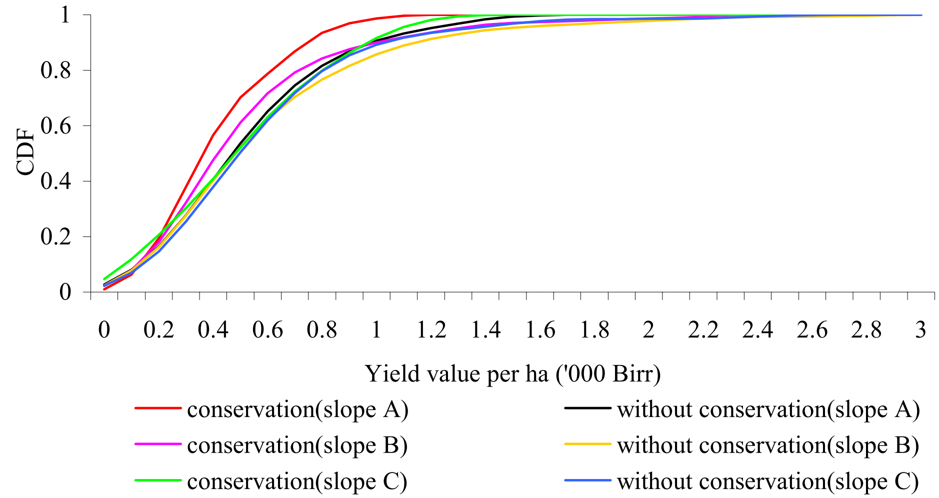

Figure 6. CDF for the Barely plots before increasing fodder grass production on the bunds

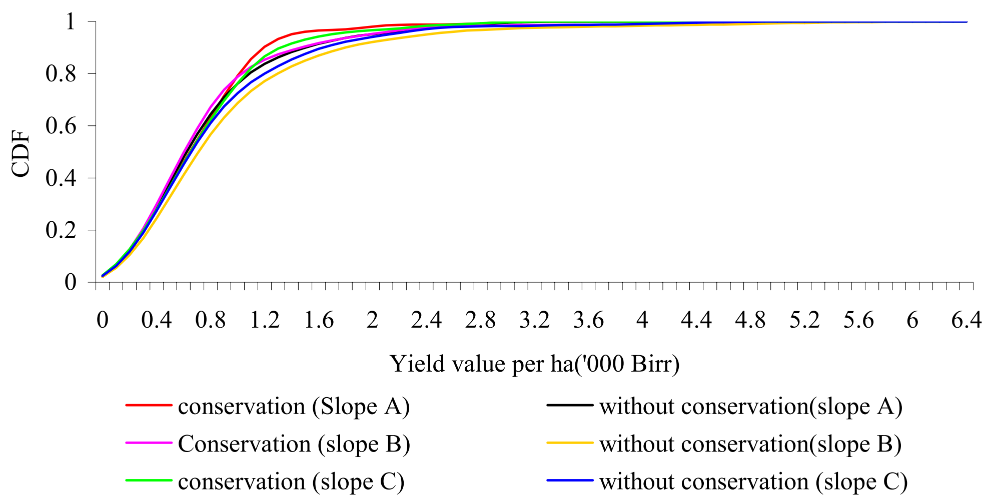

Figure 7. CDF for the entire sample plots after increasing fodder grass prduction on the bunds

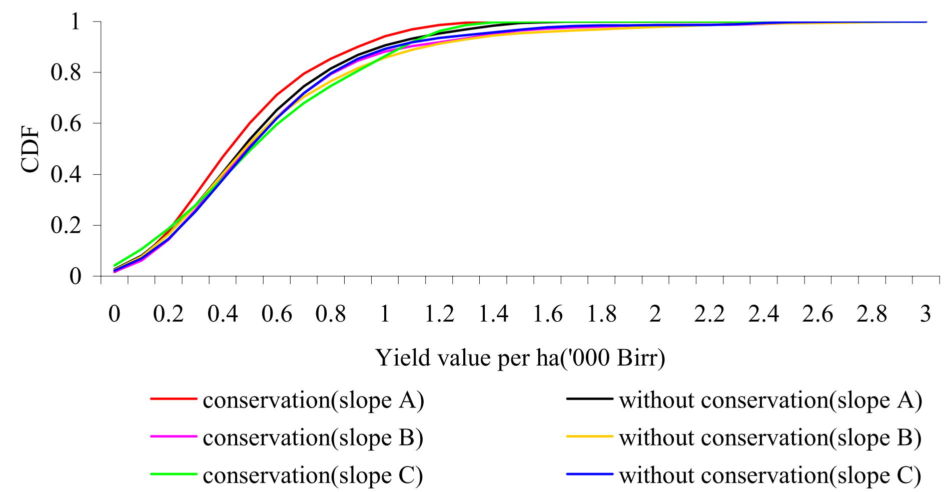

Figure 8. CDF for the barley plots after increasing fodder grass production on the bunds

II

Sharecropping Efficiency in Ethiopia: The Role of Kinship and Contract Insecurity[19]

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Abstract

We applied parametric and non-parametric methods on household-plot level data under kin and non-kin sharecropping arrangements to assess sharecropping efficiency in the Ethiopian highlands. Controlling for plot quality and household fixed effects, we found that land productivity was higher on kin and non-kin sharecrop plots than on share tenants' own plots. This result contradicts with the Marshallian inefficiency hypothesis, which stated that land productivity is lower on rented in plots than on tenants' own plots due to the disincentive effects of sharing the output under sharecropping contracts. Contrary to the findings of Sadoulet et al. (1997), we also found that non-kin sharecroppers applied more fertilizer and had higher output than kin sharecroppers. One explanation for these results could be the fear of eviction by non-kin tenants that makes them to be more productive. In rural societies where social networks and ties are extremely important it is easier to evict non-kin tenants than kin tenants. This is also confirmed by our data where the duration of contracts was relatively shorter for non-kin than for kin sharecroppers.

Key words: Sharecropping efficiency, kinship, plot quality, contract insecurity, Ethiopia

1. Introduction

Many theoretical models have been developed to explain the rationale of sharecropping and its efficiency implications. These include a) Marshall's disincentive hypothesis rendering sharecropping an inefficient institutional arrangement and b) theories that eliminate or counteract the Marshallian disincentive effect. This second category of theories include i) the cases when the non-cooperative solution is equal to the cooperative solution, ii) low cost

[19] We would like to thank the anonymous reviewers of Journal of African economies for their useful suggestion and comments that increase the quality of the paper. We are grateful for valuable comments from John Pender on an earlier draft of this paper. We thank also the participants at annual conference of the Norwegian association for development research (2005, Aas) for their comments.

monitoring and enforcement of contracts, iii) repeated contracts, imposing threat of eviction to counter the disincentive effect, and iv) interlinked contracts. There have been very many empirical studies of efficiency of sharecropping, especially in Asia (Otsuka and Hayami, 1988). The findings are mixed with some studies showing no difference between contracts and others observing lower yield or input use by sharecroppers. This may not indicate that the Marshallian inefficiency hypothesis is wrong but rather that there is a natural selection of contracts eliminating sharecropping in cases where it is clearly inefficient (Otsuka et al., 1992).

Most empirical studies compare efficiency of sharecroppers with owner-operators and fixed-rent tenants and have failed to control well for tenant and plot characteristics. Most studies have also failed to explain why specific sharecroppers are efficient or not. Exceptions include Sadoulet et al. (1997) who found sharecroppers with a kinship relationship with the landlord not to be affected by the Marshallian disincentive effect while other sharecroppers were. We follow up on this and assess the importance of kinship for sharecropping efficiency in our study in the Ethiopian highlands.

The contributions of our paper are the following. First, it is the first empirical study on the link between input use and productivity[20] and kinship sharecropping contract in Africa. Second, the only available study on the impact of kinship on input use in Asia (Philippines) is Sadoulet et al. (1997). In their study observable and unobservable household and plot heterogeneity that are likely to affect sharecropping efficiency and self-selection into different contracts were not accounted for. In our study in the Ethiopian highlands we were able to control for self-selection due to observable and unobservable household characteristics and a range of plot level characteristics using sharecroppers' own plots as the counterfactual to assess input use and output value on sharecropped plots of tenants with and without kin relationship with their landlords[21]. Third, although this is not the first paper to compare productivity and input use on tenanted and owned plots, as far as we know it is the first paper to use stochastic dominance assessment in the analysis of sharecropping efficiency. Fourth, unlike previous studies (e.g. Sadoulet et al., 1997; Okbasillassie and Holden, 2004), we estimated the impact of tenancy on fertilizer use sequentially where the decision to or not to

[20] In this paper productivity or yield will be used interchangeably and it refers to output value per hectare.
[21] In this paper we have used kin and non-kin sharecrop plots to refer to plots rented in by tenants from kin and non-kin landlords. Plot in this study refer to the area occupied by a single crop.

use and how much to use were estimated separately. Estimating these decisions simultaneously while the decisions are separate may lead to inconsistent estimates and wrong conclusion on tenancy impact on fertilizer use.

We found significantly higher output levels on kin and non-kin sharecrop plots than on share tenants' own plots. Contrary to the findings of Sadoulet et al. (1997), we found that non-kin sharecrop plots received more fertilizer and had higher output values than kin sharecrop plots. Both non-kin and kin sharecrop plots stochastically dominated share tenants' own plots in terms of output value and non-kin sharecrop plots stochastically dominated kin sharecrop plots. Our findings are consistent with the threat of eviction effect dominating over the Marshallian inefficiency effect and kinship reducing the threat of eviction effect, implying that it is more difficult to evict kin tenants than non-kin tenants. This implies that non-kin tenants feel less secure about their tenure and therefore are more productive on their sharecropped plots to increase the probability of contract renewal.

The plan of the paper is as follows. Section 2 reviews relevant literature while section 3 discusses the study area and gives an overview of the survey data. Section 4 presents the theoretical model and the key hypotheses to be tested while the methodological issues are discussed in section 5. The results and discussion follow in section 6 and the last section concludes.

2. The Discourse on Sharecropping Efficiency

While anthropologists have given due importance to kinship networks, the concept has not been extensively used in economic analysis. Yet kinship networks can induce cooperative and efficient behaviour by acting as a powerful enforcement mechanism. The existence of kinship relations between landlords and share tenants may contribute to higher trust and confidence in which cheating is less likely to occur, reduce the conflict of interest, offer longer contractual relationships (contract security), and lead to interlinked transactions particularly for assistance through stages of the life cycle and mutual insurance (Sadoulet et al., 1997). These conditions provide an efficient mechanism of contract enforcement (cooperative behaviour) and may make sharecroppers equally efficient as owner operators (Arrow, 1976; Sadoulet et al., 1997). Sadoulet et al. (1997) found that moral hazard plays much less of a role in contracts among kin than in non-kin contracts. However, their studies did not control for unobserved plot and household characteristics.

There is considerable evidence showing that the landlord–tenant relationship is typically a complex long-term informal contract with eviction threats often explicitly used as an incentive device (Banerjee and Ghatak, 2004). The threat of eviction may induce higher levels of overall input use compensating for inherent Marshallian inefficiencies irrespective of tenant-landlord relationship. Johnson (1950) wrote that by granting short-term contract, the landlord keeps the possibility of renewal threats as an extra source of incentives. He further noted that once the tenant has found a farm, he might fear that his lease will not be renewed unless sufficient rent is actually paid. The effectiveness of eviction threat (contract insecurity) depends on tenant's concern about his future utility (e.g. both material and non-material utility) from rented in land, the opportunity cost of his time and availability of farmland in the village. Moving is costly for tenants in terms of losing income (especially if there is risk of unemployment) and social status in the community (losing reputation)[22]. Farmers care not only about material satisfactions, but also about the values of social interaction and they willingly pay dearly for these (Barrett, 2003; Hayami and Otsuka, 1993). Banerjee and Ghatak (2004), using a dynamic model demonstrate the possibility that eviction threats can increase long-term investment. Bardhan (1984) and Banerjee et al. (2002) used a two-period principal-agent model to show how threat of eviction upon unsatisfactory performance increased the incentive of the agent to work hard in the first period. They emphasized the importance of such a threat to be credible, meaning that the principal can easily replace the evicted agent with another agent while the evicted tenants should not easily find another principal or alternative job so that eviction would make the agent (tenant) worse off. In our study area, land is scarce and there is no easy labour market access to absorb the available labour supply.

The degree to which a tenant internalises the threat of eviction, however, may depend on the degree of social distance inherent in tenant-landlord relations. Kin and non-kin tenants may not be equally insecure. There could be a possibility of forgiving (compromising) among kinship ties than among non-kinship ties when performance is poor on rented in plots. The higher the social distance between the tenant and landlord the less the tenants might be secured about renewal of the contract, and this may give extra incentive to use resources more intensively and to work harder to qualify for contract renewal (to reduce contract insecurity).

[22] As Hayami and Kawagoe (1993) note; in the village community everyone is watching everyone. Gossip about one's misconduct is circulated by word of mouth faster than any modern means of communication.

The implication is kinship ties may reduce contract insecurity effect on sharecroppers' behaviour.

Unobserved plot heterogeneity (rather than the above incentives and moral hazard) could be a possible explanation for the productivity and input use differences between owned and sharecropped plots. The existing results on sharecropping efficiency could be compromised by observed and unobserved plot quality heterogeneity (Bradio, 2004). In situation where land quality is distributed asymmetrically across different contracts, one must be careful when interpreting yield and input use differences among contracts.

Some empirical studies that found sharecropping as efficient are usually when the social distance between respective parties is low, such as in contracts that are made among kinship ties (Sadoulet et al., 1997), in contracts of patron-client relations[23] (Bardhan and Rudra, 1980; Hayami and Kikuchi, 1990), when cost of losing tenancy due to threat of eviction is high (Okbasillssie and Holden, 2004) and when observed and unobserved plot characteristics are taken into account properly (Bradio, 2004). Empirical studies that found sharecropping as inefficient are usually when policy limits contract choice in some way. Shaban (1987), for example, found sharecropping inefficient in India where landlords fear that land-to-the-tiller legislation made landlords hesitate to rent out land they owned or only to use short-term leases. In Bangladesh fixed rent contracts are banned that had forced the landlords to use share tenancy contracts and in the Philippines lower yields of sharecroppers were attributed to tenancy regulations that prohibited eviction of tenants, even if they shirked on effort (Otsuka et al., 1992; 1994).

Empirical evidences on sharecropping efficiency in Africa are few compared to Asia and elsewhere (Pender and Fafchamps, 2001). Limited literatures on Ethiopia did not address the effects of kinship and contract insecurity on sharecropping efficiency. Pender and Fafchamps (2001) did not find significant productivity difference between tenants' own and sharecropped plots. In the same area, Gavian and Ehui (1999) found that total factor productivity was lower on rented than owned plots but that input intensity was not different. They did not differentiate rented in plots into sharecropped, fixed and cost shared rental plots. Ahmed et al.

[23] Commonly used as a substitute for blood ties, which consists of a largely practical friendship in which a patron (landlord) uses his influences and resources to provide protection and benefits for a client (tenant), who reciprocates by offering royal services (Otsuka and Hayami, 1988).

(2002) in the same area found that productivity was lower on sharecropped plots than owner-operated plots. Pender and Fafchamps (2001) and Ahmed et al. (2002) included observed household and plot characteristics that may have caused input use and productivity differences while Gavian and Ehui (1999) did not control for these factors. These studies used different estimation methods. This makes their results not fully comparable. Holden et al. (2001), on the other hand, found that land productivity (barley yield) was significantly higher on sharecropped plots compared to owner-operated plots.

3. The Setting, Data and Descriptive Statistics

Rahmato (1984) stated in his study of the Ethiopian agrarian reform that the threat of eviction was a potent weapon in the hands of the landlord and the tenant over whom the danger of unemployment and destitution hung like the sword of Damocles, had no alternative but to accommodate all the demands of his landlord.

The Ethiopian land reform in 1975 made all land state land and introduced an egalitarian distribution of user rights to land based on household size. Land sale, mortgage, and renting were prohibited. The reform was followed up by frequent land redistributions to maintain the egalitarian distribution by providing land to newly established households and adjusting land sizes of other households. In our study area in the Amhara region the last land redistribution took place in 1997. After the change in government in 1991 land renting was allowed, but not land sale and mortgage. As indicated in Table 1 typically the poorest households rented out land to less poor households (reverse share tenancy). This implies a basic difference from the typical situation with rich landlords and poor tenants that dominate in most of Asia where most studies of sharecropping efficiency have taken place. Land rental contracts allow land to be used by farmers who are more capable to earn the highest return from it through the mobility of scarce factors of production such as labour, draft power, implements, purchased inputs and management ability (Pender and Kerr, 1999).

Rental contracts are usually self-enforced and this may lead to a preference for renting land to kin, friends and neighbours, but local leaders may also play a role in contract enforcement (Teklu, 2004). Teklu also states that landlords may use the threat of not renewing the contract in cases when a tenant fails to comply with the contract but such threats are real only where land is scarce, competition for land is increasing and the non-farm option is scarce (ibid.).

Our study area is characterised by land scarcity due to high population density and surplus labour due to poor access to non-farm income.

Household and plot level data were collected in 2001 for the 2000 production season from a random sample of 148 households operating 1290 plots in one of the villages in Dembecha district, West Gojjam zone of Northwestern Ethiopian highlands. Table 2 presents means and standard deviations of key variables for the entire sample and for the sub-samples of plots by tenancy type. The 1290 plots are categorised into kin sharecrop plots (5.2%), non-kin sharecrop plots (1.6%)[24], cost share plots (4.1%), fixed-rental plots (4.3%), landlord own cultivated plots (6.3%), share tenants own plots (25.8%), cost share tenants own plots (10.9%), fixed rental tenants own plots (10.9%) and owner-operators own plots (31.0%).

One has to be very cautious when comparing average output and input levels across contracts and plot types in Table 2. We therefore leave this for the econometric analysis. Still we may make some comparisons. There were no statistically significant wealth differences between kin tenants versus non-kin tenants as well as kin landlords versus non-kin landlords (Tables 2 and 3). The mean number of years that the same tenant had cultivated the plot was 4.3 and 3.7 for kin and non-kin sharecrop plots, respectively. Of the total sample of plots, 49% received fertilizer. About 37% of kin and non-kin sharecrop plots were fertilized.

Rented in plots were more distant from the residence compared to tenants' own plots. About thirty-five per cent of the rented in plots were accessed outside the village due to shortage of land supply within tenants' residence. It took 3-7 hours (single trip) to reach these plots[25].

The survey also contains a wide range of information on plot characteristics, household's economic conditions and contract information (output and input sharing rules, kinship relations). The average farm size in the area was 0.35 ha per adult equivalent. The most prevalent output and input sharing formula was a 50-50% split of the output between the landlord and the tenant. About 89.7, 7.4, and 2.9% of the sharecropped plots were under 50-50, 33-67, and 25-75% share arrangements (where the first share goes to the tenant). The

[24] Some landlords reside outside the study village and some are pure landlords where they entirely rent out their lands.
[25] Tenants (migrant tenants) went to some of these plots one day before the cultivation day and stayed there with their relatives since it was difficult to start work the same day after long hours walking together with oxen and farm implements.

landlord and the tenant were sharing the cost of fertilizer and seed equally in cost sharing contracts. The landlord did not share draft power and labour inputs.

4. Land rental contract effect on input intensity and productivity

4.1. Theoretical Model

We base our theoretical model on literature where contracts between landlords and tenants are seen as repeated games. Radner (1981; 1985) used infinitely repeated principal-agent games to show that cooperative solutions may be possible. He also indicated that repeated games provide the principal with the opportunity to punish the agent for inappropriate behaviour. The efficiency of such punishment will depend on the degree to which the agent discounts future utility. Bardhan (1984) and Banerjee et al. (2002) have developed two-period principal-agent models to show how a threat of eviction upon unsatisfactory performance increased the incentive of the agent to work hard in the first period. The effectiveness of eviction threats depends on the tenant's concern about his future utility on rented plots, earnings from outside farming activities, and availability of farmlands in the village. Contract non-renewal would have a negative effect on the reputation of tenants such that it becomes very difficult for him to obtain a new contract due to loss of reputation (Hayami and Otsuka, 1993). When the opportunity cost of alternative employment is higher than the benefits that will be obtained from rented land and land is not scarce, the tenant would not care about the contract insecurity, since he can easily move to other alternative income generation activities. If there is rationing of land such that it is not easy for a tenant who has lost his contract to find another landlord from which to obtain land, the threat of eviction is real and has a cost.

Following Okbasillassie and Holden (2004) a two-period utility model for owner-cum-tenant is developed. To secure future utility from rented in land and to qualify for renewal of contract, the tenant has to cultivate the rented in land with greater care and intensity. It is assumed that the probability of contract renewal (π) in period two depends on the amount of output produced (Q_{r1}) during the first period of the contract. In addition we assume that kinship relationship between landlord and tenants measured by h, where h is social distance, affects the probability of contract renewal so that,

$$\pi = \pi(Q_{r1}, h), \text{and}\, \partial\pi/\partial Q_{r1} > 0, \partial\pi/\partial h < 0\ , \partial^2\pi/\partial Q_{r1}\,\partial h > 0$$

We assume that the probability of renewal (inverse of threat of eviction) is higher among kin and that good performance (leading to high productivity) is more important to reduce the threat of non-renewal when the social distance is large. We assume it may be harder to impose eviction threats to kin. Kinship relations may cause other things than efficiency to be of highest priority in land tenancy arrangements. Kinship relations may therefore affect the performance (ability and incentives) of tenants in rental arrangements (Sadoulet et al., 1997).

Assuming a risk-averse farmer, we specified the production function with multiplicative risk. The state of nature (θ) has mean 1 and variance $\sigma_\theta^{\,2}$ (Newbery and Stiglitz, 1981). The owner-cum-tenant faces the following expected utility income maximization problem.

$$1)\ Max\ \ EU(Y) = EU_1\begin{Bmatrix} p_{q1}\theta_1 Q_{r1}(l_{r1}, x_{r1}, z_{r1}, z_{h1})\beta - (\gamma p_{x1}x_{r1} + pl_{r1}) \\ +\left(p_{q1}\theta_1 Q_{o1}(l_{o1}, x_{o1}, z_{o1}, z_{h1}) - p_{x1}x_{o1}\right) \end{Bmatrix} + \rho EU_2\begin{Bmatrix} \left(p_{q2}\theta_2 Q_{o2}(l_{o2}, x_{o2}; z_{o2}, z_{h2}) - p_{x2}x_{o2}\right) + \\ \pi(Q_{r1}(l_{r1}, x_{r1}, z_{r1}, z_{h1}), h)p_{q2}\theta_2 Q_{r2}(l_{r2}, x_{r2}, z_{r2}, z_{h2})\beta - (\gamma p_{x2}x_{r2} + p_r l_{r2}) \end{Bmatrix}$$

where β is the output share going to the tenant ($\beta = 1$ for fixed rental contract), γ is the tenant's cost share in cost-sharing contracts (γ=1 for sharecropping and fixed rent contracts), the subscripts o=own plot, r=rented plot, 1 and 2 indicate period one and two, respectively, ρ discount factor given by $\frac{1}{1+\delta}$ and δ is the discount rate, x is conventional input (fertilizer, labour, oxen, seed), l_r rented in land, l_o own land, Z observed and unobserved household and plot characteristics, p_x is price of inputs, p_q is the price of output and p_r is the fixed rent per unit of land in fixed rent contracts.

We assume that decisions are sequential and we can therefore concentrate on the first period decision variables, taking rented in land as given based on past performance. With this assumption we have simplified the maximization problem in (1) to show how non-land resources (labour, seed, fertilizer and oxen power) are allocated on own and rented in land. The input level that maximizes the expected utility of household's income by tenancy type in period one is given by

$$2)\ p_q \frac{EU_{1y}\theta_1}{EU_{1y}} \frac{\partial Q_{o(r)1}}{\partial x_{o(r)1}} = p_{x1}$$

$$3)\ \ p_q \frac{EU_{1y}\theta_1}{EU_{1y}} \frac{\partial Q_{r1}}{\partial x_{r1}} \frac{\beta}{\gamma} + \rho \frac{EU_{2y}\theta_2}{EU_{2y}} \frac{\partial Q_{r1}}{\partial x_{r1}} \frac{\partial \pi}{\partial Q_{r1}} p_q Q_{r2} \frac{\beta}{\gamma} = p_{x1}$$

$$4)\ \ p_q \frac{EU_{1y}\theta_1}{EU_{1y}} \frac{\partial Q_{o1}}{\partial x_{o1}} = p_q \frac{EU_{1y}\theta_1}{EU_{1y}} \frac{\partial Q_{r1}}{\partial x_{r1}} \frac{\beta}{\gamma} + \rho \frac{EU_{2y}\theta_2}{EU_{1y}} \frac{\partial Q_{r1}}{\partial x_{r1}} \frac{\partial \pi}{\partial Q_{r1}} p_q Q_{r2} \frac{\beta}{\gamma}$$

where equation 2) is for fixed rent contracts and owner-operators (e.g. tenants own plots), equation 3) for cost sharing ($\gamma < 1$) and pure sharecropping contracts ($\gamma = 1$), and equation 4) combines 2) and 3).

We concentrate on equation 4, which tells us that non-land resources are distributed to own land and rented land until the marginal expected returns are equal on the two types of land. The second term on the right hand side in the equation, which is positive, is the discounted expected marginal utility arising from increased non-land resources due to reduced marginal threat of eviction. Or it is the value of the potential loss of future utility due to contract non-renewal. Tenants for whom this effect is large may decide to work hard on rented in land. The term, $\partial\pi/\partial Q_{r1}$, indicates the decrease in the probability of eviction by increasing output in the first period. The expected future benefits from reducing contract insecurity therefore leads to more use of non-land resources on rented in land.

We will now look at how alternative contracts affect incentives for use of non-land resources on own and rented land by looking at how they affect equation 4. The landlord cares about the efficiency of the tenant only in sharecropping and cost sharing contracts. Sharecropping inefficiency prevails if $\rho = 0$ while cost sharing contracts should be efficient when $\beta = \gamma$ for all inputs even when $\rho = 0$. The larger ρ is, the more the tenant is concerned about his future utility and the more he applies inputs on sharecropped plots to qualify for contract renewal, despite the disincentive effect of output sharing. Likewise, under cost sharing, eviction threat may lead to higher input use and land productivity on rented in plots than on tenants' own plots.

Using the implicit function theorem on equation 4 we find that the tenant will apply more non-land resources to rented land the larger the social distance is. Kinship therefore reduces the contract insecurity effect on the use of non-land resources on rented land. Land productivity on sharecropped land may therefore be higher for non-kin sharecrop plots than for kin sharecrop plots, and the difference in productivity and input use between own land and rented in land will be smaller for kin sharecrop plots than for non-kin sharecrop plots.

4.2. Hypotheses

Based on the above theoretical model we developed the following hypotheses. We have focused on the key variables of interest.

H1. *Marshallian inefficiency hypothesis*. Sharing of the output reduces incentives to apply inputs on sharecropped plots (kin and non-sharecropped plots) and this causes output and input use on sharecropped land to be lower than on tenants own plots. Testable implication: input use and output level is lower on kin and non-kin sharecrop plots than on share tenants own plots.

H2: *Threat of eviction hypothesis*. Uncertainty about contract renewal creates incentives to increase output (and therefore input use) on sharecropping plots in order to qualify for contract renewal. Testable implications: Input use and output is higher on kin and non-kin sharecrops plots than on share tenants own plots.

H3. *Kinship eliminates/reduces Marshallian inefficiency.* Kinship ties increases the incentive of tenants to use more inputs on kin sharecrop plots. Testable implication: Input use and output on kin sharecrop plots is not lower than on share tenants own plots, while it is lower for non-kin sharecrop plots.

H4. *Kinship eliminates/reduces threat of eviction*. Kinship ties reduce contact insecurity of kin tenants and the freedom of landlords to evict kin tenants when performance is poor. Testable implication: input use and output on kin sharecrop plots is not higher than on share tenants own plots, while it is so for non-kin sharecrop plots.

5. Econometric framework

In this section we discuss the empirical model, econometric estimation procedures, and problems and associated remedies.

5.1. Empirical Model

If one further manipulates the above first order conditions using first order Taylor's series approximation around the expected income, inputs and output value per hectare can be expressed as in equation 5:

5) $x_{ph} = f(p_x, p_y, \sigma_h^2, \psi_h, h_{ph}, \rho_h, \beta_p, \gamma_p, z_p, z_h)$

where σ_h^2 and ψ_h is the risk and risk aversion variables, respectively. In the empirical analysis the parameter β, γ and h will be replaced by tenancy dummy variables (kin and non-kin sharecrop plots, cost share plots and fixed rental plots using tenants own plots as a reference groups). All household level variables that were plot invariant (σ_h^2, ψ_h, z_h and ρ_h) were dropped in some of our empirical estimations due to our estimation procedure, household fixed effects estimation. However, if a need arise to use risk, risk aversion and discount rate variables in the absence of direct measure of these variables, they can be specified as a function of a vector of household socio-economic variables (Holden et al., 1998). In cross-sectional data price variation is not often observed across households and could therefore also not be included in our analysis. Households were using the same input and output markets in the area.

5.2. Econometric Estimation Procedures

This section outlines the econometrics methods and models used to examine the determinants of fertilizer adoption, input intensity and land productivity. We compare one-step versus two-step econometric estimation of fertilizer use.

Two estimation techniques were used in this paper; parametric and non-parametric techniques.

5.2.1. Non-parametric Method

The non-parametric method is stochastic dominance (efficiency) analysis (SD) used to compare yield distribution obtained under different tenancy arrangements. In SD we compared output value on share tenants' own plots with output values on kin and non-kin sharecrop plots based on cumulative distribution functions (CDF) of output values. Similarly output value distributions for kin and non-kin sharecrop plots were also compared.

The test for first-order stochastic dominance (FSD) rests on the assumption that the decision-maker prefers more to less of output value. The distribution of output value, $G(Y)$, say from non-kin sharecrop plots first-order stochastically dominates the distribution of output value from kin sharecrop plots, $F(Y)$, if and only if $G(Y) \leq F(Y)$ for every Y (Mas-Colell et al., 1995).

The second order stochastic dominance analysis (SSD) is useful when the cumulative distribution curves of the two alternatives are crossing each other and the FSD rule cannot rank them. Under the SSD, in addition to preferring more to less, human beings usually prefer to avoid low value outcomes, that is to say they are risk averse (Hien et al., 1997). The test for SSD requires a comparison of the area under CDFs. The alternative with the greatest area under the curve at any given outcome level has the highest probability of low value results. Therefore, an alternative is dominated if the area under its cumulative probability curve is larger at every outcome level than that of the other alternative.

Despite the analytical appeal of stochastic dominance and its distribution free assumption, it precludes one from accounting for yield difference that arise for reasons other than tenancy effects. For instance, differences in output value distributions that arise from differences in plot and household specific characteristics remain embedded in the distributions being compared.

5.2.2. Parametric Methods

The advantages of parametric methods are that they may allow us to control for observable and, under certain conditions, unobservable characteristics that otherwise would bias (selection bias, endogeneity bias) the results and possibly lead to wrong conclusions. By applying household fixed effects to our multiple plots per household type of panel data, we have been able to eliminate plot invariant household and partially plot specific effects that may otherwise have created such biases. Household fixed effects regression models are used to explain the probability of fertilizer use on a plot, input use (fertilizer intensity, labour, seed, oxen) and land productivity. Household fixed effects models are traditionally used when there is cross-sectional time series data. These models can also be applied for single cross-sectional observations by assuming each plot observation within a household as a time variable. The general regression model to be estimated is

(6) $y_{hp} = x_{hp}\beta + c_h + e_{hp}$,

where y_{hp} is output value per ha and inputs per ha obtained and used by household h on plot p, c_h is the unobserved household heterogeneity that captures unreported household characteristics such as farm management ability (tenants' quality), average land fertility, unobserved dimensions of wealth and tenant's connections with landlords, households' risk preferences and time preferences that affects input use and productivity, e_{hp} is the random variable which summarizes the plot specific component other than the ones reported in the survey such as unobserved variation in plot quality and plot specific production shocks (e.g. plot level variation in rainfall, hail, frost, floods, weeds, pests and diseases infestations), x_{hp} include both plot-invariant and variant observed explanatory variables and β is a vector of parameters to be estimated. A within-estimator or fixed effects estimation method will eliminate the unobserved household specific features and partly plot heterogeneity.

Plot level censoring of input use in the case of fertilizer requires a different econometric approach than for other inputs and output. All households except one used fertilizer but only 49% of all plots were fertilized. One basic issue is whether the decision to use fertilizer or not on a plot is driven by other variables and processes than the following decision on how much fertilizer to use. There may be no good a priori knowledge that tells which model is the correct one. A cautious approach was chosen to test alternative models and combinations of models.

Where a dependent variable contains both zero and non-zero values, a Tobit model and variants of Tobit models (e.g. Cragg and Wooldridge models) may handle this problem where all zeros are considered as the outcome of an optimal choice, i.e., zeros arise if and only if the individual household decides not to use fertilizer on a plot. Empirical tests were conducted to determine whether to use the Tobit model formulation or variants of Tobit models. The Tobit model assumes that a latent variable y^* is generated by (for ease of notation we dropped the subscripts):

$$(7) y^* = x\beta + e,$$

where x is the vector of independent variables, β is the vector of coefficients and e is the error term that is independently, identically distributed (iid) with mean 0 and variance $\sigma_e^{\ 2}$. If y^* is less than or equal to zero, the variable that is actually observed, the amount of fertilizer on a plot, y, is zero. When y^* is positive, $y = y^*$. In the Tobit model, the probability that the use of fertilizer on a plot is zero is

$$(8)\ P(y = 0) = 1 - \Phi(x\beta/\sigma)$$

and the density for positive values of y is

$$(9)\ f(y/x, y>0) = \left[\Phi\left(\frac{x\beta}{\sigma}\right)\right]^{-1} \frac{1}{\sigma}\phi\left(\frac{y-x\beta}{\sigma}\right)$$

where ϕ is the standard normal probability density function and Φ is the standard normal cumulative distribution function. Equation (8) represents the adoption decision, and is a valid probit model if considered separately from equation (9). Equation (9) represents a truncated regression for positive values of the continuous decision of how much fertilizer to use given $y > 0$. The Tobit model arises when the adoption decision, represented by probit model (equation 8), and the decision of what amount of fertilize to use, represented by truncated regression model (equation 9), have the same variables x and the same parameter vector β. The log-likelihood function for the Tobit model consists of the probabilities for the non-adoption decision and a classical regression for the positive values of y

$$(10)\ \ln L = \sum_{0} \ln\left[1-\Phi(x\beta/\sigma)\right] + \sum_{+} \ln\left[\frac{1}{\sigma}\phi\left(\frac{y-x\beta}{\sigma}\right)\right],$$

in which "0" indicates summation over the zero observations in the sample, while "+"indicates summation over positive observations.

In the Tobit model, a variable that increases (decreases) the probability of adoption also increases (decreases) the quantity of fertilize use. This is not always reasonable. For instance, household characteristics and endowments may differently affect the decision to or not to use fertilizer and how much to use on a plot. We are also assuming that the fertilizer adoption decision and the extent of fertilizer adoption decision are made simultaneously. Cragg (1971) and Wooldridge (2002) relaxed the assumption that the same variables and the same parameter vector affect both the adoption decision and the decision of how much to use. Their models allow variables to have differing effects on the adoption and extent of adoption decisions. Following Cragg and Wooldridge, we consider a hurdle model in which a farmer makes a two-step decision. In the first step, a probit model represents a farmer's choice of whether to adopt fertilize on a plot (y)

$$(11)\ P(y=0 \mid x) = 1-\Phi(z\gamma).$$

If the farmer crossed this hurdle, that is the farmer has decided to adopt fertilizer on a plot $(y=1)$, a truncated regression (equation 9), Cragg second step model, or lognormal regression, Wooldridge second step model $\left[\log(y) \mid (x, y>0) \sim \text{Normal}(x\beta, \sigma^2)\right]$, may describe his choice of how much fertilizer to use on a plot conditional on $y > 0$.

The log-likelihood in Cragg's model (12) is a sum of the log-likelihood of the probit model (the first two terms) and the log-likelihood of the truncated regression model (the second two terms):

$$(12)\ \ln L = \sum_0 \ln[1-\Phi(z\gamma)] + \sum_+ \left\{ \ln\Phi(z\gamma) + \ln\phi\left[\frac{1}{\sigma}\left(\frac{y-x\beta}{\sigma}\right)\right] - \ln\Phi(x\beta/\sigma) \right\}$$

The log-likelihood function for Wooldridge model (13) is a sum of the log-likelihood of the probit model (the first two terms) and the log-likelihood of the OLS linear regression model (the second two terms) and the value of $\ln y_i$

$$(13)\ \ \ln L = \sum_0 \ln[1-\Phi(z\gamma)] + \sum_+ \left\{ \ln\Phi(z\gamma) + \left(\ln\phi\left[\frac{\ln(y)-x\beta}{\sigma}\right] - \frac{1}{2}\ln\sigma^2 - \ln y \right) \right\}.$$ For detail specification and estimation procedure of this model see Wooldridge (2002, pp 536-538).

The Cragg model has the advantage that it nests the Tobit model; when $z = x$ and $\gamma = \beta/\sigma$, the Cragg model reduces to the Tobit model log-likelihood function. A likelihood ratio test can therefore be performed easily to study if the household fertilizer use decision on the plot is best modelled by a one-step or a two-step procedure. The difficulty to compare the Wooldridge model versus the Cragg model is that they are not nested to each other. The same is true for Tobit model and Wooldridge model. We used Voung (1989) non-nested model selection test. Following, Greene (2000) and Fin and Schmidt (1984) the restriction imposed by the Tobit model is tested against the Cragg model by performing a likelihood ratio test of the following.

$$(14)\ L = 2(\ln L_{probit} + \ln L_{truncatedregression} - \ln L_{Tobit}).$$

where L is distributed as chi-square with k degree of freedom (K is the number of independent variables including a constant). The null hypothesis is the Tobit model (restricted model), with the log-likelihood function given in equation (10) and the alternative model (unrestricted) is the Cragg's model (probit and a truncated regression estimated separately), with a log-likelihood function given in equation (12). The Tobit model will be rejected in favour of Cragg's model if L exceeds the chi-square critical value. The likelihood ratio test statistics of $(chi2(34) = 290.27, p = 0.000)$ and $(chi2(30) = 177.26 p = 0.000)$ for the entire sample plots (1290 plots using all tenants own plots as reference group) and the sub-sample plots that compares kin and non-kin sharecrop plots with share tenants' own plots (420 plots), respectively, indicated that the restrictions imposed by the Tobit model rejected in favour of Cragg's model. The same household and farm characteristics did not have equal influence on both the adoption decision and the decision for how much fertilizer to use on a plot. It also implies that the fertilizer adoption decision and the extent of fertilizer adoption decision are not made simultaneously. Hypothesizing that a given variable is interrelated with the fertilizer adoption decision and not the extent of adoption decision or vice versa is difficult. Consequently, the three models are estimated with the same variables.

Once the Tobit model is rejected the Cragg model can be compared with Wooldridge model using Voung non-nested model specification test. The Voung's non-nested model specification test is given by

(15) $V = n^{-1/2} LR_n(\hat{\theta}_n, \hat{\upsilon}_n) / \hat{\omega}_n \rightarrow N(0,1)$,

where $LR_n(\hat{\theta}_n, \hat{\upsilon}_n)$ is the difference between the log-likelihood values for the two models, $\hat{\theta}_n$ and $\hat{\upsilon}_n$ is the maximum likelihood estimators from the two models, respectively[26] and V is distributed as a standard normal variable. The Voung test statistic of $(V = 4.66, p = 0.000)$ and $(V = 3.25, p = 0.000)$ for the entire sample plots and the sub-sample plots, respectively, strongly accept the Wooldridge model dominates the Cragg model. The critical values (c) for the 1 and 5 per cent significance level are 2.58 and 1.96, respectively. The results, therefore presented based on Wooldridge model.

Fixed effects may be useful to eliminate selection bias due to unobserved household characteristics. However, maximum likelihood models (e.g. Probit and Tobit models) cannot be directly estimated using fixed effects models because of the incidental parameters problem (Wooldridge, 2002; Hsiao, 2003). We used linear probability model instead of probit model to estimate the probability of fertilizer use. The advantages of the linear probability model over the probit model are that it allows for household fixed effects[27]. Wooldridge (2002) argued

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[26] $\hat{\omega}_n^{\,2} = \frac{1}{n}\sum_{i=1}^{n}\left[\log\frac{f(y_{hp} \mid x_{hp}; \hat{\theta}_n)}{g(y_{hp} \mid x_{hp}; \hat{\upsilon}_n)}\right]^2 - \left[\frac{1}{n}\sum_{i=1}^{n}\log\frac{f(y_{hp} \mid x_{hp}; \hat{\theta}_n)}{g(y_{hp} \mid x_{hp}; \hat{\upsilon}_n)}\right]^2$, and n is the number of observations. The null hypothesis is that the two models equally fit the data. We reject the null hypothesis and accept model $g_{\hat{\upsilon}}$ (Tobit or Cragg regression model) when V is smaller than c (critical value from a standard normal distribution for some significance level) and reject null and accept model $f_{\hat{\theta}}$ (Wooldridge or lognormal model) when V is higher than C (See details in Voung, 1989).

[27] Conditional fixed effect logit model can also be used but it drops out observations when the dependent variable within a household does not vary. In our case five households that contained 21 observations dropped since four households used fertilizer in all their plots and one household did not use fertilizer at all. For clear understanding see the likelihood specification of this model in Wooldridge (2002, pp 492).

that some predicted values outside the unit interval might not be very important if the main purpose is to estimate the partial effect of the explanatory variables on the response probability.

5.3. Econometric estimation problems and remedies

Equation (6) has some econometric problems to be addressed. First, unobserved tenant characteristics (c_h) may affect both the contract choice variables and some of the right hand side variables. Households may endogenously choose (self-select) contract types based on private characteristics (c_h). This renders OLS estimates of the $\beta's$ biased and inconsistent, if estimation is made without controlling for these characteristics. In this paper we control for household unobserved heterogeneity in three different ways. First, we use a household fixed effects by exploiting the fact that in most of the households, agricultural activities are carried out on many plots. As noted by Wooldridge (2002, pp. 581) self-selection in a fixed effects context is only a problem when selection is related to the idiosyncratic errors, $e_{hp.}$ Second, the selection problem based on idiosyncratic errors can be handled using observed plot characteristics and inputs (see below the detail discussion on this). Third, the estimation is restricted to the sub-sample plots of share tenants own plots and sharecropped plots, allowing one to control for household heterogeneity.

The second econometric problem is related to land quality. Land quality might be imperfectly described by variables usually available for the econometrician and farmers could have private information about plot specific-features. If unobserved plot component (e_{hp}) is correlated with kinship of landlords or contract choice and other observed regressors, parameter estimates from equation (6) will be inconsistent. If we do not control for these we are not finding the effect due to sharecropping. Unlike household heterogeneity, controlling for plot heterogeneity is not an easy task. The data set do not have good instrumental variables and we do not have plots that change contract over time to use plots fixed effects to account for plot-specific effects on land productivity and input use. The data set includes measures of the topography, soil conservation structures on plots and plots size, reported soil fertility level, soil depth, plot location, distance of plots from homestead and input use of each plot. This is a richer characterization of plot quality than in most of other studies investigating these issues. However, in this paper we tried to investigate the effect of plot-specific effects on our estimation in three different ways.

First, we can control for plot unobservabilities using factor inputs. We assumed factor inputs are not randomly allocated across plots but are chosen by farmers. If farmers accessed private information about e_{hp} such as how good the soil is on the plot or some shocks, they will accordingly adjust their factor inputs decisions (Fafchamps, 1993; Levinsohn and Petrin, 2003; Assunção and Braido, 2004). The economics underlying this concern are intuitive. Framers may respond to positive productivity shocks by expanding output, which requires additional inputs. Negative shocks lead farmers to cut back output, decreasing their input usage. Therefore, input levels contain useful missing information regarding land quality, or plot-specific shocks. Introducing inputs into the regressions would reduce the effect of plot-specific features. Levinsohn and Petrin (2003) used intermediate inputs to control for unobservable productivity shocks. Assunção and Braido (2004) used conventional farm inputs including the value of land to control for the effect of plot-specific features or shocks on the inverse relationship between farm size and productivity using data from ICRISAT.

Second, following Mundlak (1961) and Chamberlain (1984) much of the unobserved variation in plot quality not described perfectly by observed plot quality indicators could be removed using household fixed effects procedure. First, our fertility ranking variables captures difference in plot fertility across plots for a given household, but not for differences in average plots fertility across households (household level difference in land quality). Second, household heterogeneity may be correlated with plot quality.

Third, we can check whether the estimates of interest are affected by adding (dropping) observable indicators of plot quality from the regressions. It would be highly likely that observed plot quality would be positively correlated with unobserved plot quality and this may be used when assessing the outcome of alternative models. This is a common method used in the literature to assess the role of land quality plays on inverse farm size and productivity relationship (e.g. Bhalla, 1988; Lamb, 2003; Assunção and Braido, 2004) and in the literature comparing male and female crop productivity (Udry et al., 1995).

Finally, endogeneity of other explanatory variables such crop types may bias model results. Crop compositions including different varieties (multiple traditional varieties) and intercropping are among strategies being used by developing countries farmers to deal with agricultural risk (Fafchamps, 1993). Crop types may serve to control for unobserved plot fertility. A χ^2 test of the hypothesis that the distribution of crops across plots is independent of the plot soil fertility was rejected. There is statistically significant correlation between crops choices and plot soil fertility $(chi2(12) = 30.23, p = 0.003)$. Crop choice may be correlated with unobserved plot attributes and by their inclusion bias due to unobserved plot attributes may have been reduced. Crop choice may also be affected by tenancy type. A χ^2 test of the hypothesis that the cropping pattern is independent of the tenancy type was rejected $(chi2(12) = 29.19, p = 0.004)$. Thus, dropping crops type from the regression may lead to biased estimates. For instance, if crop choice was included as part of a sharecropping contract and differences in input use and output values could be explained by this systematic difference in crop choice across tenancies, dropping crop choice from the regressions may lead to wrong conclusions. In addition, the cropping pattern is stable in the village where similar crops are grown year after year based on crop rotation and preference of own product for household consumption. The crop rotation is fixed in the area. For instance, they grow *teff* after barley and vice versa. They grow maize year after year on the same plot (homestead plots) since these plots are relatively fertile compared to distance plots. Thus, crop choices can be considered as pre-determined variables. Finally, we hope that any systematic decision on the choice of crops by the household can be captured by household fixed effects procedure and the variables included in each model (e.g. plot characteristics, labour use). However, to check the robustness of our variables of interest, we adopted also the second-best soultion, running models with and without crop types variables.

6. Results and discussion

Stata version 9.0 was used to estimate the coefficients of the various equations. The results are based on comparing kin and non-kin sharecrops plots versus share tenants' own plots. We also reported fertilizer intensity estimation from entire sample data since observations for sub-sample data is relatively small.

6.1. Determinants of Output Value Per Hectare

Regression results for output value per ha are presented in Table 4. The parametric regression results suggested that conditional on plot characteristics, crop types, inputs and household fixed effects, kin and non-kin sharecrops plots were more productive than share tenants' own plots[28]. Similar results (not reported) were obtained from fixed effects of the entire sample estimation, where all tenants owned plots were used as a reference group. The stochastic dominance analysis supported this result where the yield from kin and non-kin sharecrop plots unambiguously dominated the yield from share tenants' own plots (Figure 1). This is consistent with the threat of eviction hypothesis that tenants may work harder to qualify for contract renewal in the second period (Hypothesis 2). We also found that non-kin sharecrop plots were more productive than kin sharecrop plots in each specification. Similar results obtained using stochastic dominance analysis. This result is consistent with the hypothesis that threat of eviction is stronger among non-kin than among kin partners (Hypothesis 3 and 4). Overall, these findings indicated the dominance of the threat of eviction effect over the Marshallian inefficiency effect and kinship reducing the threat of eviction effect, implying that it is more difficult to evict kin tenants than non-kin tenants. This implies that non-kin tenants feel less secure about their tenure and therefore are more productive on their sharecropped plots to increase the probability of contract renewal[29]. This is confirmed by our data set where the duration of contracts was relatively shorter for non-kin than for kin partners.

The results showed that inequality in plot quality might not be the culprit in productivity gap between kin and non-kin sharecrop and share tenants own plots. Controlling for plot quality did not eliminate the observed significant productivity difference between kin and non-kin sharecrop and share tenants' own plots (Table 4 of column B, C, and D).

After controlling for inputs and household level variables, productivity on share tenants own plots was not statistically different from landlords, owner operators, cost share and fixed rental tenants own plots (Table 8)[30]. It seems tenants average productivity was comparable with the average village level productivity. The unconditional average productivity (Birr 791 per ha) on share tenants own plots was not very much different from village level average productivity (Birr 806 per ha), obtained from owned plots of owner operators, landlords, cost share, share tenants and fixed rental tenants (Table 2). This result implies that if tenants' productivity on own plots is lower than on rented-in plots but comparable with village level

[28] We reached the same conclusion using random effects regression.
[29] Cost shared plots were more productive than on cost share tenants own plots (not reported).
[30] The random effects estimation used since owner operators and landlord own plots do not vary over plots.

average productivity, then higher productivity on rented-in plot can be explained by contract insecurity.

5.1. Determinants of Inputs use

Results for the fixed effects linear probability model of fertilizer adoption are presented in Table 5. Controlling for crop types, the probability of fertilizer use on kin sharecrop plots was lower than on tenants own plots, but fertilizer intensity difference turned out to be insignificant (Table 6). There was no statistically significant difference on the decision to use fertilizer between non-kin sharecrops plots and share tenants' own plots. Fertilizer intensity was higher on non-kin sharecrop plots than share tenants' own plots (Table 6). This may reflect the importance of the two-step estimation procedure that may reflect the inter-temporal nature of the decision process.

The parameter estimates for the lognormal regression model for fertilizer intensity estimation are presented in Table 6. Contrary to the findings of Sadoulet et al. (1997), we found that non-kin sharecrop plots received more fertilizer than other plots in each specification. There was no significant fertilizer use difference between kin sharecropper plots and tenants' own plots. The larger portion of the variation in fertilizer use between share tenants' own plots and non-kin sharecrop plots was not explained by omitted plot quality. The same argument as in the productivity estimation might explain this result.

The random effects estimation results showed that fertilizer use was not statistically different between share tenants own plots and landlords, owner operators, fixed rental and cost share tenants own plots (Table 9). The average fertilizer use by share tenants (Birr 100 per ha) was similar with the average village level fertilizer use (Birr 100 per ha) obtained from all owned plots (Table 2). Fear of contract non-renewal (contract insecurity) during the upcoming season may have boosted fertilizer use on non-kin sharecrop plots above the average village level fertilizer use.

Share tenants used significantly more seed on kin and non-kin sharecrop plots than on their own plots (Table 7 column H). In each specification the marginal effect of seed use was higher on non-kin sharecrop plots than kin-sharecrop plots. There was no statistically significant difference on labour use between kin and non-kin sharecropping plots and share tenants' own plots after controlling for plot quality (Table 7). The results showed that oxen use was higher on kin sharecrop plots controlling for plot quality but the significance level was eliminated after controlling for crop types (Table 7 column F and I).

As random effects regression results indicated, there were no statistically significant labour, seed and oxen power use differences between share tenants own plots and landlords, owner operators, fixed rental and cost share tenants own plots (Table 10).

7. Conclusions

In this paper, we investigated the impact of different sharecropping contracts on land productivity and input use in the highlands of Ethiopia. We explored different explanations for efficient sharecropping contracts system using parametric and non-parametric methods. Households cultivating multiple plots allowed us to control for household fixed effects and partly plot heterogeneity. An improvement offered by the study is that the availability of variables measuring plot quality, including inputs, allowed for more direct estimation of the importance of plot quality for explaining productivity and input use difference between kin and non-kin sharecrop plots and share tenants' own plots. Introducing plot quality variables in the regression did not change the results. Plot quality, therefore, may not be an explanation for significant productivity and input use differences between share tenants' own plots and kin and non-kin sharecrop plots. Rather, contract insecurity might explain the productivity and input use differences.

Overall, we found that share tenancy contracts were not inefficient in all circumstances for the sample considered. Thus, share tenancy could be one way of accessing farmland among land deficient households and relaxing imperfect markets for other inputs in a country where land sale and mortgage are banned and markets for other inputs are imperfect. Nevertheless, we note limitations in our data in that it was collected in one village and therefore it does not capture the diversity of cultural compositions, traditional norms, socio-economic differences among households and regional policy variations in Ethiopia. Further studies are therefore, necessary to capture these differences and test the replicability of the results in other parts of Ethiopia. In addition, since this study focused only on short-term production inputs, studies to explore how different land rental contracts affect long-term investments in productivity enhancing technologies are important.

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Table 1. Tenants' and landlords' resources comparison

Resources	Tenants		Landlords		Resources	Tenants		Landlords	
	Mean	Std.Err	Mean	Std.Err		Mean	Std.Err	Mean	Std.Err
Oxen holding (number)	1.95***	0.077	0.57	0.105	Beehives (number)	0.63***	0.164	0	0
Cow holding (number)	1.65***	0.122	0.73	0.118	Labour in standard unit	2.96***	0.120	2.30	0.185
Small ruminant (number)	3.32***	0.341	0.68	0.153	Family size in standard unit	4.67***	0.183	3.09	0.204
Chicken (number)	1.70	0.185	1.89	0.280	Household head age	38***	1.236	50	2.342
Pack animals (number)	0.82***	0.104	0.05	0.030	Farm size in ha	1.42***	0.056	1.18	0.291
Number of observations	88		56						

*** significant at 1%. We did not ask livestock age for those landlords residing outside the study area and thus livestock holding not converted into standard units

Table 2. Descriptive statistics for key variables by tenancy types

Variables	owner operated plots	cost share tenants own plots	Cost share rented in plots	Share tenants own plots	Kin sharecrop plots	Non-kin sharecrop plots	Fixed rental tenants own plots	Fixed rental plots	Landlord own plots**	All samples
Plots received fertilizer (dummy)	0.48(0.50)	0.53(0.50)	0.89(0.32)	0.45(0.50)	0.37(0.49)	0.37(0.50)	0.50(0.50)	0.67(0.47)	0.31(0.46)	0.49(0.50)
Output value per ha (Continuous)	783(757)	887(723)	1047(609)	791(668)	893(650)	1033(818)	912(747)	889(807)	659(422)	827(708)
Fertilizer value per ha (Continuous)	102(165)	108(136)	199(179)	100(251)	70(179)	121(199)	114(156)	133(128)	53(105)	104(186)
Seed value per ha (Continuous)	120(128)	131(117)	105(91)	128(157)	124(137)	112(141)	148(164)	123(109)	87(83)	124(136)
Oxen-days per ha (Continuous)	17(30)	16(13)	14(12)	17(17))	18(16)	11(7)	19(19)	17(18)	20(34)	17(23)
Man-days per ha (Continuous)	67(71)	65(48)	65(43)	71(65)	60(56)	42(28)	77(69)	59(52)	67(52)	68(63)
threshing labour per ha	20(15)	20(16)	16(13)	20(18)	14(5)	19(23)	23(16)	19(29)	19(14)	20(17)
Weeding labour per ha	18(35)	18(24)	22(20)	22(35)	13(16)	10(17)	23(38)	15(16)	15(17)	19(31)
Harvesting labour per ha	12(10)	11(8)	13(9)	12(11)	9(4)	12(14)	12(9)	10(11)	13(10)	12(10)
Ploughing labour per ha	17(30)	16(13)	14(12)	17(17)	18(16)	11(7)	19(19)	17(18)	20(34)	17(23)
Good fertile soil (dummy)	0.21(0.41)	0.11(0.31)	0.19(0.39)	0.20(0.40)	0.22(0.42)	0.16(0.37)	0.19(0.40)	0.22(0.42)	0.19(0.39)	0.19(0.39)
Medium fertile soil (dummy)	0.52(0.50)	0.53(0.50)	0.53(0.50)	0.51(0.50)	0.50(0.50)	0.42(0.51)	0.48(0.50)	0.47(0.50)	0.46(0.50)	0.50(0.50)
Poor fertile soil (dummy)	0.28(0.48)	0.36(0.48)	0.28(0.45)	0.29(0.46)	0.28(0.45)	0.42(0.51)	0.33(0.47)	0.31(0.47)	0.36(0.48)	0.30(0.46)
Shallow soil depth (dummy)	0.21(0.40)	0.33(0.47)	0.26(0.45)	0.22(0.41)	0.41(0.50)	0.26(0.45)	0.27(0.42)	0.25(0.44)	0.28(0.45)	0.25(0.43)
Medium soil depth (dummy)	0.37(0.48)	0.29(0.45)	0.25(0.43)	0.35(0.48)	0.22(0.42)	0.37(0.50)	0.23(0.42)	0.31(0.47)	0.31(0.46)	0.32(0.47)
Good soil depth (dummy)	0.43(0.49)	0.39(0.48)	0.49(0.50)	0.43(0.50)	0.37(0.49)	0.37(0.50)	0.50(0.50)	0.44(0.50)	0.41(0.49)	0.43(0.49)
Plot size in ha (Continuous)	0.24(0.14)	0.25(0.15)	0.32(0.14)	0.24 (0.14)	0.27(0.18)	0.31(0.18)	0.22(0.12)	0.25(0.12)	0.27(0.13)	0.25(0.14)
Plot distance (continuous: minutes)	13(15)	11(14)	50(74)	13(14)	40(52)	40(39)	12(15)	38(42)	14(19)	17(28)
Plot slope in degree (Continuous)	17(10)	17(8)	16(4)	17(9)	16(5)	19(10)	19(12)	16(6)	19(11)	17(9)
Conservation intensity (Continuous, ha)	0.01(0.01)	0.01(0.01)	0.004(0.01)	0.004(0.01)	0.003(0.031	0.01(0.01)	0.004(0.01)	0.002(0.01)	0.01(0.02)	0.02(0.04)
Homestead plots (dummy)	0.25(043)	0.34(0.47)	0	0.27(0.45)	0.01(0.12)	0	0.23(0.42)	0.09(0.29)	0.25(0.43)	0.23(0.42)
Intercropped plots (dummy)	0.27(0.45)	0.26(0.44)	0.21(0.41)	0.26(0.44)	0.04(0.21)	0.05(0.23)	0.27(0.45)	0.07(0.26)	0.22(0.42)	0.24(0.43)
pulses & oil crops (dummy)	0.15(0.35)	0.14(0.34)	0.06(0.23)	0.12(0.33)	0.15(0.36)	0.16(0.37)	0.14(0.34)	0.13(0.34)	0.15(0.36)	0.13(0.34)
teff crop (dummy)	0.20(0.40)	0.16(0.37)	0.19(0.39)	0.19(0.39)	0.35(0.48)	0.32(0.48)	0.18(0.39)	0.20(0.40)	0.20(0.40)	0.20(0.40)
barley crop (dummy)	0.32(0.47)	0.35(0.48)	0.09(0.30)	0.32(0.47)	0.37(0.49)	0.32(0.48)	0.33(0.47)	0.20(0.40)	0.30(0.46)	0.31(0.46)
potato crop (dummy)	0.06(0.24)	0.09(0.28)	0.02(0.14)	0.08(0.27)	0.03(0.17)	0	0.04(0.21)	0.13(0.34)	0.04(0.19)	0.06(0.24)
wheat crop (dummy)	0.05(0.21)	0.07(0.26)	0.11(0.32)	0.04(0.21)	0.04(0.21)	0.16(0.37)	0.09(0.28)	0.09(0.29)	0.06(0.24)	0.06(0.24)
Improved maize crop (dummy)	0.10(0.30)	0.09(0.28)	0.47(0.50)	0.09(0.28)	0.03(0.17)	0	0.09(0.28)	0.22(0.42)	0.07(0.26)	0.106(0.31)
local maize crop (dummy)	0.13(0.33)	0.11(0.31)	0.06(0.23)	0.16(0.37)	0.03(0.17)	0.05(0.23)	0.13(0.34)	0.04(0.19)	0.19(0.39)	0.12(0.33)
household head age in years (Continuous)	40(12)	38(12)		39(13)	38(11)	41(0.14)	37(8)		43(14)	39(12)
Extension visit (dummy)	0.76(0.43)	0.59(0.50)		0.54(0.50)	0.57(0.50)	0.42(0.51)	0.39(0.50)		0.45(0.52)	0.59(0.49)
oxen power per ha (Continuous)	0.77(0.47)	0.69(0.42)		0.68(0.31)	0.68(0.32)	0.67(0.27)	0.79(0.26)		0.65(0.45)	0.72(0.39)
Other livestock in TLU per ha (Continuous)	1.30(0.88)	1.32(0.72)		1.20(0.75)	1.16(0.74)	1.29(0.79)	1.35(0.87)		1.11(0.63)	1.26(0.79)
off farm activities participation (dummy)	0.12(0.33)	0.14(0.35)		0.17(0.38)	0.19(0.40)	0.08(0.29)	0.33(0.49)		0.27(0.47)	0.18(0.38)
Farm size per capita (Continuous)	0.37(0.10)	0.34(0.12)		0.33(0.13)	0.32(0.12)	0.38(0.18)	0.32(0.09)		0.38(0.06)	0.35(0.0.11)
Duration of rented in plots (Continuous)			2.9		4.3	3.7		2.3		
Number of observations	400(48)	140(22)	53	333(49)	68(37)	19 (12)	141(18)	55	81(11)	1290(148)

Note (A) standard deviations in parentheses except in the number of observations row where figures in parentheses are number of households, (B) No statistical significance mean difference between kin versus non-kin tenants household level variables using t-test, (C) ** indicates landlords residing outside the village and pure landlords are not included.

Table 3. Kin versus non-kin landlords resource endowments comparison *

Resources	Non-kin landlord		Kin-landlord		Resources	Non-kin landlord		Kin-landlord	
	Mean	Std. Err.	Mean	Std. Err.		Mean	Std. Err.	Mean	Std.err
Oxen holding (number)	0.55	0.12	0.61	0.20	Labour in standard unit	2.51	0.24	1.86	0.39
Cow holding (number)	0.68	0.14	0.83	0.23	Family size in standard unit	3.04	0.20	3.19	0.40
Small ruminant (number)	0.55	0.17	0.94	0.31	Household head age	51	2.89	47	4.03
Chicken (number)	1.71	0.31	2.27	0.58	Farm size in ha	1.14	0.27	1.28	0.70
Number of observations	18		38			18		38	

*No statistically significant mean differences. Landlords residing outside the village and pure landlords are included. We did not ask livestock age for those landlords residing outside the study area and thus not converted into standard units.

Table 4. Fixed effects estimates of the determinants of plot level output value (Dependent variable: log of output value per ha)

Explanatory variables	Without plot quality	With plot quality	With plot quality & crop types	With plot quality, crop types & inputs
	A	B	C	D
kin sharecrop plots	0.168(0.145)	0.301(0.152)*	0.295(0.130)**	0.205(0.116)*
non-kin sharecrop plots	0.310(0.167)*	0.439(0.162)**	0.453(0.150)***	0.334(0.124)***
Joint F test for plot quality indicator variables		5.30(0.000)***	3.86(0.001)***	1.34(0.239)
Joint F test for crop dummy variables			7.86(0.000)***	6.64(0.000)***
Joint F test for inputs				25.67(0.000)***
Constant	6.379(0.025)***	6.319(0.335)***	6.157(0.359)***	3.836(0.315)***
Observations	420	420	420	420
R-squared	0.15	0.23	0.36	0.62
Model test	F(2, 47) = 2.42(0.10)	F(12,47) =5.77(0.000)***	F(18,47) = 7.90(0.000)***	F(24,47) =32.33(0.000)***
Robust standard errors adjusted for clustering effects in parentheses				
* significant at 10%; ** significant at 5%; *** significant at 1%				

Note: (A) Plot quality indicator variables include: good fertile soil, medium fertile soil, shallow soil depth, medium soil depth, ln (plot distance from residence), ln (plot slope), homestead plot, conservation intensity & intercropped plot.
(B) Crop dummy variables include: local maize plot, pulses & oil crops plot, teff plot, barley plot, potato plot, wheat plot & improved maize plot.
(C) Factor input include: ln (weeding labour per ha), ln (ploughing labour per ha), ln(threshing labour per ha) , ln(harvesting labour per ha) ln (value of seed per ha) & ln (fertilizer value per ha)

Table 5. Fixed effect estimates of the determinants of plot level probability of fertilizer use (Dependent variable: =1 if plots received fertilizer and zero otherwise)

Explanatory variables	Without plot quality	With plot quality	With plot quality & crop types
kin sharecrop plots	-0.033(0.072)	-0.074(0.087)	-0.122(0.071)*
non-kin sharecrop plots	-0.038(0.130)	-0.124(0.125)	-0.114(0.132)
Joint F test for plot quality indicator variables [a]		5.82(0.000)***	6.63(0.000)***
Joint F test for crop dummy variables [a]			27.06(0.000)***
Constant	0.440(0.013)***	0.636(0.220)***	0.687(0.182)***
Observations	420	420	420
R-squared	0.17	0.24	0.43
Model test	F(2, 47) = 0.15(0.863)	F(11, 47) = 5.03(0.000)***	F(17, 47) = 12.18(0.000)***
Robust standard errors adjusted for clustering effects in parentheses			
* significant at 10%; ** significant at 5%; *** significant at 1%			

[a] These variables are the same as those listed under Table 4.

Table 6. Fixed effects estimates of plot level fertilizer use (Dependent variable: log of fertilizer value per ha)

Explanatory variables	Without plot quality		With plot quality		With plot quality & crop types	
	Sub-sample	Entire sample	Sub-sample	Entire sample	Sub-sample	Entire sample
	A	B	C	D	E	F
Kin sharecrop plots	-0.130(0.305)	-0.223(0.294)	-0.144(0.361)	-0.247(0.299)	-0.112(0.334)	-0.222(0.296)
Non-kin sharecrop plots	0.561(0.259)**	0.513(0.227)**	0.560(0.260)**	0.501(0.231)**	0.597(0.234)**	0.625(0.231)***
fixed rental plots		0.015(0.135)		0.015(0.146)		-0.058(0.146)
cost share plots		0.291(0.161)*		0.265(0.174)		0.196(0.182)
Joint F test for plot quality indicator variables [a]			1.09(0.393)	1.096(0.0.373)	0.570(0.833)	1.24(0.270)
Joint F test for crop dummy variables [a]					1.72(0.121)	1.461(0.195)
Constant	5.001(0.043)***	5.044(0.020)***	5.018(0.611)***	4.957(0.0.372)***	4.341(0.488)***	4.777(0.401)***
Observations	182	629	182	629	182	629
R-squared	0.40	0.31	0.44	0.34	0.47	0.36
Model test	F(2, 46) =2.48(0.095)*	F(4, 146) = 2.06(0.089)*	F(12, 46) = 1.78(0.080)*	F(14, 146) =1.65(0.072)*	F(18, 117) = 2.24(0.055)*	F(20, 146) = 1.63(0.050)*
Robust standard errors adjusted for clustering effects in parentheses						
* significant at 10%; ** significant at 5%; *** significant at 1%						

[a] These variables are the same as those listed under Table 4.

Table 7. Fixed effects estimates of the determinants of plot level labour, seed and oxen use (dependent variables: log of man-days, log of seed value and log of oxen-days per ha)

Explanatory variables	Without plot quality			With plot quality			With plot quality & crop types		
	Man days per ha	Seed value per ha	Oxen days per ha	Man days per ha	Seed value per ha	Oxen days per ha	Man days per ha	Seed value per ha	Oxen days per ha
	A	B	C	D	E	F	G	H	I
kin sharecrop plots	-0.138(0.126)	0.088(0.198)	0.105(0.095)	0.101(0.106)	0.284(0.209)	0.191(0.104)*	0.042(0.087)	0.443(0.152)***	0.129(0.079)
Non-kin sharecrop plots	-0.321(0.132)**	0.204(0.199)	-0.206(0.176)	-0.063(0.130)	0.334(0.237)	-0.149(0.146)	-0.053(0.123)	0.540(0.171)***	-0.151(0.151)
Joint test for plot quality indicator variables [a]				7.66(0.000)***	4.14(0.000)***	4.39(0.000)***	4.42(0.000)***	6.03(0.000)***	3.05(0.005)***
Joint test for crop dummy variables [a]							31.35(0.000)***	39.36(0.000)***	20.03(0.000)***
Constant	3.991(0.021)***	4.261(0.034)***	2.626(0.018)***	4.461(0.313)***	3.028(0.540)***	2.942(0.316)***	4.455(0.276)***	2.277(0.482)***	2.751(0.260)***
Observations	420	420	420	420	420	420	420	420	420
R-squared	0.15	0.11	0.23	0.28	0.15	0.29	0.54	0.49	0.50
Model test	F(2, 47) = 3.60(0.000)***	F(2, 47) = 0.60(0.555)	F(2, 47) = 1.36(0.267)	F(12, 47) = 6.52(0.000)***	F(12, 47) = 3.86(0.000)***	F(12, 47) = 3.92(0.000)***	F(18, 47) = 22.55(0.000)***	F(18, 47) = 23.62 (0.000)***	F(18, 47) = 17.56(0.000)***
Robust standard errors adjusted for clustering effects in parentheses									
* significant at 10%; ** significant at 5%; *** significant at 1%									

[a] These variables are the same as those listed under Table 4.

Table 8. Random effects estimates of the determinants of output value per ha (share tenants' own plots compared with others own plots)

Explanatory variables	Without plot quality	With plot quality	With plot quality & crop types	With plot quality, crop types & input levels	With plot quality, crop types, input & household level variables
Owner operator plots	-0.023(0.069)	-0.025(0.070)	-0.002(0.069)	-0.003(0.055)	-0.015(0.049)
Cost share tenants' owned plots	0.130(0.089)	0.138(0.094)	0.154(0.087)*	0.095(0.067)	0.081(0.063)
fixed rental tenants owned plots	0.148(0.085)*	0.149(0.080)*	0.172(0.077)**	0.047(0.060)	0.030(0.057)
landlords owned plots	-0.106(0.098)	-0.082(0.103)	-0.060(0.098)	-0.034(0.102)	0.011(0.073)
Joint chi-square test for plot quality indicator variables		137.98(0.000)***	96.33(0.000)***	44.56(0.000)***	40.58(0.000)***
Joint chi-square test for crop dummy variables			121.16(0.000)***	34.36(0.000)***	32.86(0.000)***
Joint chi-square test for factor input				379.69(0.000)***	363.82(0.000)***
Joint chi-square test for household level variables					30.31(0.000)***
Constant	6.381(0.050)***	6.011(0.166)***	5.905(0.187)***	3.748(0.188)***	4.633(0.394)***
Observations	1095	1095	1095	1095	1095
Model test	Wald chi2(4)= 8.90(0.064)*	Wald chi2(13)= 150.71(0.000)***	Wald chi2(19)= 316.12(0.000)***	Wald chi2(25) = 991.20(0.000)***	Wald chi2(31) = 1171.96 (0.000)***
Robust standard errors adjusted for clustering effects in parentheses					
* significant at 10%; ** significant at 5%; *** significant at 1%					

Note: (A) plot quality indicator, crop dummy and inputs variables are the same as those listed under Table 4, (B) Household level variables include: ln (household age in years), extension visit, ln(oxen power supply per ha), ln (other livestock in TLU per ha), off farm income & ln(family size per ha).

Table 9. Random effects estimates of the determinants of fertilizer use per ha (share tenants' own plots compared with others own plots)

Explanatory variables	Without plot quality	With plot quality	With plot quality & crop types	With plot quality, crop types & household level variables
owner operator plots	0.026(0.101)	0.023(0.099)	0.017(0.099)	-0.004(0.092)
cost share tenants' owned plots	0.077(0.105)	0.091(0.105)	0.068(0.104)	0.062(0.096)
fixed rental tenants owned plots	0.160(0.109)	0.169(0.112)	0.162(0.111)	0.121(0.107)
landlords owned plots	-0.193(0.117)*	-0.156(0.129)	-0.162(0.135)	-0.188(0.149)
Joint chi-square test for plot quality indicator variables [a]		15.39(0.081)*	12.77(0.173)	8.53(0.202)
Joint chi-square test for crop dummy variables [a]			8.57(0.199)	9.92(0.357)
Joint chi-square test for household level variables [a]				16.75(0.010)**
Constant	5.035(0.078)***	4.822(0.354)***	4.515(0.388)***	4.620(0.662)***
Observations	513	513	513	513
Model test	Wald chi2(4) = 10.17(0.034)**	Wald chi2(13) = 28.61(0.007)***	Wald chi2(19) = 44.37 (0.001)***	Wald chi2(25) = 59.07(0.000)***
Robust standard errors adjusted for clustering effects in parentheses				
* significant at 10%; ** significant at 5%; *** significant at 1%				

[a] These variables are the same as those listed under Table 8.

Table 10. Random effects estimates of the determinants of labour, seed and oxen use per ha (share tenants' own plots compared with others own plots)

Explanatory variables	Without plot quality			With plot quality		
	Man days per ha	Seed value per ha	Oxen days per ha	Man days per ha	Seed value per ha	Oxen days per ha
owner operator plots	-0.030(0.061)	-0.057(0.104)	-0.044(0.066)	-0.042(0.062)	-0.056(0.104)	-0.050(0.066)
cost share tenants' owned plots	-0.017(0.073)	0.187(0.100)*	0.020(0.074)	-0.021(0.077)	0.184(0.099)*	0.012(0.075)
fixed rental tenants owned plots	0.095(0.085)	0.201(0.118)*	0.091(0.098)	0.101(0.087)	0.214(0.115)*	0.097(0.099)
landlords owned plots	0.001(0.107)	-0.284(0.119)**	0.061(0.139)	0.020(0.115)	-0.266(0.121)**	0.065(0.148)
Joint chi-square test for plot quality indicator variables				109.41(0.000)***	36.14(0.000)***	38.36(0.000)***
Joint chi-square test for crop dummy variables						
Constant	3.990(0.044)***	4.273(0.065)***	2.619(0.055)***	3.908(0.148)***	3.874(0.282)***	2.862(0.153)***
Observations	1095	1095	1095	1095	1095	1095
Model test	Wald chi2(4)= 2.27 (0.686)	Wald chi2(4)= 18.61 (0.001)***	Wald chi2(4)= 3.10(0.541)***	Wald chi2(13) = 112.42 (0.000)***	Wald chi2(13) = 54.91(0.000)***	Wald chi2(13)= 40.10(0.000)***
Robust standard errors adjusted for clustering effects in parentheses						
* significant at 10%; ** significant at 5%; *** significant at 1%						

Table 10 (cont'd)

Explanatory variables	With plot quality & crop types			With plot quality, crop types & household level variables		
	Man days per ha	Seed value per ha	Oxen days per ha	Man days per ha	Seed value per ha	Oxen days per ha
owner operator plots	-0.021(0.057)	-0.044(0.089)	-0.030(0.060)	-0.044(0.060)	-0.052(0.083)	-0.051(0.061)
cost share tenants' owned plots	0.032(0.070)	0.092(0.098)	0.042(0.073)	0.024(0.067)	0.092(0.095)	0.041(0.071)
fixed rental tenants owned plots	0.125(0.075)*	0.231(0.105)**	0.110(0.090)	0.097(0.075)	0.136(0.113)	0.105(0.092)
landlords owned plots	-0.001(0.107)	-0.134(0.096)	0.061(0.138)	-0.023(0.105)	-0.136(0.103)	0.030(0.135)
Joint test for plot quality indicator variables [a]	65.03(0.000)***	86.66(0.000)***	22.99(0.000)***	61.65(0.000)***	84.21(0.000)***	22.93(0.006)***
Joint test for crop dummy variables [a]	548.05(0.000)***	537.25(0.000)***	340.38(0.000)***	548.85(0.000)***	544.16(0.000)***	337.84(0.000)***
Joint chi-square test for household level variables [a]				8.67(0.193)	19.84(0.003)***	3.75(0.711)
Constant	4.066(0.141)***	2.884(0.270)***	2.836(0.148)***	4.040(0.363)***	2.917(0.496)***	2.725(0.422)***
Observations	1095	1095	1095	1095	1095	1095
Model test	Wald chi2(19) = 682.93(0.000)***	Wald chi2(19)= 680.61(0.000)***	Wald chi2(19)= 447.03(0.000)***	Wald chi2(25)= 713.05(0.000)***	Wald chi2(25)= 713.52(0.000)***	Wald chi2(25)= 460.63 (0.000)***
Robust standard errors adjusted for clustering effects in parentheses						
* significant at 10%; ** significant at 5%; *** significant at 1%						

[a] These variables are the same as those listed under Table 8.

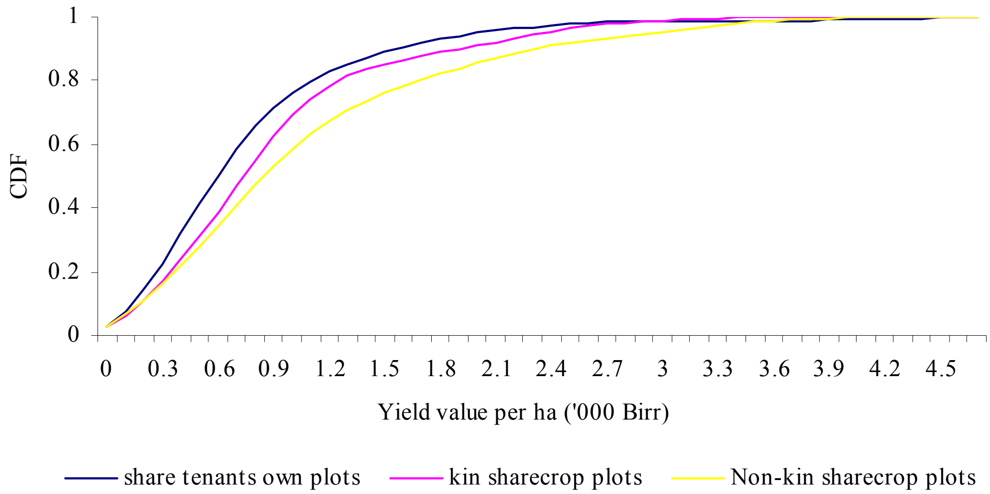
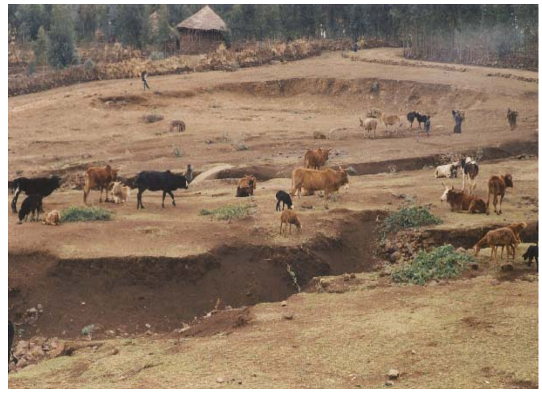


Figure 1: CDF for impact of share tenancy on yield: First order stochastic dominance analysis

Unbalanced grazing system



Grazing on bare land!!(Dry Season)

Dung cakes for fuel and Straw for livestock

III

Improved forage production

Improved livestock and forage

The Economic Potential of Forage Legumes Adoption in the Ethiopian Highlands

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Abstract

Fodder and land degradation are major constraints in the Ethiopian highlands. These constraints are contributing to low and declining agricultural productivity, poverty and food insecurity. Forage legumes can offer a ray of hope for small-scale resource poor because they can provide high quality and quantity of feed, soil nitrogen, extra income to farmers and reduce soil erosion when they are intercropped with cereals. Despite these benefits, few empirical evidences exist to show the effects of intercropping forage legumes with cereals on agricultural productivity and soil conservation. This study assesses the impact of forage legumes-cereals intercropping on household income and soil conservation using a bio-economic linear programming model combining household survey and experimental data from North-Western Ethiopian highlands. The results indicated that introducing legumes in cereal based cropping system increased household income and resource productivity. The farm income was further increased when forage legumes combined with crossbred cows for milk production. The results also indicated that forage legumes-cereals intercropping reduced soil erosion and pressure on grazing lands as source of livestock feed. Overall, results imply that development interventions that consider forage legumes will achieve a double advantage of enhancing the livelihood of rural households while checking land degradation.

Key words: forage legumes; intercropping; income, soil conservation; bio-economic modelling; Ethiopia

1. Introduction

Legumes are known to perform multiple functions. Grain legumes provide food and feed and facilitate soil nutrient management. Herbaceous and tree legumes can restore soil fertility and prevent land degradation while improving crop and livestock productivity on a more sustainable basis. Experimental researches throughout the developing world have shown the benefits of different kinds of legumes (Nnadi and Haque, 1986; 1988; Tarawali, 1991; Khalili et al., 1992, 1994; McIntire et al., 1992; Gutteridge and Shelton, 1994; Humpherys, 1994; D'Mello and Devendra, 1995; Umunna et al., 1995; Griller, 2001; Peters et al., 2001; Mpairwe et al., 2002, 2003). However, adoption of legumes, especially for feed and soil management is very poor in developing countries (Gryseels and Anderson, 1983; Saka et al., 1993/1994; Thomas and Sumberg, 1995; Zewdu et al., 2000; Ahmed et al., 2003; Seyoum Mezgeb, 2004, personal communication[31]). First and foremost, a legume technology needs to fit the existing farming systems and be economic to be adopted. The economic benefits may come from one or more functions, some major and some minor, but in such cases all perceptible potential benefits need to be assessed to judge the adoption potential of the technology. Research to date has more focused on biophysical aspects of legume technologies with little emphasis given to socio-economic and environmental studies relating to the adoption of these technologies.

In this study, the potential economic gains from adoption of forage legumes (here after legumes), especially legumes-cereals intercropping, in the mixed farming systems of Northern-Western (here after NW) Ethiopian highlands will be examined. The main purpose is to assess the role of legumes for household income and soil conservation benefits. Intercropping of annual forage legumes with cereals is the focus of this paper.

Fodder degradation (low quantity and quality of feed resources) and land degradation (soil erosion and low soil fertility) are major constraints to improving the productivity of livestock and crops in the Ethiopian highlands (Kruseman et al., 2002; Tangka et al., 2002). Soils are eroding and soil nutrient stocks are being depleted because of low use of chemical fertilizer, expanding cultivation onto marginal lands, alternative uses of dung and crop residues as household fuels and animal feeds, insufficient investment in soil and water conservation measures and absence or declining of fallow periods (Lakew, et al., 2000; Pender, 2000). A decrease in grazing land due to expansion of cropland, scarcity of feed during the dry season, high price and lack of feed concentrates and the generally low quality of available pasture and crop residues are mentioned

[31] Team leader for livestock and forage production development section, Bureau of Agriculture, Bahir Dar, Ethiopia.

as the causes of feed shortage in Ethiopia (Lakew et al., 2000; Ahmed et al., 2003). These problems are contributing to income and food insecurity in the country.

The adoption of improved farming systems such as dual-purpose legumes that enhance agricultural productivity while conserving the natural resource base may be instrumental for achieving income, food security and to reverse land degradation. Integration of legumes into cereal-based systems can provide services such as prevention of soil erosion when they are intercropped with cereals, restoration of soil fertility, soil organic matter and high quantity and quality fodder. Enhanced availability of livestock feed can reduce degradation of grazing lands. Legumes-cereals intercropping are environmentally friendly and scale neutral technology as all farmers (poor & rich in terms of resources) can easily adopt them. The only external resource required for legume-cereal intercropping is legume seeds that can be accessed from district Agricultural Offices or development agents.

The paper is organized as follows. The next section discusses the benefits of legumes, followed by the theoretical framework section. Methodology follows the theoretical framework section. The results and discussion are presented in section 5 and the last section concludes.

The contribution of the paper is of three major points. First, to our knowledge, it is the first empirical paper to assess the link between annual legumes-cereals intercropping and soil conservation benefits while examining the economics of legumes. Second, we accounted for the impact of legumes-cereals intercropping on soil fertility and thereby on household income by estimating the marginal value of soil fertility due to nitrogen fixation by legumes. Third, as there exists limited study in this area, the results of this paper will inform development practitioners, researchers and policy makers the role of forage legumes to combat poverty and land degradations.

3. Benefits of Forage Legumes: crop and livestock productivity and soil conservation

The available literature on legumes has focused more on their biophysical performance with limited emphasis on their profitability. This section presents some of the literature available on these technologies in Ethiopia and elsewhere (see fig 1 for summary of the benefits of legumes).

The increase in crop yields that are widely observed following legumes may arise from breaking cycles of pests and diseases, through improved soil structure or through increase of organic matter (Fujita et al., 1992). But most often residual benefits can be attributed to an improvement in the Nitrogen (N) economy of soils (Wani et al., 1995). Nitrogen present in root systems of various legumes have ranged from less than 15 kg N /ha (Bergeersen et al., 1989) to between 30 and 50 kg N /ha (Unkovich et al., 1994). Research results in Nigeria showed that the N contribution of legumes to subsequent crops varies from 30-80 kg N /ha (Tarawali, 1991). Results in Ethiopia showed that vetch, lablab and clovers are capable of leaving 30-60 kg N /ha through their root systems when they are intercropped with cereal crops (Nnadi and Haque, 1986; 1988). This is relatively high amount compared to projected N losses of 47 Kg/ha (Stoorvogel et al., 1993) and farmers' nutrient application rates, 15.8 kg of nutrients per ha on cultivated land (World Bank, 2000). In the North-Western India, Singh (1983) estimated N benefits to wheat derived from various legume intercrops. Legumes intercrop such as groundnuts, cowpeas (both for fodder and grain production) and green gram with sorghum reduced the need for fertilizer nitrogen on wheat field in the succeeding season by 30-84 kg/ha. The maximum increase in yield of wheat (4.69 ton/ha) was obtained when cowpea for fodder production is intercropped with sorghum compared to wheat yield after sole sorghum (3.17 ton/ha). The yield of wheat when cowpea for grain production is intercropped with sorghum was 4.49 ton/ha. Patil and Pal (1988) have reported that 80 kg N /ha was saved for the succeeding bread wheat by the preceding intercrop of pear millet with black gram or cowpea. In Ethiopia, experimental results on the lagged effects of legume crops on grain yield of maize showed that the yield of maize was greater after vetch (3.27 ton/ha) than growing maize after oat (1.57 ton/ha). Similar results showed that the yield of wheat was 2.6 ton/ha after vetch and clover and 1.8 and 2.1 ton/ha after oat and unplanted fallow, respectively (Nnadi and Haque, 1988). Research results in Ethiopia indicated that there were no statistically significant cereal grain yield differences when cereals are grown alone and intercropped with legumes (Abate et al., 1992; Zewdu, et al., 2000). For instance, average grain yield of 4912 and 1793 kg per hectare of maize-vetch and barley-clover, respectively reported in the NW Ethiopian highlands compared to 5000 and 1653 kg per hectare of sole maize and barley, respectively (Zewdu et al., 2000).

Legumes have been shown to improve both the quantity and quality of fodder, which sustain feed production during the dry season and increase livestock productivity. Average fodder yields of 14.2 and 3.4 tons per hectare of maize-vetch and barley-clover, respectively reported compared to 9.3 and 2.3 tons per hectare of sole maize and barley, respectively (Zewdu et al., 2000). The average crude protein content of crop residues is about 3.8% of dry matter whereas legumes crude protein content on average various between 14-24% of dry matter (Annido et al., 1994; D'Mello and Devendra, 1995; Mpairwe et al., 2003).

In Ethiopia, Crossbred cows given oats-vetch diet produced on average 1.40kg/day more milk than those given hay diet (5.54 vs. 4.14 kg milk/day (Khalili et al., 1992). The addition of 20-25% of *Trifolium tembense* hay to *teff* straw increased feed intake of sheep by 20-30% in Ethiopia (Butterworth and Mois, 1985). Culled oxen supplemented with *Trifolium tembense* hay gained 362 g/day more than twice as much as culled oxen fed poor quality grass alone, 163 g/day (Nnadi and Haque, 1988). Legumes mixed with crop residues also increased other livestock production parameters (Table 1).

Soil conservation is an important benefit of intercropping. Studies on the impact of legume-cereal intercrop on soil erosion control are very scarce. Intercropping vetch with maize in central Kenya reduced cumulative soil loss over an eight-month period by three fold compared to bare plots which had 7.1 ton per ha cumulative loss (Gachene and Haru, 1997). In Nigeria, experimental results conducted at 5% slope showed that soil loss declined from 87 ton/ha/year to 50 ton/ha/year when cassava is grown alone and intercropped with maize, respectively (Lal, 1984).

The literatures on economics of legumes are limited. In Africa research on economics of legumes focused on comparison of fallows with alley cropping, growing of leguminous trees with annual crops, to improve livestock production and soil fertility. In Nigeria results indicated that alley cropping was more profitable than fallow systems (Ngambeki, 1985; Ehui et al., 1990; Jabbar et al., 1994). They used capital budgeting approach where it does not fully capture the interaction between alley cropping and livestock production. The study by Ehui et al. (1990) did not take into account the nitrogen fixing capabilities of leguminous trees, but they considered soil conservation effects of alley cropping. On the other hand, Ngambeki (1985) and Jabbar et al.

(1994) were considered soil fertility impact of leguminous trees, but they did not consider soil erosion impact of alley cropping. Economic analysis on growing of annual legumes with food crops in South-Eastern Ethiopia showed that growing legumes with food crops was more profitable than growing food crops alone (Kassie et al., 1998). This study, however, did not account for the link between annual legumes-cereals intercropping and soil conservation benefits. It also lacks estimation on the marginal value of soil fertility due to nitrogen fixation by legumes.

3. Theoretical framework

Households in the study area both produce and consume their agricultural products. Our conceptual approach is based on the theory of the farm household model (Singh et al., 1986). The household utility maximization function consists of three basic components: income, leisure and basic food requirements. Normally, leisure and income decisions are non-separable. Sampled households in the study area belong to the Orthodox Church where they are strictly respecting religious holidays. Work on the farm on religious holidays is not allowed[32]. These holidays must be subtracted to get actual number of available working days for farm work. Any day that is not a religious holiday is used for farm work. Leisure is then a part of the church holidays and can be assumed fixed and separable from income in the utility function.

Households' in the rural area rely more on their own production for food supplies than on external resources (e.g. market). We assumed pre-determined minimum food requirements based on an adult equivalent basis and then are treated as scalars and separable from income. Holding religious holidays constant and assuming pre-determined minimum food requirements leave the income as the only argument in the utility function.

Based on this assumption, we develop the following model that captures the role of legumes in improving livestock and crop productivity through better feed and soil fertility management based on the work of Babu et al. (1995). We extend their model by including livestock production activities and soil depletion rate. The farmer is assumed to grow crop and have

[32] Holidays divided into two: strict church holidays and less strict church holidays. During strict holidays farmers are not allowed to do any kind of work. On the other hand, during less strict holidays farmers are allowed to do other activities such as preparing farm equipments, splitting fuel-wood and off-farm activity, but farming activities are not allowed.

constant herd structure through out his planning horizon of t seasons. Let the crop yield is given by $Q_{1t} = q_1(f_t, s_t, z_t, x_t)$, where Q_{1t} is the yield of crop in season t, f_t is a vector of inputs for instance farm yard manure, mulch and green manure (f_1), and chemical fertilizer (f_2), s_t is soil depletion rate, z_t is other conventional inputs other than f_t and x_t is a vector of soil fertility. Soil fertility could be described in a number of ways: soil depth, soil moisture, humus content, soil nutrients (soil nitrogen, soil phosphorus, and soil potassium) or a combination or index of relevant soil characteristics. For simplicity, the soil fertility level is represented by a single variable x_t. The legumes output is given by $Q_{2t} = q_2(f_t, s_t, z_t, x_t)$, where Q_{2t} is the legume output in season t. The legume output includes nitrogen fixed by legumes and fodder, which may be used as feed for livestock and/or as mulch and green manure for soil fertility management. These outputs will be used in season $t+1$ to crop and livestock production. The livestock production function is also given by $Q_{3t} = q_3(h_t)$, where Q_{3t} is the yield of livestock in season t and h_t is a vector of inputs. Assuming constant prices of inputs and outputs, the gross farm income from farming can be written as:

(1) $\pi_t = P_1Q_1 - K_1 f_t - K_2 z_t + P_2Q_2 + P_3Q_3 - K_3 h_t$,

where K is the price of inputs and P is the price of outputs.

The growth of soil fertility in any season is represented by a growth function of:

(2) $\dot{x}_t = \psi_t(x_t, f_t) - s_t$

Assuming that the farmer maximize the present value of the future stream of gross farm income over time, the problem of optimal input choice can be written as:

(3) $Max\pi = \int_{t=0}^{T} e^{-\rho t}\left[P_1q_1(x, f, s, z) - K_1 f_t - K_2 z_t + P_2 q_2(x, u, s, z) + P_3 q_3(h) - K_3 h\right]dt$,

where ρ denotes discount rate. Under the existing land tenure system in the region farmers have the right to transfer land to their family. A terminal value for soil fertility level (land) is not included in this model. Then, the farmer will maximize π subject to (2) and initial stock of soil fertility indicators:

(4) $x(0) = x_0$, and $\mathrm{x}_t, f_t, s_t \geq 0$.

The Hamiltonian for the problem is given as:

(5) $H(x, f, s, z, h, \lambda) = e^{-\rho t}\left[P_1Q_1 - K_1 f_t - K_2 Z_t + P_2Q_2 + P_3Q_3 - K_3 h_t\right] + \lambda \left[\psi(x, f) - s\right]$,

where λ is the co-state variable and represents the marginal value of soil nutrients (marginal user cost of soil depletion) at any time t. The first order conditions include:

(6) $\partial H/\partial f_2 = e^{-\rho t}\left[P_1 Q_{1f_2} - K_1 + P_2 Q_{2f_2}\right] + \lambda\psi_{f_2} = 0$

(7) $\partial H/\partial X = -\dot{\lambda} = e^{-\rho t}\left[P_1 Q_{1x} + P_2 Q_{2x}\right] + \lambda\psi_x = 0$

(8) $\partial H/\partial S = e^{-\rho t}\left[P_1 Q_{1s} + P_2 Q_{2s}\right] - \lambda = 0$

(9) $\partial H/\partial\lambda = \psi(x, f) - s$.

The first order conditions for the variable f_1 and h can also be derived similarly. $P_1 Q_{1f_2} + P_2 Q_{2f_2}$ is the marginal value product of crop output and legume output due to an additional increase in the use of chemical fertilizer. In the absence of legume we will end up only with the marginal value product of crop output $(P_1 Q_{1f_2})$.

Equation (6) requires that the optimal level of any soil fertility input should be chosen such that the discounted marginal benefits from its use $e^{-\rho t}\left[P_1 Q_{1f_2} + P_2 Q_{2f_2}\right]$ and the marginal effect of these inputs on the growth of soil fertility (nutrients), $\lambda\psi_{f_2}$, should be equal to the discunted marginal cost of using it $e^{-\rho t}K_1$. Equation (7) states that the rate at which the marginal value of soil fertility changes $(\dot{\lambda})$ is equal to the discounted marginal value product of soil fertility $(P_1 Q_{1x} + P_2 Q_{2x})$ plus its contribution to the improvement of soil fertility $(\lambda\psi_x)$ at any season t. Equation (8) requires the discounted marginal benefits of soil depletion $e^{-\rho^t}(P_1 Q_{1s} + P_2 Q_{2s})$ to equal the marginal value (user cost) of soil fertility level at each point in time, λ. The change in the value of Hamiltonian function due to change in the marginal value of soil fertility by the equation of motion of stock of soil fertility is given by equation (9).

As mentioned above, the legumes output (Q_{2t}) is an intermediate product that could form an input in livestock and crop production activities in season $t+1$. Q_{2t} in season t, will then become f_3 in season $t+1$ and P_2 will become K_3, the implicit cost of using fodder and green manure (if any).

Then, the following additional first order conditions for f_3 which is explicitly used for crop and livestock production will follow:

(10) $\partial H \big/ \partial f_3 = e^{-\rho t}\left[P_1 Q_{1f_3} - K_3 + P_3 Q_{3f_3}\right] + \lambda \psi_{f_3} = 0$

Equation (10) captures the soil fertility and livestock productivity benefits of legumes. If legumes are grown in association with food crops in subsequent season, additional term $(P_2 Q_{2f_3})$ in (10) is needed. This part is missed in Babu et al. (1995) model formulation. This equation indicates that in any season $t+1$, the level of use of legumes output (nitrogen, fodder, mulch, green manure) should be chosen such that the discounted marginal benefits of each input $e^{-\rho t}(P_1 Q_1 f_3 + P_3 Q_{3f_3})$ plus the cumulative value of soil fertility to the farmer $\lambda \psi_{f_3}$ (the value of soil nutrients added to the soil from legume nitrogen fixation and fodder returned to the soil) must be equal to the discounted marginal cost of using it $(e^{-\rho t} K_3)$.

To sum up, the value added by the legumes to the farming systems can be incorporated in the empirical model in different ways. First, the productivity of livestock is increased in the next season $(P_3 Q_{3f_3})$ due to higher quality and quantity of feed available from legumes. Second, the opportunity cost of soil fertility inputs is increased in the next season (λ_{t+1}) due to addition of nitrogen fixed by legumes. This may lift up crop yield by λ_{t+1} in season $t+1$ keeping other things constant. Third, legumes-cereals intercropping may also reduce the level of soil fertility depletion by reducing the soil erosion level due to higher ground cover, which may result in an increase in household income in season $t+1$. Fourth, the presence of legumes component may enable farmers to reduce the level of chemical fertilizer (f_2) use in season $t+1$ and thereby reduce the cost of soil fertility management. In the empirical model, we considered the first, second and third options. The impact of legumes-cereals intercropping on soil erosion and fertility are estimated as follows.

The effect of soil erosion on *teff* yield is estimated based on time series data collected by Soil Conservation Research Project (SCRP) in the highlands of NW Ethiopia (see Appendix, Table

A)[33]. The project is located in the same place (West Gojjam) as in the study area. We used soil depth as a proxy for soil quality (productivity)[34]. A loss of 1 cm of soil depth per ha was estimated to reduce yields by 17.2 kg[35]. A loss of 1 cm of soil depth is approximately equivalent to 100-ton/ha soil losses (Shiferaw and Holden, 1999). The marginal value product of soil depth is the marginal user cost of soil, the discounted value of future productivity losses resulting from a unit of soil erosion. The total user cost of soil erosion is thus the marginal user cost of soil times the level of soil erosion. A discount rate of 12 percent used, which is the current interest rate of short-term inputs (e.g. fertilizer and seed) in the study area.

We assumed that nitrogen added through legume is available for next crop season although there could also be nitrogen transfer to cereals during the current season. The effect of nitrogen fixed by legumes (organic nitrogen) on yield of the subsequent crops is estimated from barley and maize responses to inorganic nitrogen fertilizer. The barley fertilizer response function (equation 1) was based on the estimates of Ho (1992), and we estimated the maize fertilizer response function (equation 2) using three years on-farm fertilizer trials conducted by AARC (see Appendix)[36]. A one kg increase in nitrogen fertilizer was estimated to increase barley (local variety) and maize (improved variety) yield by 6.2 and 29 kg, respectively. The marginal value product of nitrogen fertilizer is the marginal benefit of soil fertility, the discounted value of future productivity gains resulting from an additional unit of soil fertility. The total benefit of soil fertility (nutrients) is thus the marginal benefit of soil fertility times the level of nitrogen fixed by legumes in season t. The discounted marginal user cost and marginal soil fertility benefits are thus entered on the soil erosion and organic nitrogen production activities of the objective function, respectively.

[33] The experiments do not cover all crops. It focused only on *teff*, barley and faba bean crops.
[34] We assumed current soil depth is an indicator of past erosion and used as a proxy indicator for soil quality (productivity).
[35] It can be easily derived from Table A at the mean value of each variable except the trend variable. The elasticity is calculated year by year and we took the average. After the elasticity, marginal value of soil depth is calculated by multiplying the marginal product of soil depth by *teff* output price to obtain the marginal monetary loss due to soil erosion.
[36] Inorganic fertilizer may not correctly approximate the productivity effect of organic fertilizer but may serve as rough approximation.

4. Methodology

4.1. Empirical model

When new and potential technologies have to be included, households have multiple goals, activities, and constraints to maximize their welfare, and where a single cropping year cross section data does not permit econometric estimation, mathematical programming approaches are generally used (Ruben and Van Ruijven, 2001). It is not uncommon to use linear programming technique at farm household level to analyse the adoption impact of technology on household income and environmental concerns (Ramaswamy and Sanders, 1992; Deleforce, 1994; Dalton, 1996; Kassie et al., 1998; Shiferaw and Holden, 1999; Kruseman and Bade, 1998; Barbier and Bergeron, 1999). A bio-economic linear programming (LP) model is used in our analysis that integrates biophysical (soil erosion and organic nitrogen) and socio-economic data for simulating micro-level responses to technology changes.

4.2. Data sources

Data to generate coefficients for the model were collected both from primary and secondary sources. A survey of 87 farmers by Adet Agricultural research centre (AARC) in the Bahir Dar Zuria *woreda* (district), West Gojjam zone of NW Ethiopian highlands yielded information on livestock holding, own farm size, rented in and out land, private grazing land, crop production, crop area, feed sources, family labour, family size and milk production. The survey also provided other important information used in paper four of this thesis.

Framers grow a combination of crops including maize, finger millet, *teff*, barley, rough pea and niger seed. They have one rainy season and the average annual rainfall they get is 1000 mm (Woreda Agricultural office, 2002). On average a farmer has about 1.61 and 0.55 hectares of cropland and private grazing land, respectively. The cropland is dominated by *Nitosols* (90%) followed by *vertisols* (10%) (Woreda Agricultural Office, 2002). Farmers also rear different types of livestock to support crop production and provide animal products for home consumption. The mixed farmer has on average three local cows, two work-oxen, one equine, one sheep and one goat.

Coefficients for legumes-cereals intercropping activities were obtained form on-farm and on-station experiments carried out by AARC (Zewdu et al., 2000). The experiments include two years cereals grain and fodder production with and without intercropping legumes. The intercropping activities include maize-vetch (on-station) and barley-clover (on-farm). About 36.8 percent of the sampled households practiced maize-vetch intercropping, but farmers never practiced barley-clover intercropping[37].

Data also were collected by the first author of this paper on household's major expenditures, labour and draft power use for each crop, cropping pattern, average number of days used for off-farm activities, available farm working days per month. Other data including rainfall, total communal grazing area and human population of the study areas, plot slope and length, soil depth, sole crop yield with and without fertilizer, fertilizer and seed rates, price data for crop output, crop residues, dung cakes and, livestock and livestock products were also collected from the district Agricultural Office.

The nutrient content of each feed type, milk, manure production, calving rate with and without improved forage fodders, economic life span of livestock, mortality rates of livestock and data on labour requirements for livestock keeping were constructed from data obtained from Adet Agricultural research centre survey, GOE (1986), Abate et al. (1992), Nordblom et al. (1992); Panin and Brokken, (1993), Annido et al. (1994), Omiti, (1995), Buta and Kassa, (1998), Betew and Addis, (2003) and Mpairwe et al. (2003).

Soil loss coefficient for the cropping activities were calculated using Universal Soil Loss Equation (USLE) modified for the Ethiopian condition (Hurni, 1987).

4.2. Model Objective function

The LP model maximizes current gross farm income from crop and livestock production plus the present value of future income gain due to yield increase as a result of enhanced soil fertility less the present value of future income loss caused by yield losses resulting from soil erosion subject

[37] Maize is an improved variety and barley is local variety. The Adet Agricultural research centre survey did not include crop residues data.

to various constraints (see equations 1 in the appendix). The mathematical formulation of each activity and constraints is shown in the Appendix. An aggregated tableau for the model is also shown in Table B. The entries in Table B are model coefficients; coefficients labelled $'A'$ are generally non-unitary. A positive coefficient indicates activity demand for a resource while a negative coefficient represents activity supply for a resource. The model is constructed for the representative household.

4.3. Description of activities

The activities include cropping, livestock, feed supply, selling, purchasing, borrowing, land rental and consumption activities. The major activities used in the model are presented below.

4.3.1. Crop and fodder production activities

The crop activities in the model include: crop production with and without fertilizer, and with and without intercropping. Crop yield is specified net of seed requirements except the improved maize variety. Farmers keep their own seed of local varieties from previous production for the following season. Lack of information (asymmetric information) on the quality of purchased seed of local varieties may be the reason for farmers' dependence on own produced seeds. They know best about the quality of their own seeds, which they have screened from the total production. Farmers' buy improved maize seed from the nearby service cooperatives on a loan. The crop activities incur variable costs in the objective function. These variable costs include the cost for improved maize and forage seeds, and fertilizer cost for the production of one unit (hectare). The following crop activities are included in the model: maize-vetch intercrop, barley-clover intercrop, sole maize, sole barley, finger millet, *teff,* rough pea and niger seed. On-farm and on-station experimental data managed by researchers adjusted downward respectively by 10% and 20% in order to account for the difference between extra care taken by researchers on small experimental plots and the real farm condition (Ndengu, 1993; Regassa, 1990).

4.3.2. Livestock production activities

Two approaches, stationary equilibrium and multi-period linear programming model of investments, are used to model investment decisions in linear programming models (Hazell and Norton, 1986). We assume a steady-state (stationary equilibrium) livestock investment where the replacement and culled rates are equal each year. Assuming a steady-state herd structure, the necessity of local breed livestock purchases is avoided. The representative household keeps three local cows, two work-oxen, one equine, one sheep and one goat. Draft power, fuel dung, milk, butter, replacement, and culling herd are the main outputs from livestock activities. Milk except for household consumption is processed to butter since it may be difficult to sell milk every day. High-yielding livestock (crossbred cows) are also introduced into the model. The district Agricultural Offices have been distributing six months pregnant crossbred heifer to farmers on a loan of Birr 1200 at interest rate of 10% per annum. Ten years breeding life of local cow and oxen (Gryseels, 1988); 5 years breeding life of sheep and goat; 20 and 10% mortality rate for calves, and lambs and kids, respectively and 8 years for crossbred cow are considered (Nordblom et al., 1992; Panin and Brokken, 1993). We assumed no herd change in short run due to legumes.

4.3.3. Sales and purchases activities

Surplus grain, straw, butter, manure, culled and surplus animals after replacement are transferred to selling activities. Any deficit feed will be met by purchase. There is market for crop residues as people living around and in Bahir Dar town demand for fodder for their livestock. Market for improved forage is not common, but we assumed the same price as crop residues (Birr 0.2 per kg). We also assumed that farmers will sale poor quality fodder and keep quality higher fodder for own livestock consumption.

4.3.4. Consumption activities

Households seek to maximize farm income but must generate family food requirements from on-farm production. The crop and livestock product markets are functioning well compared to other markets. However, cultural (habitual) and social issues force households to grow and store their own production for consumption purpose. When subsistence constraints are met, households often generate income by selling the available surplus. Thus, consumption is included as a separate activity.

4.4. Description of constraints

The model include constraints on land owned and rented, communal and private grazing land, household labour, draft power, credit, crop and livestock product balance, soil erosion, household and livestock consumption requirements.

4.4.1. Land constraints

Four land types included: own cropland, rented-in land, private grazing land and communal grazing land. A representative household on average cultivated 1.61 and 0.57 ha owned and rented-in land, respectively (see equation 2 & 3). The private grazing land holding is 0.55 ha. We assumed that the household would have access to an equivalent amount of 0.53 ha of communal grazing land (Wereda Agricultural Office, 2002) and dry matter grass production of 4500 kg per hectare (Panin and Brokken, 1993; Mengistu, 1987). However, this figure is adjusted downward by 50% to take into account the effect of trampling, fire, cattle selectivity, overstocking and wildlife (Houerou and Hoste, 1977). Data on productivity of private grazing land is not available, but we assumed the same productivity as communal grazing land (4500 kg per ha) without adjusting it downward.

4.4.2. Labour constraints

Framers have very limited access to labour markets although they are located closed to Bahir Dar town. There are continuous flows of many labourers from rural areas to this town. There is no labour market within the villages. The family labour is the major source of workforce for farming. Labour exchanges among neighbouring households and relatives are common during harvesting and threshing.

The additional labour requirements due to legumes are taken into account. Legumes increase the labour requirements for sowing, harvesting and transporting the fodder to homestead area. Food crops are sown first and legumes later, for instance when maize reaches at knee height. But legumes are harvested first at 10-50% flowering stage and food crops at a later stage (Zewdu et al., 2000). This doubles the harvesting labour requirements for maize and barley crops. The amount of labour for each crop activity was determined by splitting the cropping year into six periods of two months (March-April, May-June, etc.), each starting from cultivation to threshing and transporting outputs (See equation 4). All the days that farmers did not work due to religious holidays were calculated and subtracted from labour hours available in each period. There was no need to consider hours spent in off-farm activities as a survey carried out by the first author of the paper on these activities found to be insignificant. Farmers often use non-strict church holidays for off-farm activities (if any). On average a household works seven hours per day.

4.4.3. Draft power constraints

Oxen rental market is inexistent but it is common to exchange among households with one ox each. There is also exchange of oxen for labour. Cultural barriers and fear of mismanagement of oxen by renters may have attributed to the inexistence of oxen rental contracts. In order to estimate oxen pair hours, a procedure similar to the one used for human labour hours calculations was used. Working days in each month were determined which were then converted into working hours. We considered three periods (March-April, May-June and July-August) of ploughing for draft power (see equation 5).

4.4.4. Livestock feed demand per annum

Feed sources include private and communal pasturelands, aftermath grazing, weeds and crop residues. In the case of legume-cereal intercropping, additional feed was available from legumes. It is assumed that the feed from aftermath grazing and weeds covered 25% of the total feed requirement of the livestock in terms of dry matter (Kassie and Holden, 2005). Households were also observed purchasing *Noug* cake, by-product of edible oil from niger seed, to supplement the protein deficiency of crop residues. On average they purchased 77 kg. The availability of oil seed cake is limited and expensive as well (Birr 2.26 per kg). Livestock feed requirements are for crude protein (CP), metabolizable energy (ME) and dry matter (DM) intake. These feed demands are calculated as a function of total number of livestock, their classes, functions (maintenance, pregnancy, milk production and draft power) and weight (Kearl, 1982; MAFF, 1984; Nordblom et al., 1992; Nicholson et al., 1994; Mpairwe et al., 2003). Equation 6 in the appendix indicates animal feed constraints.

3.4.5. Minimum consumption constraints

Based on the work of Gryseels and Anderson (1983) 200 kg of cereals, 50 kg of pulses and 30 kg of milk are assumed as average annual subsistence requirements per adult equivalent (see equation 7). It is assumed that families consumed the produced crops to meet their subsistence requirements in the same ratio as the average cropping pattern and amount of production. Fuel dung cakes consumption is based on our survey data used in paper one and two. A household uses 350 kg dried dug cakes per year. Other sources of fuel, crop residues and wood are not included in the model as we lack data on these sources. The household has 5.36 adult equivalent. We assumed that in the short run the consumption pattern of the household would not change due to legumes.

4.4.6. Crop balance (grain, fodder and nitrogen)

These constraints are included in order to ensure that grain and nitrogen yield form crop production will be transferred to the subsistence balance and selling equations. In addition, straw and pasture yields from crop and pasture production is transferred to the livestock production, selling and purchasing equations (see equation 8). The average grain and straw yields are shown in Table 2. The straw yields for sole cropping activities are based on grain-straw conversion factors (Adugna and Said, 1991; Mengistu, 1994).

In addition to grain and fodder production in the intercropping activity, legumes fix nitrogen in their root systems. From various experiments in the Ethiopian highlands, legumes (lablab, clover, and vetch) were found to leave 30-60 kg N /ha in their root systems that will be available for uptake by the next crop (Nnadi and Haque, 1986; 1988). It is assumed that legumes-cereals intercropping produces 45 kg N /ha for the benefit of the next crop. To account for the lagged effect of legumes the discounted marginal value product of nitrogen fertilizer is estimated based on the above discussion.

4.4.7. Livestock balance

This restriction ensures that there is a balance between production, consumption and marketing activities for each livestock keeping activity (see equation 9).

Livestock production is a function of diet. The livestock production coefficients used in the model are shown in Table 1.

4.4.8. Livestock Transfer constraints

Transfer rows relate the output of one activity to another activity in the model. Replacement of animals will be made from the existing stock on the farm. Culled animals and surplus animals over replacement will be disposed of through sales. To keep the herd structure constants, livestock number on the right hand side of the model is formulated as an equality (integer) constraint (see equation 10).

4.4.9. Soil erosion estimation

Intercropping reduces soil erosion by increasing the vegetative cover of a plot. Soil loss for each crop activity was estimated using the Universal Soil Loss Equation (USLE) modified for the Ethiopian conditions (Hurni, 1987). In consultation with forage experts and agronomists in the AARC, dense intercrop was considered as management factor (I_j) (see Appendix). The effect of soil loss (erosion) on household income was included in the model as discussed above (see equation 11).

4.4.10. Capital constraint

The available working capital required financing purchases of seeds, feeds, fertilizer, and other direct inputs can be an important constraint on the farm. Framers can get forage seed loan from Agricultural Offices. Some working capital may be available from the farmer's own savings, but this can be supplemented by borrowing. Households have limited access to credit to finance their input expenditures, especially fertilizer. There is no formal credit for consumption purpose in the region in general and in the study area in particular, but we do not have information on informal credit sources (see equation 12 and 13).

4.5. Risk and Sensitivity analysis

Even if direct incorporation of risk is not possible due to data limitation, maximizing farm income under the condition of satisfying the pre-determined food and feed requirements from crops grown, could be considered an indirect mechanism to account for some aspects of risk as this was a common strategy farmers used as a means of risk management. We tried to capture other elements of risk such as market and production variability using sensitivity analysis.

The LP model assumes that input-output coefficients are invariant, i.e., non-stochastic. However, many of the coefficients used in the model are in reality subject to variation. Price of outputs and inputs may vary in a largely unpredictable way. For instance, due to the recent aggressive extension system in Ethiopia the price of maize was going down drastically to the point where farmers stopped using improved maize seed. Hence it is necessary to carry out sensitivity analysis to examine the impact of variation on the profitability of the legume-cereal intercropping system.

Sensitivity analysis involves changes to model coefficients within reasonable bounds of the original estimate and is often used to determine if the original ranking of alternative plans is affected (Dillion and Hardaker, 1993). In this study, it is also applied to assess the stability of the objective values and cropping patterns of improved plans compared to the base plan.

The sensitivity test is performed on: (a) 50% reduction in the price of the major crop (maize). Price of maize is sensitive to change since its production can be easily increased due to availability of improved seed compared to other crops (*teff*, millet, barley) and also maize is not a staple food by the majority of urban people, (b) 50% reduction in the amount of nitrogen fixed by forage legumes that will be used for subsequent crops, (c) 50% reduction in the price of fodder, and (d) the last scenario combines scenario (a) and (b). We focused on output prices since the major challenge in surplus producing area including our study area is a fall in prices of crops. The government often sets the major input prices (e.g. fertilizer and improved seed).

4.6. Model scenarios

In order to simulate the situation with and without technology intervention the following farm plans were constructed. These plans represent specific scenarios and are obtained through adjustments of the basic structure model. The specific scenarios are summarized as follows:

Base plan: Actual situation simulation

To assess the economic potential of legumes we run the model with and without legumes. The actual situation represents farming activities without legumes intervention. It helps as a basis for comparison with plans that represent changes in the system. This is the base plan from which the following improved plans are derived.

Plan I: Forage legumes intervention

It is the same as base plan but legume intercropping with cereals is introduced to provide improved feed for local bred cattle and maximize farm income.

Plan II: Crossbred cow technology intervention

It is the same as Plan I but we introduced crossbred cow using the existing farm household resources and maximize farm income. The demand for forage and the opportunities for diffusion of forage technology may be high where livestock response to improved feed technology and where profitability is high from livestock enterprise. Farmers are responsive to the amounts of economic incentives provided by the new technology.

5. Results and Discussion

Generalized algebraic modelling system (GAMS) is used to estimate the model.

5.1. Actual land use patterns and base plan outcomes

The 2001 actual and predicted land use patterns are indicated in column 1 and 2 of Table 3. The observed and predicted land use patterns are close to each other with the standard deviation of 0.23 and correlation coefficient of 0.91[38]. However, there is a bias towards maize production. The

[38] It measures the degree of association between predicted and actual land use value. It is defined as: $r = \frac{\sum_{i=1}^{N}\left(X_i^p - \overline{X}^p\right)\left(X_i^a - \overline{X}_a\right)}{\sqrt{\sum_{i=1}^{N}\left(X_i^p - \overline{X}^p\right)^2 \sum_{i=1}^{N}\left(X_i^a - \overline{X}_a\right)^2}}$, where p and a stands for predicted & actual land use values, respectively, X_i^p & X_i^a stands for mean value of predicted & actual land use, respectively.

bias arises due to the combined effects of higher grain and Stover yields production[39]. About 62.8% of the cropland was under maize production while the rest was shared among finger millet cultivation (19.8%) and other crops such as *teff* (11.6%), rough pea (2.5%), barley (2.8%) and niger seed (0.7%). Households generate income from sale of maize and finger millet crops. The area allocated to other crops was influenced to a great extent by the need to satisfy subsistence requirements. The estimated level of soil loss arising from the base plan was 11.7 ton/ha/year. The high marginal value productivity (Table 4) in the base plan indicated that grazing lands was an important feed source both in terms of quality and quantity. High pressure on grazing land may lead to land degradation. In the base plan the households purchased Noug cakes (33 kg) to supplement the feed shortage, especially protein shortage.

In the following section, against the base plan, two scenarios are run to examine the potential impact of legumes adoption on household income and soil conservation.

5.2. Improved plans outcome

The introduction of legumes has increased per capita income (hereafter income) considerable compared to the base plan. The results indicated that per capita income is increased by 51.7% (from Birr 1149 to 1743) over the base plan scenario only by introducing legumes into the existing farming system (Plan I). This was accompanied by a 9.4% (decline in soil loss from 11.7 to10.6 ton/ha/year) compared to the base plan (Table 4). The increase in income is substantial considering the only change occurring is intercropping of legumes with cereal crops. This result is due to an increase in sale of butter, dung cakes, surplus fodder products, reduction in soil loss and productivity gain due to nitrogen fixation. The income increase due to introduction of crossbred cow (CBC) along with legumes was 74.5% (from Birr 1149 to 2006) compared to the base plan (Table 4). Keeping other things constant, this value can be increased to 81% once the household paid his/her CBC loan after three years. This was accompanied by a decline of 7.7% (11.7 to 10.8 ton/ha/year) in soil loss compared to the base plan. Introduction of crossbred cow (CBC) increases income by 15% in plan II compared to plan I without CBC. This value can be increased to 19% once the household has paid his/her CBC loan after three years. Crossbred cow

[39] When all cereal crops (maize, finger millet, *teff* and barley) area is pooled the standard deviation drops to 0.07 and correlation coefficient increased to 0.998.

produces higher milk (butter) and dung compared to local breeds. The demand for legumes and the opportunities for diffusion of legume technology may be high where livestock response to improved feed technology and profitability is high from livestock enterprise.

The land use patterns underlying these results were also shown in Table 3. The principal land use pattern difference from the base plan is that the mono-cropping activities (maize and barely) are replaced by intercropping maize-vetch and barley-clover activities.

In the improved plans, households can produce surplus fodder over livestock demand. In the base plan the on-farm fodder production (crop residues) is entirely used for livestock and 33 kg of oil seed cake purchased to supplement the protein deficiency of the existing feed sources. Although excess fodder over livestock demand was transferred to selling activity in the present study, it can serve other purposes such as mulching and freeing grazing lands for crop cultivation and/or recovering overgrazed lands, especially the communal grazing lands. Further research on these alternatives may be important to exploit the potential of legumes.

The productivity of resources (return per unit of resource) increases with introduction of forage legumes and CBC (Table 4). Legumes and CBC generate more employment opportunities to the household. Labour uses increase by 9.7% (1133 to 1243 man days) in plan I and by 13.6% (1133 to 1287 man days) in plan II compared to the base plan.

The marginal value productivity (MVP) of grazing lands decreased in the improved plans in relation to the base plan (Table 5). This is a result of an increase in feed dry matter availability from intercropping. Increased high quality dry matter feed from intercropping, may reduces the problem of overgrazing and hence soil erosion and compaction of arable land. On the other hand, the shadow price of own cropland increased in the improved plans compared to the base plan, because the overall productivity has increased. The MVP of labour and oxen, however, is zero. This is not surprising for three reasons. First, the dominant crop is maize where its resources requirement is very low compared to other crops. Second, employment opportunity outside farm is low. Third, for reasons mentioned in section 5, there is no oxen rental market to sell surplus draft power over own farming. Introducing labour intensive technologies may help to utilize the abundant labour. Multipurpose animal traction can be introduced to reduce excess draft power. For instance, Buta and Kassa (1998) showed that crossbred cows could serve as draft power without affecting milk production. This can reduce the pressure on feed sources.

5.3. Sensitivity Analysis

The impact of changes in the price of outputs and nitrogen output are indicated in Table 6 and 7. A decrease in maize price by 50% reduced the income of the household in each plan. The drop in income was lower for plan I (27%) and plan II (22%), compared to the base plan (38%). The land use pattern and sources of farm income after the change were close to those before the change in the improved plans. But the base plan was unstable with this shock, as indicated by the standard deviation of the change in land use pattern. The standard deviation was 0.42, 0.11 and 0.11 for the base plan, plan I, and II, respectively. High yield from livestock due to legumes may serve as insurance when there is a shock on crop production.

Reducing the amount of nitrogen fixed by legumes by 50% has only reduced the income of the household. The decrease in income was higher in plan I (5%) compared to plan II (4%). The land use pattern and sources of income remain unchanged, indicating the models were stable. The resulting farm incomes were still higher for the improved plans compared to the base plan. This is due to the fact that more manure and surplus fodder were sold under improved plans unlike the base plan where there was no surplus fodder over livestock demand.

With a 50% maize price and nitrogen output reduction, household income decreased by 31.7% under plan I without CBC and by 25.6% under plan II with CBC. The land use pattern after change had similar trend as in before change. However, improved plan with crossbred cow (plan II) was more stable than plan I. The standard deviation was 0.21 and 0.16, respectively for plan I and plan II. The household income also was higher in these plans compared to the base plan.
The effect of decreasing fodder price by 50% on income was higher for plan I (8%) compared to plan II (3%). Crossbred animals use more fodder and convert it into higher value products.
These results show that the economic benefits from all plans decline when output prices and the amount of nitrogen fixed by legumes decreased. Yet, the improved plans remain profitable and the relative profitability of the plans remained the same compared to the plans before change.

6. Conclusions

Declining soil fertility, increased soil erosion and falling crop yield are major problems in the Ethiopian highlands. The poor quality and quantity of feeds are also problems of livestock production. Legumes have been developed to solve these problems. In this study, we investigated the impact of legumes-cereals intercropping on household income and soil conservation using a bio-economic linear programming model combining household survey and experimental data. The findings indicated that legumes-cereals intercropping increased farm income while reducing pressure on the land resources. The farm income was further enhanced when legumes-cereals intercropping were combined with crossbred cows for milk production. The marginal value productivity of grazing lands decreased with the introduction of legumes into the farming system. This is a result of an increase in feed dry matter availability from intercropping. Increased high quality and quantity of feed dry matter from intercropping may reduce the problem of overgrazing and hence soil erosion and compaction of arable land by livestock. Overall, these results imply that development interventions that consider forage legumes will achieve a double advantage of enhancing the livelihood of rural households while checking land degradation.

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Table 1. Livestock productivity with and without forage legumes

Parameters	Animal types	Productivity	
		Without forage (Traditional feed)	With forage legumes
Weaning rate per year	Local cow	0.5	0.7
	Crossbreed cow	NA	1.0
	Sheep	1.2	1.6
	Goat	1.25	1.65
Manure per year (kg dry matter)	Local cow	800	965
	Crossbreed cow	NA	1172
	Sheep	70	112
	Goat	70	112
Lactation yield (kg)	Local cow	225	420
	Crossbreed cow	1153	2228

Sources: (Omiti, 1995; Mpairwe et al., 2002; Betew and Addis, 2003, GOE, 1986). NA= not available

Table 2. Average grain and straw yields (kg per ha)

Crop types	Grain yield		Straw yield	
	With fertilizer	Without fertilizer	With fertilizer	Without fertilizer
Sole maize	5000	NA	9300	NA
Maize-vetch	4912	NA	14200	NA
Sole barley	1653	750	2300	750
Barley-clover	1793	NA	3400	NA
Teff	1200	665	1080	599
Finger millet	1965	1200	5364	3276
Niger seed	NA	500	NA	600
Rough pea	NA	925	NA	823

Sources: Wereda Agricultural offices (2002); Mengistu (1994); Zewdu et al. (2000); Adugan and Said (1991)

Table 3. Actual and model estimated values of land use (in hectare)*

Crop type	Farmer's practice (in 2001)	Base plan	Plan I	Plan II
Sole Maize	0.860	1.368	0.000	0.000
Teff	0.500	0.252	0.252	0.252
Finger millet	0.530	0.429	0.524	0.607
Sole barley	0.120	0.060	0.000	0.000
Grass pea	0.070	0.054	0.054	0.054
Niger seed	0.100	0.016	0.016	0.016
Maize-vetch intercrop	-	-	1.307	1.224
Barley-clover intercrop	-	-	0.026	0.026

*0.000 means the crop is included in the model but not selected in the optimal plan.

Table 4. Legumes' income contribution, per capita income, soil loss and resource productivity

Particulars	Base plan		Plan I			Plan II		
	quantity	Value	quantity	Value	Income differences	quantity	Value	Income differences
Income sources	A	B	C	D	E= D-B	F	G	H= G-B
Butter (kg)	7	151	27	581	430 (13.5)	125	2688	2537(55.3)
Manure (kg)	4010	401	4589	459	58(1.8)	5761	576	175(3.8)
Livestock (head)	2.768	698	4.368	1153	455(14.3)	4.962	1382	684(14.9)
Straw (kg)	0	0	8145	1629	1629(51.2)	4353	871	871(19.0)
Grain (kg)	5688	4909	5419	4628	-281 (-8.8)	5149	4365	-544(-11.8)
Nitrogen fixed (kg)	0	0	60	892	892(28.0)	57	868	868(18.9)
Total farm income		6159		9342	3183(52%)		10750	4591(74.5)
Per capita income & resource productivity								
Farm income:								
Per capita	1149		1743			2006		
Per cropped area (ha)	2990		4185			4931		
Per person day employed on the farm	4.84		7.51			8.35		
Per total person days available	2.30		3.50			4.02		
3. Soil loss (ton/ha/year)	11.7		10.6			10.8		

Note: 1) value indicated in term of the country currency (ETB), 2) figure in parenthesis indicate percentage income contribution of each source

Table 5. Marginal value productivity of resources

Resources	Base plan	Plan I	Plan II
Own cultivated land (Birr/ha)	2271	2281	2281
Rented in land(Birr/ha)	873	436	436
Private grazing land(Birr/ha)	2199	779	779
Communal grazing land (Birr/ha)	1094	388	388

Table 6. Sensitivity analysis report for per capita income change due to prices and nitrogen output change

Plans	Before change	50% maize price reduction			50% Nitrogen output reduction			50% maize price reduction & 50% nitrogen output reduction			50% fodder price change*		
	A	B			C			D			E		
	Income	Income	Change	%Change	Income	Change	%Change	Income	Change	%Change	Income	Change	%Change
Base plan	1149	707	-442	38	NA	NA	NA	NA	NA	NA	1149	0	0
Plan I	1743	1272	-471	27	1658	-85	4.9	1135	-553	31.7	1601	-141	8.1
Plan II	2006	1569	-437	22	1926	-80	4	1492	-514	25.6	1940	-66	3.3

* For the base plan sensitivity analysis for straw was not reported since there was no surplus fodder over livestock demand.

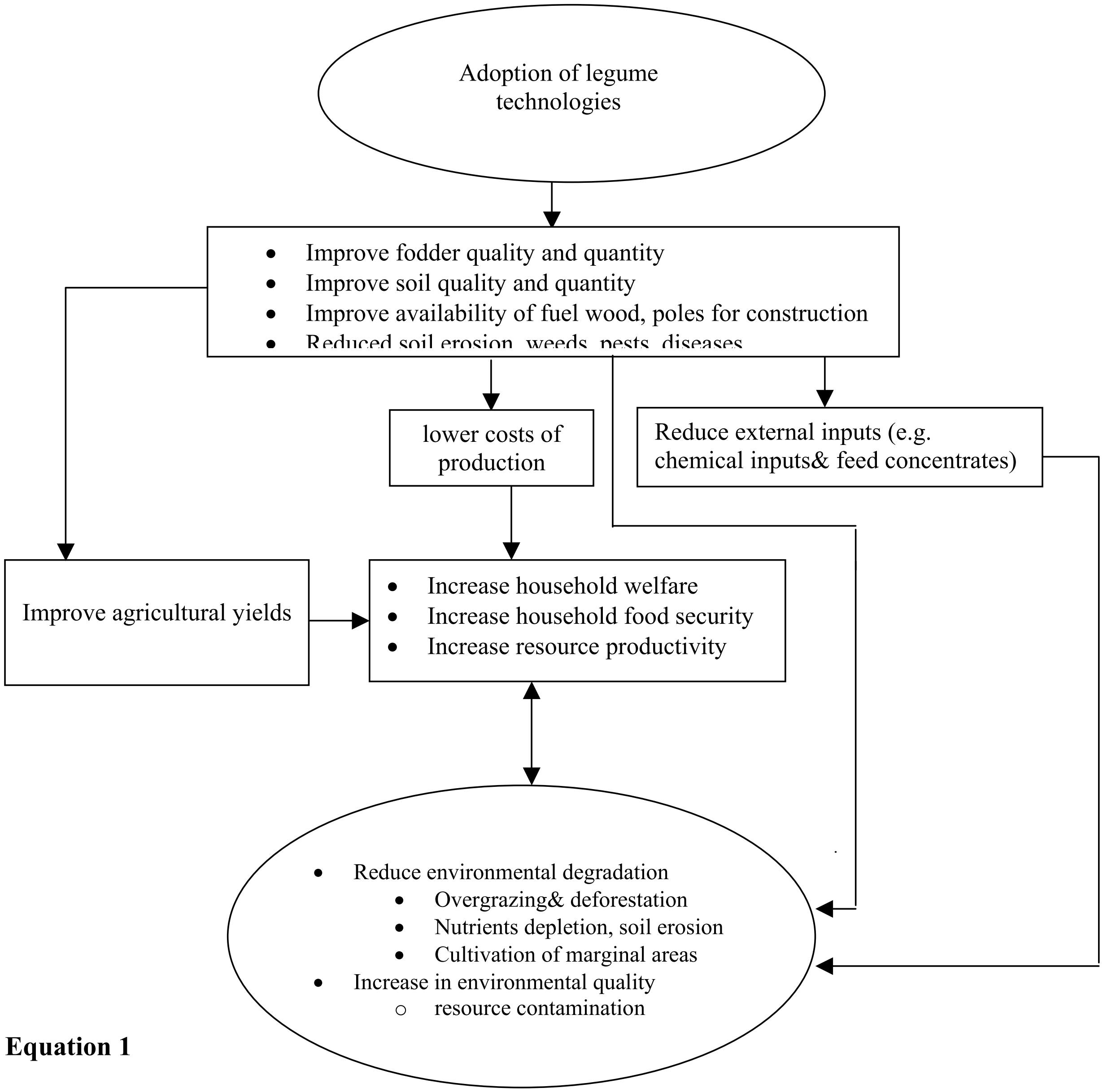
Table 7. Sensitivity analysis report for land use changes due to prices and nitrogen output changes

Crop type	50%maize price reduction			50% nitrogen output reduction		50% maize price reduction & 50% nitrogen output reduction		50% fodder price reduction	
	A			B		C		D	
	Base	Plan I	Plan II	Plan I	Plan II	Plan I	Plan II	Plan I	Plan II
Sole Maize	0.784	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Teff	0.127	0.204	0.204	0.252	0.252	0.127	0.127	0.576	0.252
Finger millet	1.139	0.597	0.680	0.524	0.607	0.715	0.798	0.175	0.524
Sole barley	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Grass pea	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
Niger seed	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Maize-vetch intercrop	-	1.282	1.199	1.307	1.224	1.241	1.158	1.332	1.307
Barley-clover intercrop	-	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026

* For the base plan sensitivity analysis for straw was not reported since there was no surplus fodder over livestock demand.

Appendix

Figure 1. Conceptual model linking legumes adoption with household welfare (income) and environmental conservation



Equation 1

Barley (local variety) fertilizer response

Barley (kg/ha) = $965 + 7.74N + 24.12P - 0.0637N^2 - 0.1695P^2 + 0.0693NP$

t-value: (2.5)* (7.8)** (-4.5)** (-1.7) (1.8)

R-square = 0.97 , observations = 704

Farmers average N and P application rate is 34 and 40 kg/ha, respectively.

Source: Ho (1992)

Equation 2

Maize (improved variety) fertilizer response

$$maize(kg/ha) = 2191.18 + 53.04N + 56.82P - 0.217N^2 - 0.280P^2 + 0.085NP$$

Robust p-value (0.000) (0.000) (0.000) (0.000) (0.000) (0.034)

R-square = 0.56, Observations = 160, F(5, 154) = 55.8(0.000)

N = nitrogen in kg/ha, P = phosphorus fertilizer in kg/ha. The average N and P application rate by farmers is 64 and 46 kg/ha, respectively

Source: our own estimates

Table A. OLS estimates of the effect of soil depth on *teff* yield (Dependent variable: logarithm of *teff* yield ton/ha)

Independent variables	Coefficients
Level variables	
trend variable in years	9.460(0.215)
frequency of ploughing	156.514(0.000)***
soil depth in cm	12.492(0.004)***
slope in percent	1.031(0.886)
rain fall in mm	172.655(0.002)***
Squared terms	
trend variable in years	0.577(0.000)***
frequency of ploughing	0.452(0.046)**
soil depth in cm	0.235(0.076)*
slope in percent	0.166(0.193)
rain fall in mm	-8.313(0.030)**
Interaction terms	
soil depth*trend variable	0.358(0.014)**
soil depth * rain fall	-1.871(0.005)***
soil depth * slope	0.336(0.010)***
soil depth * frequency of ploughing	-0.756(0.145)
slope * trend variable	0.353(0.017)**
slope*rain fall	-0.268(0.780)
slope * frequency of ploughing	-0.956(0.099)*
rain fall* frequency of ploughing	-20.545(0.000)***
rain fall * trend variable	-2.091(0.044)**
frequency of ploughing * trend variable	1.245(0.002)***
Constant	822.377(0.000)***
Observations	184
R-squared	0.665
Robust p values in parentheses	
* significant at 10%; ** significant at 5%; *** significant at 1%	
Average *teff* yield	0.95 ton
Average soil depth	95 cm
Average slope	7.5%
Average ploughing frequency	5
Average rain fall	1000 mm

*all variables are expressed in natural logarithms

Table B. Aggregated representation of Linear Programming Model

		Production					Buying	Selling	Home consumption	Borrowing (BOW)	RHS
		Crop & feed	organic nitrogen	grazing	Soil loss	Livestock, livestock product, transfer	Feed, Land-rental	crop, fodder, livestock & livestock product			
Constraints	Units	Ha	Kg			Head/kg	Kg		kg/liter	Birr	
Croplands	Ha	+ 1					- 1				$\leq$ L
Pasturelands	Ha			+ 1							$\leq$ pasl
Human labour	PD	+ A									$\leq L_s$
Ox labour	OD	+ A									$\leq O_s$
Home consumption	Kg								+ 1		$\geq$ Min
Capital constraint	Birr	+ A				+ A	+ A			- 1	$\leq$ OF
Credit limit	Birr									+ 1	$\leq$ CRL
Soil erosion	ton/ha	- A			+ 1						$= 0$
Nitrogen balance	Kg	- A	+ 1								= 0
Crop & feed balance*	Kg	- A		- A		+ A	- 1	+ 1/+A	+ 1		$<=>0$
Livestock balance	Head/ Kg					± A/± 1		+ 1	+ 1		≤ 0
Objective: Max .gross farm income	Birr	$-C_j$	λ_n		$-\lambda_e$	$-C_j$	$-C_j$	P_j		$-i$	=Z

Where: C indicates unit cost, P_j is unit revenue, PD is person-day, OD is ox day, Min & Max are mininum & maximum requirments respectively and other variables are defined below.

* the feed balance include DCP (digestible crude protein content in kg), ME (metabolaizable energy in mega calorie) and DM (dry matter in kg).

$$1)\ Max\pi = \sum_{j=1}^{m}\sum_{k=1}^{B} p_{jk} Q_{jk} - \sum_{i=1}^{h}\sum_{j=1}^{m} p_i X_{ij} A_j + \lambda_n N - \lambda_e E + \sum_{l=1}^{D} p_l X_{lcs} + \sum_{p=1}^{L}\sum_{l=1}^{D} p_{pl} Q_{lp} - \sum_{g=1}^{E}\sum_{l=1}^{D} p_{gl} X_{lg} - iBOW$$

$subject$ to :

2) Land constraints

$$\sum_{j=1}^{m} A_j \leq L$$

3) Pasture land constraints

$$A_p \leq pasl$$

4) Human labour constraints

$$\sum_{s=1}^{6}\sum_{j=1}^{m} L_{sj} A_j + \sum_{s=1}^{6} \lambda_{sl} X_l \leq L_s$$

5) draft power constraints

$$\sum_{s=1}^{3}\sum_{j=1}^{m} w_{si} A_j \leq O_s$$

6) Animal feed constraints and balance

$$\sum_{j=1}^{m} N_{nj} A_j \pm N_{nj}^{\ ps} >=< \sum_{l=1}^{D} r_{nl} X_l$$

7) Home consumption

$$Q^c{}_j \geq Q_j^{\ mr}$$

8) Crop balances

$$\sum_{j=1}^{m} q_{jk} A_j - Q_j^{\ s} \geq Q_j^{\ c}$$

9) Livestock output balances

$$y_{pl} X_l - sale_{pl} \geq C_{pl}^c$$

10) Livestock replacement and culling rate

$$cur_l X_l - X_l^{\ culs} \geq 0$$

$$cur_l X_l - X_l^{\ R} \leq 0$$

$$sur X_l - X_l^{\ surs} \geq 0$$

11) Soil erosion

$$\sum_{j=1}^{m} eros_j A_j = E \text{ (total soil loss cropland)}$$

12) Capital constraint

$$\sum_{j=1}^{m} k_j A_j + \sum_{l=1}^{D} k_l X_l - BOW \leq OF$$

13) Credit limit

$$BOW \leq CRL$$

where:

Q_{jk} = total quantity of output k produced by crop j activity and available for sale

p_{jk} = per kg selling price of crop output type k (grain and fodder) from crop j activity,

p_i = per kg buying price of input i (fertilizer and seed) used by crop j activity,

X_{ij} = level of input i used per hectare by crop j activity,

A_j = level of crop j activity in hectare,

λ_n = the discounted marginal benefits of soil fertility level,

N = level of nitrogen fixed by intercropping activity in kg,

λ_e = the discounted marginal user cost of soil,

$eros_j = R * K * L * S * C_j * I_j$. This is USLE and it refers to per ha soil losses under crop j activity

C_j = land cover by crop j activity, I_j is management factor under crop j, R is rain fall, $K, L, \& S$ are soil erodibility, slope length & slope gradient, respectively.

p_l = per head selling price of type l livestock,

X_{lcs} = number of heads of type l livestock available for sale (culled (c) and surplus stock (s)),

p_{pl} = selling price of type p (manure and butter)livestock product produced by type l livestock,

Q_{pl} = quantity of livestock product p from type l livestock,

p_{gl} = price of livestock variable input g used by livestock type l,

X_{lg} = number of heads of type l livestock using type g livestock input,

L = total cropland available in ha,

$pasl$ = total pasture land available (communal and private) to farmers

A_p =total pastureland used for grazing

L_{sj} = the number of labour man-days required per ha by crop j during period s,

λ_{sl} = the number of human labour hours required to keep available livestock stock during period s,

L_s = total human labour hours available during period s,

w_{sj} = the number of oxen pair hours required per ha by crop j during period s,

O_s = total number of oxen pair hours available during period s,

$Q^c{}_j$ = household subsistence requirement from crop j activity

Q^c_{pl} = type p product from type l livestock that is consumed by household

Q_j^{mr} = the level of household consumption of crop j activity,

N_{nj} = amount of fodder type n (dry matter, protein and energy) per ha produced by crop j activity,

N_{nj}^{ps} = amount of fodder sold (s) or purchased (p),

r_{nl} = quantity of fodder type n required per head by livestock type l (X_l),

Q_j^s = quantity of crop j sold (s),

q_{ik} = per hectare yield of crop j activity,

y_{pl} = per head yield of animal product type p from livestock type l,

$sale_{pl}$ = sale of animal product type p from type l livestock activity

cur_l = culling rate(cur) from type l livestock,

X_l^{culs} = number of culled animal sold (culs) from type l livestock,

X_l^R = number of type l livestock born and reared on the farm to replace (R) culled livestock type l

sur_l = number of surplus stock (sur) over replacement from type l livestock,

X_l^{surs} = number of surplus stock sold (surs) from type l livestock,

k_j = working capital requirements for crop j production,

k_l = the working capital requirements for type l livestock,

CRL = credit limit,

OF = amount of own fund available

IV

Adoption of forage legumes-cereals intercropping in the Ethiopian highlands

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Abstract

Low quality and quantity of feed resources and low soil fertility are major constraints to improving the productivity of livestock and crop in the Ethiopian highlands. These problems contribute to low and declining agricultural productivity and food insecurity. There is growing evidence that forage legumes can offer a ray of hope by increasing the quality and quantity of fodder production, enhancing land productivity, reducing soil erosion and generating extra income to farmers. However despite these benefits forage legumes are not widely adopted at the farm level. This paper presents a household level analysis of factors influencing the decision to adopt vetch-maize intercropping by smallholder farmers in the North-Western Ethiopian highlands. The paper uses the innovation-diffusion, economic constraint and adopter perception paradigm and previous technology adoption studies to develop both a theoretical and empirical framework for our study. The empirical results showed that access to information through extension and radio significantly affects the likelihood of adoption. We also found that household's education level, access to crossbred cow and problem of livestock feed shortage in the household are more likely to encourage adoption. Results of this study imply that policies that facilitate farmer access to information and crossbred cows will promote the adoption of legumes.

Key words: adoption; forage legumes; intercropping; probit regression; Ethiopia;

1. Introduction

Low quality and quantity of feed resources and low soil fertility are major constraints to improving the productivity of livestock and crop in the Ethiopian highlands (Kruseman et al., 2002; Tangka et al., 2002). Conversion of grazing land to cropland, overgrazing, scarcity of feed during the dry season, high price and lack of feed concentrates, and the generally low quality of available pasture, and crop residues are causes of feed shortage. On the other hand, high and increasing fertilizer prices, production and price uncertainty and unavailability at the right time are mentioned as major explanations for limited use of inorganic fertilizer (Lakew et al., 2000; Ahmed et al., 2003). The use of organic fertilizers to enrich soil fertility is also very limited, leading to further deterioration in soil fertility and thereby lower productivity. This is because crop residues are used for livestock feed and fuel-wood while the amount of manure available is limited due to the small number of livestock holdings per household as well as poor performance of livestock. A shrinking land frontier due to land pressure as a result of rapid population growth makes area expansion and fallowing options infeasible.

Improved forage legumes (hereafter legumes) integrated with food crops and livestock are often advocated to minimise external inputs and improve the productivity and sustainability of crop-livestock production in developing countries (e.g. McIntire et al., 1992; Humphreys, 1994; Gutteridge and Shelton, 1994; Thapa, 1996; Griller, 2001; Peter and Lascano, 2003). There are ample evidences that legumes have resulted in increased crop and animal production in Sub-Saharan Africa (Tarawali, 1991; McIntire et al., 1992; Khalili et al., 1992, 1994; D'Mello and Devendra, 1995; Umunna et al., 1995; Omiti, 1995; Mpairwe et al., 2002, 2003). The adoption of legumes has the potential to substantially increase the amount and quality of forage supply to supplement the low quality of naturally occurring forages and crop residues, while at the same time promoting sustainability by improving soil quality and preventing soil run off when they are intercropped with cereals (Abate et al., 1992; McIntire et al., 1992; Umunna et al., 1995; Zewdu et al., 2000; Lapar and Ehui, 2004; Mpairwe et al., 2002; 2003). However, in many regions of Sub-Saharan Africa, the adoption of legumes has so far been limited (Gryseels and Anderson, 1983; Saka et al., 1993/1994; Thomas and Sumberg, 1995; Zewdu et al., 2000; Ahmed et al., 2003; Seyoum Mezgeb, 2004, personal communication[40]).

Considerable research has been directed to the issues of technological adoption in agriculture during the last decades[41]. However, relatively few empirical studies have examined the adoption of intercropping systems. Thangata and Alavalapati (2003) in Malawi, Lapar and Ehui (2004) in the Philippines, Neupane et al. (2002) in Nepal and Adesian et al. (2000) in Cameroon analyse the factors involved in the adoption of agro-forestry technologies. Hearth and Takeya (2003) in Sri Lanka attempt to quantify the factors influencing intercropping of perennial cash crop such as rubber with banana and pineapple. We do not know specific

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[41] See Feder et al. (1985) for detail literature review on adoption of agricultural innovations in developing countries.

research work on the adoption of intercropping system in which annual food crops are intercropped with annual legumes.

The objective of this paper is to identify the determinants of factors influencing farmers' decisions to adopt legumes intercropping practices with food crops in the crop-livestock farming systems of the North-Western Ethiopian highlands. The results will aid development practitioners and policy makers to speed up the adoption process by understanding the constraints to introduce legumes into the smallholder farming system.

The paper is structured in the following line. The next section discusses the adoption theories of the factors that affect the adoption of technologies, followed by the methodology section. Results and discussion follows the methodology section, and finally, this paper concludes and discusses the policy implications of our findings.

2. Adoption theories

Different paradigms have been suggested to explain the decision to adopt new technologies. These include: the innovation-diffusion paradigm (IDP), the economic constraint paradigm (ECP) and adopter perception paradigm (APP) (Roger, 1962, Aikens et al., 1975; Agarwal, 1983; Gould et al., 1989; Biggs, 1990; Adesian and Zinnah, 1993; Negatu and Parikh, 1999). According to IDP access to information about an innovation through extension services, media, experiment station and on-farm trial visit is the key factor determining adoption decisions. It is also assumed that the diffusion of the technology in potential user communities depends on the personal characteristics of the potential individual. The technology is assumed appropriate for use unless hindered by lack of effective communication (Roger, 1962; Agarwal, 1983; Adesian and Zinnah, 1993; Negatu and Parikh, 1990). The ECP states that the distributions of resource endowments among the potential users in a region could significantly constrain the pattern of technology adoption (Aikens et al., 1975; Adesian and Zinnah, 1993; Negatu and Parikh, 1999). The APP suggests that decision makers' perception of the technology-specific attributes condition adoption behaviour (Kivlin and Fliegel, 1967; Gould et al., 1989; Biggs, 1990; Adesina and Zinnah, 1993). Decision makers have subjective preferences for technology characteristics that play a major role in technology adoption (Ashby and Sperling, 1992 cited in Adesina and Zinnah, 1993). This model underlines the importance of farmers' involvement in the technology development process with the aim of generating technologies with appropriate and acceptable characteristics.

The effect of the above factors may be conditioned by the characteristics of the rural market. If perfect market exists for all goods and services, households' resource endowments may not affect investment and production decisions (Pender and Kerr, 1998; Holden et al., 2001). Imperfection in labour markets forces households to equate labour demands with family labour supply, and thereby families with more labour supply are more likely to adopt labour intensive technologies. The same can be said about credit or capital market imperfections. Households with higher savings or productive assets will be able to invest if the technologies are capital-intensive. When market imperfections are important inclusion of household characteristics and resource endowments in explaining adoption decision is important (Ibid). This enforces the IDP and ECP.

3. Methodology

3.1. Legumes extension in the Amhara region

The Amhara regional state covers the North-Western and North-Eastern part of Ethiopia. Inadequate livestock feed and low soil fertility are major constraints to agricultural production in many parts of the region (Zewdu et al., 2000; Lakew et al., 2000). Governmental and non-governmental (e.g. Fourth Livestock Development Project) organisations have been promoting adoption of different types of annual and perennial legumes such as vetch, lablab, clover, tree lucerne and sesbania to reduce feed shortage in the region.

Forages are grown intercropped with food crops, as mixed pasture, backyard/homestead, agro-forestry, and pure stand forage production. Intercropping and backyard strategies are dominant in the region (Zewdu et al., 2000). Vetch intercropped with maize is the dominant annual forage crop adopted by the farmers[42]. Intercropping of clover with barley and wheat crops have been experimented within on-station and on-farm fields and showed promising results both in terms of grain yield and fodder production (Ibid). However, farmers in the region rarely practice intercropping of barley and wheat with clover. This is due to lack of strong research and extension linkage. The main reason for intercropping is shortage of farmland. The total area covered by vetch-maize intercropping in three years period between 2001 and 2003 was 16752 ha. These are small figures in relation to the size of the cultivated land area in the region per year, which is about 4.6 million ha (BoA, 2001, 2002; 2003). The previous extension systems in Ethiopia in general and in the region in particular were

[42] Lablab and clover are recently introduced legumes and there are some practices of growing these legumes on farm boundary and communal grazing land in the region.

focusing on food crops production neglecting forage crops and livestock production. Low priority is given for forage crops research and development. Awareness on the importance of and contribution of improved forage crops to food security is low by framers, policy makers, and professionals (Zewdu et al., 2000).

The cultivated area covered by legumes in the study district between 2001 and 2003 was 6050 ha (BoA, 2001, 2002; 2003).

3.2. Data sources

The study was carried out in Bahir Dar Zuria district, West Gojjam zone of North-Western Ethiopian highlands. Mixed farming systems, involving complementary interactions between crop and livestock such as using animal traction and manure for cropping and feeding crop residues to livestock, are the dominant production systems in the area. Farmers have good access to road, transport and output markets, as they are located nearby the capital city of the Amhara regional state (Bahir Dar town).

Survey data collected in 2002 by experts in the socio-economic and livestock forage production divisions of Adet Agricultural Research Centre were used for the empirical analysis (Table 1 & 2). The data were collected to investigate the factors affecting the introduction and use of improved forage crops in North-Western Ethiopian highlands. Ninety-six farmers were randomly selected, 12 from each of 8 sample villages. For the present study, we considered 87 farmers for which a complete data set is available.

3.3. Modelling Technology adoption

The adoption decision is modeled as the decision between planting cereals in intercropping with legumes and planting cereals alone. In making decisions about the adoption of a given technology, we assume that a farmer will evaluate the new technology in terms of its expected incremental benefit. If the expected utility of monetary benefit (income) using legumes (new technology) in intercropping (π_1) is higher than the old technology (without legumes) income (π_0), the preference or utility for new technology will be higher than the old technology. We assume that there is an unobserved or latent variable, y^*, that generates the observed variable y, which represents a farmer's decision to adopt legume technology or not. The latent variable y^* equals $E[U(\pi_1)] - E[U(\pi_0)]$, the net benefit from adoption. The farmer will adopt legumes in intercropping if the expected utility of income with adoption is greater than the expected utility before adoption, i.e., when $y^* > 0$, the household adopts legumes in intercropping and $y = 1$ is observed and when $y^* \leq 0$, the households do not adopt legumes in intercropping and $y = 0$ is observed.

For farmer i, the latent variable y^* is related to observed farmer and other characteristics through a structural model as follows:

$$y_i^* = \beta' X_i + \varepsilon_i, (i = 1,..., N)$$

where X_i represent a set of explanatory variables, which influence adoption decision of the farmers, β' is a coefficient vector and ε_i is a random disturbances associated with the adoption and non-adoption of improved practice. Then y_i^* is linked to y_i as follows using indicator function:

$$y_i = 1 [\, y_i^* > 0 \,]$$

Farmer i adopts the forage legumes as intercrop if $y_i^* > 0$. The probability that $y_i = 1$ is then:

$$\Pr[y_i = 1] = \Pr[y_i^* > 0] = \Pr[\beta' X_i + \varepsilon_i > 0] = 1 - F(-\beta' X_i) = F(\beta' X_i),$$

where $\Pr[.]$ is a probability function and $F(.)$ is the cumulative distribution function. The function, $F(\beta' X_i)$, cannot be estimated directly without knowing the form of *F*. The exact distribution of *F* depends on the distribution of the random term ε. A probit model will be used in this paper assuming the disturbance term is normally distributed with mean zero and variance one.

3.4. Hypothesis and variables used in the model

This section discusses the definitions and measurements of variables (Table 1); expected signs and justification of the variables used in the model based upon the theories we discussed above and the literature on technology adoption. The dependent variable is dichotomous, and equals 1 if a farmer adopts vetch-maize intercropping and 0 otherwise.

Information is important to stimulate adoption of new technologies. Extension contact and radio ownership are expected to have a positive impact on adoption based upon innovation-diffusion theory. Extension services allow farmers to have access to information on forage production and utilisation. Extension contact is a key variable in developing a favourable attitude among farmers towards the technology. Studies have shown that extension contact positively influence adoption of new agricultural technologies (Baidu-Forson, 1999; Adesina et al., 2000; Hearth and Takeya, 2003; Thangata and Alavalapati, 2003). Contact with extension agents is therefore expected to have a positive effect on legumes adoption.

Mass media channels are important in broadcasting agricultural information. A farmer who owns a radio is assumed to listen to news from outside and thus expected to have more exposure to outside information compared to farmers who do not own radio. Framers who own radio are more likely to adopt legumes.

Adoption of technology may also be determined by human capital as measured by household head's level of education and age. Farmers who are more educated are open to new ideas and technologies that will promote technical change (Weir and Knight, 2000; Feder et al., 1985). In the Philippines, Lapar and Ehui (2004) found that educated farmers have greater likelihood of adopting forage species used as contour hedgerow. Other empirical studies also found similar results (Mittal and Kumar 2000; Herath and Takeya, 2003). The level of farmers' education is believed to influence the use of legumes positively.

Studies have shown that age of the farmer is related to adoption decisions. Younger farmers have the tendency to be more innovative and may be more willing to bear risk due to their longer planning horizons (Gould et al., 1989; Polson and Spencer, 1991). Longer farming experience equated with age square could lead more accurate assessment of the benefits of adoption. Shiyami et al. (2000) and Herath and Takeya (2003), respectively, found positive impact of experience on chickpea and on intercropping of rubber tree with banana and pineapple. Therefore, the age variable is hypothesised to have a positive effect and the effect of its square is ambiguous on adoption.

If an agricultural technology increases the seasonal demand for labour, it would be less attractive to a household with limited family labour. Intercropping legumes with food crops demand extra labour for harvesting and transporting biomass production (forage fodder plus crop residues) as compared to the conventional system (mono-cropping). Intercropping increases biomass production. Larger families with more labour supply would be expected to adopt legumes.

The most important contribution of improved forage is its direct effect on livestock production. Direct short-term benefits to farmers are usually important in fostering adoption of technologies (Harrington, 1994 cited in Lapar and Ehui, 2004). Livestock productivity will potentially improve because of high quality feed from legumes. The number and type of livestock herds being raised by a farmer may determine his or her demand for forages. We divide livestock into local breeds and crossbred animals since their demand for and response to improved forage production is different and thereby their influence on adoption may vary. It is hypothesised that livestock holding is positively related to adoption.

The impact of farm size per capita on legumes' adoption may be positive or negative. Farmers with larger farm size can produce more crop residues. Crop residues may have substitution and complementary effect depending on farmer's awareness on the quality of fodders available from crop production. Even in the presence of abundant crop residues, legumes help to improve the feeding value and utilization of crop residues (Mpairwe et al., 2002) [43]. Farm size can also be associated with greater wealth and increased availability of capital, which makes investment in technology more feasible (Norris and Batie, 1987). In addition, wealthier people are willing to bear more risk than poorer people, due to the fact that richer people can afford to take greater chance (Mas-Collel et al., 1995).

Intercropping legumes with food crops increase both the quantity and quality of the available feed sources. Farmer's who encountered livestock feed shortage and participated in the fodder market are likely to adopt legumes.

Off-farm income may reduce risks from experimenting with new technologies. Off-farm activities may reduce the management resources available for the adoption process, but access to outside information may have positive effects. It is shown that off-farm income positively influence adoption of new technologies (Adesina, 1996; Herath and Takeya, 2003). Considering the above factors, off-farm income is positively linked to adoption of legumes.
Besides the above variables seven village dummy variables will also be included in the model. This may serve to control factors (e.g. difference in feed sources, variation in distance from village to regional capital) not included in the model.

[43] According to the existing property right regime all farmers have access to communal grazing areas and crop aftermath. These variables are not included in the empirical model.

4. Results and Discussion

4.1. Descriptive statistics

In the study areas, vetch is grown intercropped with maize crops. About thirty-seven percent of the sampled households were practicing in maize-vetch intercropping during the survey period. Farmers' perceptions of the advantage of intercropping are presented in Table 1. The perceived advantages relate to shortage of land, controlling weeds and improving soil fertility. About 4.6% of the total sampled households have also planted elephant grass. The period of adoption varies by household that the majority of farmers (75%) started growing legumes between 1991-2000 while some (19%) have started recently, 2001 and two farmers started growing before 1991.

Table 3 presents a summary of the mean characteristics of all the sample households, adopters and non-adopters. As mentioned earlier, the study sample consisted of 87 farmers drawn from eight villages. The sample had 37% adopters and 63% non-adopters with an average age of about 39 and 40 years, respectively. Out of 87 farmers, about 39% had feed shortage problem. About 63% of those farmers who intercropped vetch with maize crop (adopters) perceived livestock feed shortage problems while only 26% of the non-adopters reported feed shortage problem. It is evident that most adopters of legumes had more contact with extension workers, own radio, and were more educated than non-adopters. This difference was statistically significant. About 54% of the total sampled households and 72% of adopters got extension services on forage production and utilization. Twenty-four percent of the total sampled households and 38% of the adopters have heard about improved forage production and utilization broadcasted by mass media channel. This implies that adopters have more access to technical information and legume related support services available in the study area than non-adopters. The proportions of adopters (28%) who had crossbred cow were higher than their counterpart (11%). Similar trend was observed for local breed animals. Twenty-two percent of the adopters were involved in off-farm activity and only 7% of the non-adopters had access to off-farm activity.

4.2. Empirical results

The probit regression model was estimated using Stata econometric software, version 8.2. Including off-farm activity and fodder market participation in the probit model may cause endogeneity problem. Appropriate variables with which to construct instrumented values for these variables were unavailable. The probit model was estimated with (column A) and without (column B) these variables. The variable crossbred cow considered exogenous variable. Farmers already owned the crossbred cows by the period of data collection.

The probit model results are presented in Table 3. The model was significant at less than 1% level. The model correctly predicted 83 to 84% of both adopters and non-adopters. The following variables significantly affected the decision to adopt legumes with food crops: extension contact, farmer education level, radio ownership, access to crossbred animals, and livestock feed shortage in the household.

The uptake of new technologies is often influenced by the farmer's access to agricultural information. The positive and significant effect of extension indicator variable suggested the importance of extension contact in influencing the adoption of forage technologies. This is similar to the finding that the availability of extension service has positive significant effect on probability of adoption of chemical inputs, soil and water conservation, and agro-forestry technologies (Baidu-Forson, 1999; Adessina et al., 2000; Thangata and Alavalapai, 2003). Equally important to access to agricultural information through extension service is farmers' access to mass media channels. Radio ownership had a positive significant impact on forage technology adoption. Education was significantly and positively correlated with legumes adoption. Better-educated farmers are more likely to recognize the benefits of adopting legumes as sources of feed for livestock and soil conservation input. These specific results are important since these variables may be easily influenced through policy. The results therefore suggested that the dissemination of information and support of educational infrastructure could increase the adoption rate of legumes.

Access to crossbred cow positively influenced the probability of adoption suggesting the complementarity between improved animals and high quality feed production from legumes. This indicated that the adoption of legumes is high where livestock productivity and response to improved feed due to legumes is higher. Livestock feed shortage in the household, as reported by each farmer, has a positive significant impact on legumes adoption.

5. Conclusions

Adoption of legumes in developing countries has been proposed by researchers to alleviate agricultural problems such as feed scarcity and poor quality feed, soil nutrient depletion and soil erosion. However, legumes have not been widely adopted in smallholders farming environment. In this paper, the factors influencing the decision of smallholder farmers to adopt vetch-maize intercropping were studied in the Ethiopian highlands. The probit model results indicated that extension contact, level of farmers' education, radio ownership, ownership of crossbred animal and problem of livestock feed shortage in the household were significant determinants of the adoption decision.

The policy implication of these findings are that there is a need for strengthening information flow through extension services, mass media, educational infrastructure and complementary inputs (e.g., crossbred animals) to speed up the adoption of legumes.

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Table1. Definitions and measurements of variables used in the model

Variables	Variable meaning	Type of variable
Adopt	Adoption of vetch-maize intercrop	Dummy (=1 if farmer adopted and 0 otherwise)
Extension	Farmer contact with extension agents	dummy (=1 if farmer visited by extension worker and 0 otherwise)
Radio	Radio ownership	dummy (=1 if farmer owns radio and 0 otherwise)
Education	household education level	dummy (= 1 if farmer can read and write and = 0 if farmer is illiterate)
age	Age of the household head in years	continuous
Crossbred cow	crossbred cow ownership	dummy (=1 if farmer owns crossbred cow and 0 otherwise)
Local breed animals	local breed animals excluding oxen (tropical livestock unit; TLU)	Continuous
Oxen power	oxen ownership in TLU	Continuous
farm size	farm size per capita	Continuous
Adult male labour	Adult male labour supply per hectare	Continuous
Adult female labour	Adult female labour supply per hectare	Continuous
Off-farm activity	participation in off-farm activity	dummy (= 1 if farmer participate and 0 otherwise)
Feed shortage	Farmer who has feed scarcity problem	dummy (= 1 if farmer has feed shortage problem and 0 otherwise)
Market	Participation in fodder market	Dummy(=1 if farmer bought feed and zero otherwise)

Table 2. Farmers' perceptions on the importance of intercropping

Reasons for intercropping	Number of respondents	% share
Control weeds	3	9.3
Improve soil fertility	2	6.2
Land shortage	15	46.9
Control weeds, improve soil fertility, and farm land shortage	8	25
Control weed and farm land shortage	2	6.3
Improve soil fertility and farm land shortage	2	6.3
Total	32	100

Table 3. Adopter and non-adopter characteristics and mean values of the variables used in the model

Variables	All sample	Adopters	Non-adopters	Mean difference
adopt	0.368			
age	39(1.397)	39(1.901)	40(1.923)	1.051(2.705)
local breed animals	3.227(0.313)	3.826(0.542)	2.878(0.377)	0.948 (0.644)*
Oxen ownership	1.602(0.124)	1.495(0.207)	1.664(0.156)	0.169(0.258)
farm size	0.406(0.036)	0.416(0.229)	0.400(0.414)	0.016(0.069)
Crossbred cow	0.172(0.090)	0.281(0.079)	0.109(0.042)	0.172(0.090)**
Radio	0.437(0.105)	0.656(0.084)	0.309(0.062)	0.347(0.105)***
Education	0.644(0.085)	0.906(0.052)	0.491(0.067)	0.415(0.085)***
Extension	0.739(0.065)	0.869(0.031)	0.664(0.058)	0.205(0.065)***
Off-farm activity	0.126(0.081)	0.219(0.073)	0.073(0.035)	0.146(0.081)**
Feed shoartage	0.391(0.053)	0.625(0.087)	0.255(0.059)	0.370(0.104)***
Market	0.851(0.038)	0.938(0.043)	0.800(0.054)	0.138(0.079)*
Adult male labour	1.869(0.151)	1.665(0.233)	1.988(0.196)	0.323(0.254)
Adult female labour	1.579(0.144)	1.347(0.142)	1.714(0.211)	0.367(0.106)*
Number of observations	87	37	55	
* significant at 10%; ** significant at 5%; *** significant at 1%.				

Note: (A) We used t-test for continuous variables and pr-test (proportion test) for dummy variables; (B) figure in parenthesis is standard errors

Table 4. Probit model results for legumes adoption[1]

Explanatory variables	Estimated coefficients	Estimated coefficients
	A	B
Extension	2.808(1.117)**	2.835(1.130)**
Radio	0.780(0.421)*	0.785(0.415)*
Education	1.102(0.551)**	1.073(0.523)**
oxen ownership	0.019(0.205)	0.002(0.207)
local bred animals	0.099(0.101)	0.117(0.099)
crossbred cow	1.017(0.514)**	1.055(0.502)**
farm size	-0.637(0.898)	-0.788(0.855)
Male adult labour	-0.087(0.647)	-0.145(0.641)
Male adult labour squared	-0.032(0.091)	-0.026(0.090)
female adult labour	0.089(0.623)	0.033(0.622)
female adult labour squared	-0.035(0.115)	-0.033(0.118)
age	0.015(0.096)	0.001(0.089)
Age square	-0.000(0.001)	0.000(0.001)
Feed shoartage	1.361(0.723)*	1.359(0.729)*
off farm activity	0.139(0.658)	
Market	0.331(0.600)	
Joint chi-square test for village dummy variables	5.09(0.650)	5.27(0.628)
constant	-4.714(2.724)*	-3.936(2.474)
Observations	87	87
Correct prediction (%)		
Total	84	83
Adopters	75	75
Non-adopters	89	87
Pseudo R2	0.43	0.43
Model test	Wald chi2(23) = 0.84(0.001)***	Wald chi2(21)= 49.10(0.001)***
Robust standard errors in parenthesis		
* significant at 10%; ** significant at 5%; *** significant at 1%.		

[1]Note: Seven villages we were included in the model. Their coefficients are not reported.

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Menale Kassie was born in Bahir Dar, Ethiopia, in 1970. He holds a Master of Science Degree in Agricultural Economics from Alemaya University of Agriculture, Ethiopia, (1997).

This dissertation explores the potential for adoption of agricultural technologies and how alternative land rental contracts and kinship influence agricultural productivity and input use. It contains an introduction and four independent papers. In Paper I, we examine conservation impact on land productivity and factors contributing to yield gap between conserved and non-conserved plots. The empirical results show that conservation results in lower yield for the samples considered, and plots with and without conservation barely differ in their endowments of soil fertility and depth although the return to these endowments is higher for plots without conservation. In paper II, we distinguished between sharecropping contracts among kin and non-kin partners and found that non-kin sharecrop plots are more productive and received significantly more fertilizer than other plots. This finding is consistent with the hypothesis that the threat of eviction is stronger among non-kin than among kin partners. Paper III examines the economic potential of forage legumes-cereals intercropping adoption on household income and soil conservation. The results indicate that forage legumes increase household income significantly while at the same time reducing pressure on the land resources. Paper IV investigates socio-economic and institutional factors influencing forage legume-cereal intercropping adoption. The empirical results suggest that facilitating information flow with introduction of crossbred cows would play a key role for the adoption of legumes.

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