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ESSAYS ON LAND LEASE MARKETS, PRODUCTIVITY, BIODIVERSITY, AND ENVNIRONMENTAL VARIABILITY

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Mintewab Bezabih

To my father

Contents

Abstracts

This thesis consists of four papers. The titles and abstracts of the various essays are as follows.

Paper 1: Tenure Insecurity, Transaction Costs in the Land Lease Market and Implications for Gendered Productivity Differentials

This study assesses the link between land leasing behavior and productivity differentials between male and female-headed households. A double-moral hazard model allows us to show that the landlord's tenure insecurity leads to a sub-optimal level of effort on the tenant's part, via its impact on the likelihood of contract renewal. The model also predicts that a high search cost of a landlord leads to a higher probability of contract renewal. A lower probability of contract renewal leads to lower levels of tenant's effort, and vice versa. The empirical findings support the hypotheses that female household heads have lower enforcement ability and that tenure insecurity is a significant negative determinant of productivity. However, the results show no support for a lower likelihood of contract renewal by female-headed households or for a significant impact of contract renewal on productivity.

Paper 2: Heterogeneous Risk Preferences, Transaction Costs and Land Contract Choice

The paper analyzes how heterogeneities in risk preferences, rate of time preferences and transaction costs affect the choice of contracts among participants in the land lease market. The analysis draws from both agency and transaction cost theories, which propose alternative explanations of contract choice. Unique data from Ethiopia, containing experimental risk, rate of time preference measures and transaction costs are employed in the analysis. Tenant characteristics are more important than those of landlords in explaining contract choice. The results do not support the risk-sharing hypothesis of the agency theory as a motivation for contract choice while there is some support that discount rates and transaction costs affect contract choice. The results also indicate that the land lease market serves as a resource pooling mechanism by bringing poorer landlords and tenants into sharing arrangements.

Paper 3: Biodiversity Conservation Under an Imperfect Seed System: The role of Community Seed Banking Scheme

The study is an empirical investigation of agrobiodiversity conservation decisions of small farmers in the central highlands of Ethiopia. The primary objective is to measure the effectiveness of Community Seed Banking (CSB) in enhancing diversity while providing productivity incentives. Our results indicate a significant impact of participation in CSB on farm-level agrobiodiversity. However, the level biodiversity conservation was not found to have the expected reinforcing impact on participation indicating no support for simultaneity. CSB participation also led to increase in productivity consistent with the need for such incentives to enhance diversity at a farm level. Our assessment of the performance of the GLS estimator yielded a significant discrepancy between the GLS and bootstrap estimates. This led to the conclusion that bootstrapping asymptotic estimations might be required for appropriate inference.

Paper 4: Environmental Change, Species' Coping Ability and the Insurance Value of Biodiversity

This paper develops a measure of the value of biodiversity by incorporating a stochastic change in the environmental factor into an economy-ecosystem model of biodiversity. The analysis draws from an ecological model specifying the relationship between aggregate productivity, responsiveness to environmental change, and diversity. The value of biodiversity is derived as the contribution of diversity in enhancing the ecosystem's adaptive response to environmental change. The results are relevant to biodiversity conservation efforts that target areas with differing degrees of environmental variation. In addition, our analysis of some features of global warming the results imply that with increased concerns of global warming, more needs to be invested in biodiversity.

Preface

I developed the interest in assessing the economic constraints rural households face from my exposure to the issue in my undergraduate and graduate classes. This doctoral study has enabled me to pursue my interest in contributing to a formal, albeit humble analysis of the issue. For this, I wish to express my sincere gratitude to the Environmental Economics Unit for accepting me as a PhD student, and to Sida for financing this study.

My deepest thanks goes to my supervisors Fredrik Carlsson and Gunnar Köhlin who greatly contributed to this study and to my professional development, through their intellectual guidance and relentless support. I am very thankful for all their insights, critical comments and for their optimism about my research projects. Fredrik has always traced flaws in my arguments and methods, and has shown me the totally different side of my story. Gunnar's intriguing questions about the value of the research questions I raise and the links between them and policy were critical in defining what I need to do.

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I owe the success of both the surveys I have undertaken for this dissertation to the dedication and hard work of the data collection team and to the kind cooperation of the respondent farmers in Gojjam, Wollo and Chorisa. Special thanks to Melkie Taye, Girma Mengistu and Sisay Tadesse for assisting me in conducting the pilot surveys and coordinating the main surveys. I would like to thank Ayneye for typing the questionnaires in Amharic. Thanks are also due to Debbie and Anatu for proofreading the thesis and making it readable.

The contribution of my ever loving and caring family is colossal. The support of my brothers Behailu and Dawit, my sister Ayneye and my mother Mesaytu, and their enthusiasm about my success has not only been the reason for me to finish what I have started but also the motivation behind setting what I pursue next. *Yalenante meswaitnet hilme iwin ayhonim neber.*

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Mintewab Bezabih

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Introduction

Acute poverty, physical and economic alienation, and severe vulnerability to natural and anthropogenic factors characterize rural households in low-income countries, which mainly derive their livelihood from agriculture and related activities. This manuscript deals with the economic choices that households make and their impact on welfare in low-income, rural settings where the production environment is fragile and uncertain, market opportunities are limited, and underlying institutional settings are less than fully favorable. Particular focus is placed on Ethiopia, a country where overwhelming majority (85%) of its 77 million citizens are rural; and agricultural performance, even in good years, is dire (FAO,2001).

In light of this, the thesis consists of four papers aiming to assess the role of institutional and market constraints as well as natural environmental factors in conditioning the economic choices rural households make and the impact of the choices on the households' welfare. In particular, focus is made on determining access to land, productivity, and the management of biodiversity. The first two papers deal with the role of institutional, socio-cultural, and local market constraints in conditioning the performance of land lease markets. The last two papers focus on the incentive structures in managing indigenous planting materials and the differentials in the value of diversity under varying degrees of environmental uncertainty.

In a predominantly agricultural economy like Ethiopia, land is a critical factor of production owing to the fact that it is an immobile natural asset which is a source of livelihood, investment, and wealth. Moreover, unlike other inputs in agricultural production, access to it depends on the national tenure system set up by the government. A distinct feature of the Ethiopian land tenure[1] system is state-ownership of land that bestows land to peasant farmers on *usufruct* basis. An obvious implication of this form of private land access is its ban on sale, which limits land ownership[2] to village-administered (re)distribution. An additional implication is that such an ownership

[1] Land tenure is defined as a system of rights and institutions governing access to and use of land and other resources (Bruce, 1998)

[2] In the sense it is used throughout the thesis, private land ownership refers to access to land by a household that involves own-use of land for production, short and medium term rentals and inheritance to immediate members of family.

structure induces tenure insecurity among the farmers who have experienced/expect to experience land redistribution in a manner that affects their farm size. Moreover, population pressure and ever decreasing farm size constitute a limit to redistribution as a viable form of land access.

The limited access to ownership under the existing tenural arrangement provides a wide space for the development of vibrant land lease markets that transfer land to landless/land-poor households. Indeed, land leasing increasingly constitutes an important source of land access and transfer. Many studies indicate that, in a given village, 30% or more households are engaged in leasing in/out (Teklu, 2004). However, the development of land leasing comes against the background that past policies have also outlawed all forms of land transactions. This could have a cascading impact in the sense that experience with land leasing is at an early stage and hence the land lease market may not be fully developed yet. Moreover, the underlying tenure insecurity of the land owning households may set an additional barrier.

In line with this, the first paper deals with the interactions between the underlying tenure insecurity of land owning households and socio–cultural settings that may condition land-leasing behavior. In particular, we look into the leasing behavior of households where the head of the family is a woman, and compare these to male headed ones. The land ownership patterns of female-headed households are different from those of male-headed households in three major ways. One is that formal titling of women to land ownership is a fairly recent phenomenon. Previously, women could inherit land from their parents or deceased husbands; they could not, however, claim ownership upon divorce or could not be included in village redistribution schemes if they do not already own land (Gebreslassie, 2005). Even with recent legislations that ascertain their entitlement to redistributed land and right to claim land upon divorce, effective claim has been less than complete. Upon divorce, for instance, asking for part of the land, although legally rightful, may lead to alienation by the community members. It might also be impractical in situations where a woman is married to a man in a different village than her home village since dividing up the land might require the woman to live outside her home village, in which asking for her share of the land is “inappropriate” in the first place. Similarly, upon the death of the spouse, although it is the woman who generally keeps the land, her in-laws might be inclined to interfering in the management and the lease of the land.

This is also reinforced by the fact that there is a taboo against women undertaking major farming activities (Gebresilassie, 2005), which effectively bars them from managing their own land, and hence their heavy reliance on leasing out land for production. By emphasizing the socio-cultural constraints that typify female land ownership in Ethiopia, the first paper of the thesis spots key land-leasing features that distinguish female land-owners from their male counterparts. Differentials in tenure insecurity, enforcement ability, and other transaction costs related to search and screening in the land lease market are identified as the most critical factors. The paper goes on to identify the role of these key factors in maintaining the gender gap in agricultural productivity in Ethiopia.

The major role of the land lease market is to transfer land from less efficient to more efficient producers without actually transferring ownership rights. A wide variety of such transfer arrangements exist, each with a distinct set of input and output sharing rules. On the basis of previously established theories and empirical analyses regarding multiple contractual arrangements, it can be argued that leasing households attempt to address concerns regarding risk preferences, liquidity constraints, as well as attributes of trading partners. Heterogeneities with respect to such concerns among landlords and tenants tend to be aligned with the range of rules regarding input and output sharing. The second paper of the thesis analyzes how heterogeneities in risk, credit constraints, and transaction costs affect the choice of alternative contracts among participants in the land lease market.

In economies where insurance, output, seed and input markets work perfectly, seed portfolio decisions reflect input and output market price concerns only. However, in agricultural economies like that of Ethiopia, because of very low market integration and high production risk, production decisions go beyond ordinary profit maximization to incorporate yield stability as well as varying consumption requirements. As a result, production is largely subsistent and highly diversified. Hence, diversity in planting materials is the base for attaining the multiple objectives at the farm level. In addition, diversity provides the possibility to combine complementary planting materials that are adaptable to moisture, temperature, and soil type variability. Furthermore, it maintains the available pool of genetic materials for breeding to enhance productivity and ensure environmental stability. Moreover, moving towards a more market-oriented production relies on understanding the opportunities in diversification, tradeoffs in productivity and their interaction with the conditioning natural environment, which is highly uncertain.

While Ethiopia is not one of the mega-diversity centers compared to Central American, Southeast Asian or Central African countries, it has a considerable wealth of diversity in food crops and their wild relatives (Edwards, 1991). Indeed, owing to its huge altitudinal variation, [3] Ethiopia is home to a number of food crop varieties suited to the dry and high temperature conditions of the lowlands and the wet and cooler temperature conditions of the highlands.

Nonetheless, long-running neglect for agrobiodiversity has led to a huge loss of planting materials. While this has a cost to the global environment in general, the loss of diversity in planting materials threatens the livelihoods of millions of small holders who have local seeds as their major source of planting materials. Thus, reversing the biodiversity loss and enhancing its conservation calls for understanding of farm-level incentives for and constraints to conservation at a farm level.

Given this, the aim of the third paper is to look into farm-level incentives in landrace variety conservation in light of imperfections in seed systems, which lead to overall constraints to seed access. The study brings together several interlinked issues: on-farm conservation of crop genetic resources, household decision making, and the role of seed systems to address the question of how policies or programs like Community Seed Banking impact household decisions. It also assesses the resulting farm level diversity and what tradeoffs exist between diversity and productivity.

The last paper takes a wider perspective of studying biodiversity conservation decisions in the context of considerable environmental volatility. In line with this, the objective of the paper is to come up with a measure of biodiversity that provides guidelines to differential policies in biodiversity conservation under different degrees and patterns of environmental uncertainty. The valuation exercise is based on an ecological model of evolution of a biodiverse ecosystem that models interspecies relationships and their performance in connection to the external environment.

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[3] Ethiopia has more than half of the total highland and mountain areas of Africa, the altitudnal effect of which dissipates the arid and semiarid climate prevalent in the Sahel Zone (Edwards, 1991).

In sum, the thesis attempts to address what we identify to be critical issues in using, leasing and accessing land, a major factor of agricultural production with multifarious socio-cultural, political and behavioral dimensions. In addition, the thesis endeavors to tackle issues surrounding the concern in biodiversity conservation with a special focus on diversity as a source of planting material and as an insurance against environmental uncertainty.

The intricate development and natural resource use problems of poor rural economies provide a myriad of policy and academic challenges, calling for a deeper look into institutional, socioeconomic, and cultural factors that act as stumbling blocks to the economic progress of small agricultural households. In the words of T.W. Schultz (1979) in Barrett (2003):

> ‘ Most of the people in the world are poor so if we know the economics of being poor, we would know much of the economics that matters. Most of the world’s poor people earn their living from agriculture, so if we know the economics of agriculture, we know much of the economics of being poor. ’

In light of the research questions that we attempted to address in this manuscript, we feel that two major gaps need to be filled to further understand the constraints to rural development and natural resource management. One is the lack of a comprehensive understanding of the determinants and patterns of access to rural factor and output markets. One way of addressing this could be to employ sampling procedures that take into account not only observed participants in the market but also “potential” participants that are not “observed” as participants. In addition, gaining a fully contextual grasp of the economic decisions that rural households make constitutes another formidable challenge. In line with this, attempts to study rural household behavior in an inter-disciplinary approach that takes behavioral, socio-cultural, political and natural environmental factors, into account could be an additional path for future research.

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Tenure Insecurity, Transaction Costs in the Land Lease Market, and their Implications for Gendered Productivity Differentials

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Abstract

This study assesses the link between land leasing behavior and productivity differentials between male and female-headed households. A double-moral hazard model allows us to show that the landlord's tenure insecurity leads to a sub-optimal level of effort on the tenant's part, via its impact on the likelihood of contract renewal. The model also predicts that a high search cost of a landlord leads to a higher probability of contract renewal. A lower probability of contract renewal leads to lower levels of tenant's effort, and vice versa. The empirical findings support the hypotheses that female household heads have lower enforcement ability and that tenure insecurity is a significant negative determinant of productivity. However, the results show no support for a lower likelihood of contract renewal by female-headed households or for a significant impact of contract renewal on productivity.

JEL classification: D2, Q12, Q15, C21, C7.

Key words: productivity; Female-headed households; Contract renewal; Tenure insecurity; Enforcement ability

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1. Introduction

Empowering poor and vulnerable household groups in a fundamental manner, as opposed to providing them with transitory support, has been increasingly sought as a way of ensuring their effective participation in the development process (Barrett et al., 2006). Hence, the importance of identifying the underlying institutional constraints vulnerable household groups face has been receiving considerable attention In line with this, the study focuses on female-headed households[1], and the institutional and socio-cultural constraints they face in poor rural communities in Ethiopia.

A number of studies have noted a systematic downward bias in the productivity of female-owned plots (e.g. Holden et al., 2001; Tikabo, 2003). Such results persist irrespective of attempts to control for differences in labor endowment and heterogeneities in land quality. Even within the same household, empirical evidence from Burkina Faso (Udry, 1996) shows that plots controlled by women are farmed much less intensively than similar plots within the household controlled by men.

Female-headed households are characterized by lack of assets (including draught power) as well as labor shortage. [2] Under conditions where factor markets are working perfectly, female-headed households would be able to hire in labor and oxen or rent out land to adjust the cultivated area to other factors of production the household possesses. This would make up for the potential inefficiency in production created by labor/oxen shortage and the resulting "excess" cultivated land in proportion to the availability of labor/oxen. Equivalently, this would dissipate the productivity differentials between the less labor/oxen endowed female-headed households and the more labor/oxen endowed male-headed households. However, the markets for the complementary non-land factors (i.e. labor and oxen) are characterized by notorious imperfections and, thus, cannot play effective factor adjustment roles. The land rental market is then sought as the main mechanism by which households may adjust

[1] In rural Ethiopia, female household heads comprise the poorest part of the population. Many of them are widows, separated or women who live on their own making a living out of selling liquor. They are characterized as the most resource poor, having a small amount of land, usually no pair of oxen, no full farm equipment, insufficient adult labor and little working capital.

[2] This is true for Ethiopia where there is a taboo against women doing certain farming operations like ploughing with oxen.

cultivated area to their access to the semi- or non-tradable factor endowments[3] (Deininger and Binswanger, 1982; Tikabo, 2003). Accordingly, female-headed households would rely heavily on the land lease market as a mechanism to adjust their factor endowments to cultivated area.

On the other hand, the extent to which land lease markets contribute to factor adjustment depends on the performance of the land market itself. Hence, the better the performance of the land market in terms of adjusting factor endowments to cultivated area, the higher the agricultural productivity per unit of land. The main objective of this paper is to seek explanations to productivity differentials between male and female households in terms of differences in land leasing behavior. Particularly, we plan to test the impacts of household differences in tenure insecurity, contract renewal and enforcement ability as factors explaining productivity differentials. As mentioned earlier, the existence of productivity differentials between male and female owned farms has been documented in previous studies. However, our study is the first to assess why such differences exist by linking them to the socio-cultural and institutional settings that Ethiopian peasant farmers operate under and by the subsequent differences in their land leasing behavior.

In societies where the main agricultural activities are undertaken only by men, there are tendencies to disregard the role of women as farmers (Mutimba and Bekele, 2002), which may lead to an undermining of women's positions as farmers and landowners. Historically, for instance, village-level land redistributions have been gender-uneven with women losing out disproportionately (Crummy, 2000). This might induce systematically higher tenure insecurity of female-headed households compared to male-headed ones. This might manifest in their decision to lease, since they might opt for shorter-term rental contracts. This is because female headed households would fear that tenants might establish claims towards their land if the same tenant continues to stay on the land for long. In line with this, Bellemare and Barrett (2003) argue that when choosing the terms of contract, the landlord considers the impact of his/her choice on the probability that he/she will retain future rights to the rented land. On the tenant's part, expectations of being evicted from the (rented) land may curb the incentive to exert a high level of effort.

[3] By factor endowments, we are referring to land, oxen and active labor that the household has under its possession.

In addition, female landlords might not be regarded as knowledgeable farmers by tenants; thus tenants would have incentives to under-provide effort on land rented from female landlords. This is particularly true during peak labor and oxen seasons (days), when the tenant is labor constrained and meeting labor requirements of both his and the landlord's land is straining. Thus, female-headed households may need to exert extra monitoring and supervision to ensure an optimal level of tenant.

In sum, this study hypothesizes the following: heterogeneities with respect to tenure security lead to a lower likelihood of renewing contracts with the same tenant, which reduces the tenant's incentives to exert a high level of effort. This could lead to lower land productivity of female landlords. On the other hand, the inability of female headed households to enforce the terms of the contract may lead to lower tenant effort and hence lower productivity.

The paper is organized as follows: In the next section we give the theoretical background of the paper. The estimation methodology along with some considerations in the estimation procedure is provided in Section 3. Section 4 details the survey design and data employed in the empirical analysis. Section 5 presents the empirical findings and section 6 concludes the paper.

2. The Model

Our main premise is that female landlords are tenure insecure and face higher costs of search screening and monitoring (higher transaction cost) in the land lease market. Higher tenure insecurity and a high level of transaction cost could make female-headed households behave differently from their male counterparts in terms of land leasing behavior. Tenure insecurity might lead to a lower likelihood of contract renewal and a higher transaction cost might be associated with inability to find a good quality/ a hard working tenant or lower contract enforcement ability. The tenant may tailor his effort in accordance with the prospect of contract renewal and the landlord's enforcement ability. The resulting difference in tenant effort could lead to a difference in productivity between rented plots of male and female headed landlord households.

Given this, the essence of the model is to assess how landlord tenure insecurity and transaction costs faced in the land lease market are linked to the tenant's optimal level of effort. As with any other contractual arrangement, land transactions could take place for shorter or longer durations.[4] When search processes are costless and the landlord is fully secure about his/her land ownership, a shorter duration contract is as good as one of longer duration in terms of search cost. With positive search costs and full tenure security, however, a longer duration contract is more attractive as it reduces search costs for both parties. Thus, the landlord is then expected to renew the contract and the tenant expected to work harder not to be evicted from the land. On the other hand, if the landlord is less than fully tenure-secure, longer term contracting could induce the risk of losing land to the tenant. Thus, to the landlord, deciding on the contract renewal involves weighing the benefit of reduced search cost against the risk of losing the land to the tenant. Similarly, to the tenant, deciding on the level of effort to exert entails weighing the benefit of increased production against the chance of being evicted from the (rented) land. Accordingly, a landlord with higher tenure security will be more likely to renew the contract since the risk of losing land is going to be low. Furthermore, a tenant is likely to exert larger effort on land where contract renewal is more likely.

We consider a contract by a landlord and a tenant that stipulates output sharing conditions from rented out land. However, the tenant's effort, which is not observable to the landlord, will be one of the critical aspects of the land leasing arrangement that is not stipulated in the contract. Unobservability of tenant effort leads to moral hazard on the tenant's part since he could shirk on effort.

Another vital element in the land leasing arrangement that is not stipulated in the contract and that is also a source of moral hazard is the possibility that the landlord renews contract with the same tenant. In the Ethiopian context, contracts are typically entered for one year with a possibility of renewal. Unobservability of the likelihood of contract renewal by the landlord constitutes a source of moral hazard on the landlord's part. This situation leads to a double moral hazard problem where the landlord's decision to renew the contract is not observed by the tenant and the tenant's choice of optimal level of effort is not observed by the landlord.

[4] In this context, short duration contracts refer to one-year (one production season) agreements, while longer duration contracts involve repeated and continuous renewals with the same tenant.

The landlord's problem:

What we formulate in the landlord's problem is the relationship between the constraints faced by female household heads in the land lease market and their tendency to renew contracts. We argue that female landlords are tenure insecure and face higher transaction costs of search and contract enforcement in the land lease market. Because of the tenure insecurity, there is a tendency for them to renew contracts less often. On the other hand, high search cost for a tenant may increase the likelihood of renewing a contract with the same tenant.[5]

We consider the landlord's standard expected utility function from production profit with positive search costs that is augmented to allow for the risk of losing the land due to longer-term rentals.[6] The landlord's profit function is represented by the total revenue from agricultural production net the cost of searching for a tenant. The revenue is represented by the function, θf, where θ is a positive random variable with an expected value of unity, intended to embody the effects of uncertainty in the agricultural production (Eswaran and Kotwal, 1985), and where f is an increasing function of effort. The cost of time and resources that the landlord incurs searching for the tenant is given by c^L and α represents the share of the total output that goes to the tenant.[7] Since it is actual output that is observable to the landlord, we set $Q=\theta f$. Given this, at each period, the landlord will have the option of: 1) terminating the contract with the current tenant, incurring a search cost and obtaining a new tenant without running into the risk of losing land, or 2) renewing the contract with the same tenant and running into the risk of losing the land to the tenant. The first scenario (terminating the contract and searching for a new tenant) is represented by the following net profit function:

$$\pi_R = (1-\alpha)Q - c^L \qquad (1)$$

Under this scenario, the landlord gets a share of the output represented by $(1-\alpha)Q$ and incurs a search cost, c^L. The second option (renewing the contract with the same tenant) gives the following profit equation:

[5] Transaction cost in the land lease market includes the cost of search, screening and monitoring and we only model the search cost aspect here while in the empirical analysis, we use the combined costs and refer to them as enforcement ability.

[6] We have assumed that a fixed amount of land is to be rented out and the risk of losing land is associated exclusively to contract renewals.

[7] Fixed rentals are very few in the data, thus we have assumed away linear contracting.

$$\pi_A = (1-G)(1-\alpha)Q \qquad (2)$$

Here the landlord does not incur any search cost and he/she is guaranteed to get the share of the output, $(1-\alpha)Q$, with probability, *G,* that he/she loses the rented out land. In other words, the landlord faces the risk that the tenant attempts to expropriate land and stops paying the share to the landlord. Equation (3) represents the determinants of the probability that the landlord loses the rented out land:

$$G = G(E, g, L_s, T_s, Cl, S) \qquad (3)$$

G is a composite variable which is a function of *E*, is the tenant's ability to expropriate the land; *g,* the gender of the household head; L_s, the landlord's socioeconomic characteristics; T_s, the tenant's socioeconomic characteristics; *Cl,* the duration of the contract; *S*, policy variables that condition the extent to which the landlord is secure about his/her tenure. *S* could include experience of village level redistribution, future expectations of redistribution, experience of conflict, and sense of ownership (Holden and Ghebru, 2005).

Let *w* be the discounted present value of expected utility for a landlord who is deciding whether to renew a contract or not to renew the contract. The utility function is given by:

$$w = \begin{cases} w_0 = EU\left[(1-\alpha)Q - c^L\right] & if \;\; h = 0 \\ w_1 = EU\left[(1-G)(1-\alpha)Q\right] & if \;\; h = 1 \end{cases} \qquad (4)$$

where *h* is a binary variable which takes a value one if the landlord decides to renew the contract and zero if the decision is to not renew the contract. The maximization problem is a choice between two actions: renew the contract or terminate the current contract and engage in searching for a new tenant. The condition for optimization is given by the switch point, at which the landlord is indifferent between renewing and terminating the contract. In other words, the condition for optimality is given by equating the terms corresponding to $h = 0$ and $h = 1$ in equation (4), which is given by:

$$EU\left[(1-\alpha)Q - c^L\right] = EU\left[(1-G)(1-\alpha)Q\right] \qquad (5)$$

which is equivalent to:

$$(1-\alpha)Q - c^L = (1-G)(1-\alpha)Q \qquad (6)$$

Equation (6) could be solved for $Q*$, the level of output that makes the landlord break the old contract and go for a new tenant.

$$Q* = \frac{c^L}{(1-\alpha)G} \qquad (7)$$

The landlord will have an expectation of the output he/she is getting, which is denoted by $\bar{Q}$. The decision of whether or not to renew the contract/ not is based on the levels of $Q*$ and $\bar{Q}$. If $\bar{Q} \leq Q*$, then the landlord will stick with the old tenant and will renew the contract. However, if $\bar{Q} > Q*$, the landlord will be better off not renewing the contract and searching for a new tenant.

Based on (7), comparative statics give the following relationship between $Q*$ and the search cost, c^L, and the risk of losing land, *G*.

$$\frac{\partial Q*}{\partial G} = -\frac{c^L}{G^2\left(1-\alpha\right)} < 0 \qquad (8)$$

$$\frac{\partial Q*}{\partial c^L} = \frac{1}{(1-G)(1-\alpha)} > 0 \qquad (9)$$

Thus, from (8) we can see that higher *G* decreases, $Q*$, the level of output that makes the landlord go for a new tenant. This is because when *G* is high, the risk of losing land is high and the amount of output the landlord requires to be compensated for the risk of losing land increases. Hence, the level of output required by the new tenant will be lower. The intuitive interpretation of (8) is that if the landlord is likely to lose the land to the tenant because of renting out, then the landlord would need higher compensation in terms of output in order to renew the contract. Equation (9) shows that a higher search cost of the tenant increases $Q*$. This is because a higher search cost increases the level of output the landlord demands from the new tenant.

Proposition 1: Higher risk of expropriation reduces the probability of contract renewal by the landlord.

Proposition 2: Higher search cost by the landlord increases the probability of contract renewal by the landlord.

The empirical implication of proposition (1) is that tenure insecurity, which increases the risk of land expropriation, decreases the likelihood of contract renewal. Similarly, higher search cost, reduces the probability of contract renewal. Thus, female-headed households, who are supposedly tenure insecure households are less likely to renew contracts with the same tenant than their male counterparts while higher search cost leads to higher probability of contract renewal.

The tenant's problem:

The tenant's optimization problem considers the decision on the level of effort to put into production by taking into account the conditions of land leasing. In particular, we consider the effects of the probability of contract renewal and the tenant's search cost on the optimal level of tenant's effort.

In contracting the land, the tenant has two options: attempting to expropriate the land and not attempting to do so. The decision to go ahead with attempting to expropriate the land could lead to success or failure with some probabilities. If the attempt succeeds, the tenant would enjoy a stream of lifetime income from the land, where the yearly income is represented by $\overline{S}$. If the attempt fails, the tenant not only loses the prospect of renewing contract with the same landlord, but also damages his reputation and getting a good land becomes more difficult for him. We capture this damage in reputation as the inability to obtain the same quality land as before incurring the same search cost. Hence the production function of the tenant if expropriation is not successful is represented by f^n, which is lower than if the tenant did not face a damage in reputation. C_E represents the cost of expropriation. Thus, the decision to expropriate could follow the following pattern.

$$Z = \begin{cases} \sum_{1}^{\infty} e^{-rt}\overline{S} \quad \textit{if expropriation is successful} \\ \sum_{1}^{\infty} e^{-rt}(\alpha\theta f^{n}(e) - c^{T} - C_{E}) \quad \textit{if expropriation is not successful} \end{cases} \tag{10}$$

The decision to expropriate is dependent on the tenant's power to expropriate. We keep the tendency of expropriation (and its outcome) independent of effort. However, if he does not attempt to expropriate the land, he retains the prospect of the contract being renewed for him by the landlord.

In a situation where the tenant is not attempting expropriation, his optimization problem depends on the probability of contract renewal. The decision to renew the contract, *h*, is observed only as a probability *P*, to the tenant. Thus, at every period, the tenant could get a renewal with a probability *P* and a termination probability (1-*P*). Upon termination, the tenant would have to incur a search cost c^{T} to find another land with the same quality, thus identical production function. The disutility to the tenant I exerting effort is given by *k(e)*. The likelihood of contract renewal, *P*, is a function of the probability that the landlord loses the rented out land to the tenant, *G*, and effort, *e* where, $\frac{\partial P}{\partial G} < 0$, $\frac{\partial P}{\partial e} > 0 \; and \; \frac{\partial P}{\partial e \partial G} < 0$. In other words, the probability of contract renewal decreases with the risk of losing land and increases with effort. In addition, the responsiveness of the likelihood of contract renewal to effort decreases with the probability that the landlord loses the rented out land to the tenant.

With this, the tenant's problem is given by:

$$v = \max_{e} EV\left[P(e)(\alpha\theta f(e) - k(e)) + (1 - P(e))(\alpha\theta f(e) - k(e) - c^{T})\right] \tag{11}$$

which is equivalent to:

$$v = \max_{e} EV\left[(\alpha\theta f(e) - k(e) - c^{T}) - P(e))c^{T}\right] \tag{12}$$

The condition for optimality is given by:

$$\frac{\partial v}{\partial e} = (\alpha\theta f_{e} - k_{e}) + P_{e}c^{T} = 0 \tag{13}$$

The first two terms in the expression, $\alpha\theta(f_{e} - k_{e})$ give the standard conditions for determining the optimal level of effort under linear contracting (sharecropping). The last term, $P_{e}C^{T}$, gives the additional effort as a result of the probability of contract renewal which depends on the responsiveness of the probability to effort and the search cost the tenant faces upon non renewal.

Proposition 3: The likelihood of contract renewal has a positive impact on the tenant's effort.

The results are in line with the model and empirical findings of Kassie and Holden (2006) in Western Gojjam, Ethiopia.

3. Empirical Methodology and Estimation Considerations

The aim of this section is to set up a framework for analyzing the link between land leasing behavior and the gender gap in agricultural productivity. First, we specify the relationships between gender of the household head and land productivity to investigate the existence of significant productivity differences between farms owned by male and female household heads. To assess differentials in land leasing behavior, we define the econometric relationships between contract renewal, gender, tenure security and enforcement ability. Finally, investigate if a significant proportion of the differences are attributable to differences in the working of the land lease market by studying the relationships between productivity, contract renewal and tenure insecurity as additional determinants in the productivity regression.

3.1.The existence of gender gaps in productivity

As per the standard productivity analysis, plot-level productivity is determined by plot characteristics and household level characteristics. In addition, because some plots are leased, lease status is included as an additional determinant of productivity. Accordingly, the econometric relationship is specified as:

$$y_{ip} = \alpha + \varpi L_{ip} + \gamma g_{ip} + \mu X_{ip} + \vartheta R_{ip} + u_{ip} \qquad (14)$$

where for household i and plot p; y_{ip} is the value of output per ha; L_{ip} represents socioeconomic characteristics including gender; X_{ip} is physical farm characteristics of the plot; R_{ip} stands for the plot's lease status; α, ω π and ζ are the respective coefficients to be estimated; and u_{ip} is an error term.

In order to see whether differences exist between leased and non-leased plots, we estimate a Treatment Effects regression where the treatment variable is the plot's lease status.

Up to this point, we have ruled out the possibility that heterogeneities exist with respect to land leasing behavior. In other words, equation (1) implicitly assumes that the choice to lease is a decision determined by an exogenous set of factors with no bearing on productivity. However, as argued in Section 2, differences in underlying tenure insecurity and enforcement ability should lead to differences in land leasing behavior and eventually to differences in tenant effort (productivity). Sections 3.2 and 3.3 present the econometric relationships that allow for such analyses.

3.2. Contract Renewal

Analysis of the contract renewal decision is done using a bivariate probit model with sample selection. The estimation procedure involves two stages where in the first stage a possible sample selection is addressed by estimating a selection equation for leased out versus non-leased plots. In the second stage, a survival equation is estimated where the dependent variable is contract renewal. For the ith household and p^{th} plot, the selection equation that represents whether a plot is leased out or not is given by:

$$P_{ip} = \begin{cases} 1\, if\;\; \beta^{P} L_{ip} + \gamma^{P} X_{ip} + v_{ip} > 0, \\ 0 \quad otherwise \end{cases} \tag{15}$$

where P_{ip} is an indicator variable equal to 1 if plot is leased out, L_{ip} is a vector of socioeconomic characteristics, X_{ip} is a vector of physical farm characteristics and v_{ip} is an error term.

The survival equation is given by

$$h_{ip} = \begin{cases} 1\, if\;\; \phi + \psi L_{ip} + \pi T_{ip} + \eta g_{ip} + \mu Cl_{ip} + \gamma Cl_{ip} * g_{ip} + \lambda S_{ip} + \varepsilon E_{ip} + w_{ip} \succ 0 \\ 0\; otherwise \end{cases} \tag{16}$$

where L_{ip} represents socioeconomic characteristics; Cl_{ip} is the number of years the tenant has managed plot p of household i ; T_{ip} is a set of variables measuring the tenant characteristics; S_{ip} represents the underlying tenure security variables; $Cl * g_{ip}$ is the interaction between gender and contract renewal; h_{ip} is a dichotomous variable indicating whether a contract will be renewed or not for the next production year; E_{ip} represents the enforcement variables and w_{ip} is the error term.

3.3.Productivity analysis including land leasing behavior

Considering heterogeneous land leasing behavior implies taking contract renewal and tenure insecurity as additional determinants of productivity. Since plots that are rented out are likely to be systematically different from plots that are not rented out, the selection problem is addressed by estimating the plot lease status selection equation given in (15). The productivity equation for the non-leased plots is given by:

$$y_{ip}^N = \alpha + \varpi L_{ip}^N + \gamma g_{ip}^N + \mu X_{ip}^N + \delta S_{ip}^N + \varpi_{ip}^N \quad (17)$$

The productivity equation for the leased plots is given by:

$$y_{ip}^T = \alpha + \varpi L_{ip}^T + \gamma g_{ip}^T + \mu X_{ip}^T + \delta S_{ip}^T + \varphi h_{ip}^* + \partial T_{ip} + \varpi_{ip}^T \quad (18)$$

The variable definitions follow from equations (14) and (16). ϖ_{ip} represents the error terhm and the superscripts *N* and *T* represent non-leased and leased plots respectively. To estimate the selection equation along with the leased out and non-leased out plot regimes, we employ an endogenous switching regression estimation. In addition, since contract renewal is endogenous in equation (18); direct use of the variable in the regression would lead to biased and inconsistent estimates. Thus, we use an instrumental variable estimation where a predicted value of the contract renewal is used in estimating equation (16). Hence h_{ip}^* represents the predicted value of contract renewal.

In order to construct the instrumental variable for contract renewal, we formed groups of households by *Kebele*. With 12 *Kebeles* in our sample, we ended up with 12 groups of households. The average contract renewal of all households within a group other than that of the household itself is calculated for each household to form the instrument for contract renewal.

4. The data

We gathered the data employed in the empirical analysis from households in two districts of the Amhara National Regional State, a region that encompasses part of the Northern and Central Highlands of Ethiopia. One of the Zones (Districts), East Gojjam is a fertile plateau receiving good average rainfall while the South Wollo zone is characterized by degraded hill side plots receiving lower and highly erratic rainfall.

Our sampling is based on a larger complementary a survey that involved approximately 2000 households. Among the 2000 households, information on about 230 landlord households (130 male-headed and 100 female headed) and matching tenants are included in this study. Table 1 and Table 2 present the summary statistics and definition of the variables used in the regressions.

The survey consists of details of socioeconomic and physical farm characteristics of the landlord households. In addition, socioeconomic characteristics of tenant households are also included. The level of transaction costs faced in the land lease market and the degree of contract enforcement are represented by kinship between the tenant and the landlord, the extent to which the landlord is satisfied with the performance of the tenant and the landlord's inability to monitor the performance of the tenant. Tenure insecurity is measured in terms of past experience of changes in land holdings, expectations about changes in holdings and experience of conflict.

Table 1: Description of variables used in the regressions

Variables	Description
Landlord socioeconomic	**and farm Characteristics**
Education	Head's formal education (1=read and write; 2= read only; 3=none)
Age	Age of household head
Female	Gender of the household head
Male adult	The number of male working-age family member of the landlord per ha
Female adult	The number of female working-age family member of the landlord per ha
Livestock	The number of livestock per ha
Oxen	The number of oxen per ha
Zone	Zone the household belongs in (1=Gojjam; 0=Wello)
Flat slope plot	Flat slope of the plot (1=flat; 0=not flat)
Moderate slope plot	Medium slope of the plot (1=medium; 0=not medium)
Fertile soil	Fertile plot (1=fertile; 0=not fertile)
Medium fertile soil	Medium fertile plot (1=medium fertile; 0=not medium fertile)
Black soil	Plot with black soil color (1=black; 0=not black)
Red soil	Plot with red soil color (1=red; 0=not red)
Plot area	Total farm size (ha)
Farm area	Plot size (ha)
Plot distance	Distance of the plot from homestead (minutes)
Addis mender	Dummy for Kebele 1 (1=addismender;0=other)
Addis gudguadit	Dummy for Kebele 2(1=Gudguadit;0=other)
Ambamariam	Dummy for Kebele 3 (1=Ambamariam;0=other)
Chorisa	Dummy for Kebele 4 (1=chorisar;0=other)
Kebi	Dummy for Kebele 5 (1=kebi;0=other)
Kete	Dummy for Kebele 6 (1=kete;0=other)
Sekela debir	Dummy for Kebele 7 (1=sekeladebir;0=other)
Telima	Dummy for Kebele 8 (1=telima;0=other)
Weleke	Dummy for Kebele 9 (1=welekie;0=other)
Yamed	Dummy for Kebele 10 (1=yamed;0=other)
Amanuel	Dummy for Kebele 11 (1=amanuel;0=other)
Inputs	
Fertilizer	Amount of fertilizer applied (kg)

Manure	Amount of manure applied (kg)
Tenant	**Characteristics**
Tenant's age	Tenant's age
Tenant's oxen	The number of oxen owned by the tenant
Enforcement	**Variables**
Blood relation	A dummy variable indicating whether the tenant is a blood relation or not (1=blood relation, 0=no)
Spouse relation	A dummy variable indicating whether the tenant is an in-law or not
Blood relation*female	A dummy variable indicating whether the tenant is a blood relative given that the landlord is a female
Spouse relation*female	A dummy variable indicating whether the tenant is an in-law given that the landlord is a female
Satisfaction	A dummy variable indicating whether the landlord is satisfied with the performance of the tenant (1=satisfied, 0=otherwise)
Satisfaction*female	A dummy variable indicating whether the landlord is satisfied with the performance of the tenant given that the landlord is a female
Inability to monitor	A dummy variable indicating whether the landlord is unable to monitor the activities of the tenant (1=unable to monitor, 0=otherwise)
Inability to monitor*female	A dummy variable indicating whether the landlord is unable to monitor the activities of the tenant given that the landlord is a female
Contract renewal	A dummy variable indicating whether the current tenant will get contract renewal or not in the following production year
Contract renewal*female	A dummy variable indicating whether the current tenant will get contract renewal or not in the following production year given that the landlord is a female
Predicted survival	The predicted probability that the current tenant will get contract renewal or not in the following production year
Tenure security	**Variables**
Security	Whether the landlord expects increase, no change or decrease in the land size in the coming five years (1=decrease 2=no change 3=increase)
Changeland	Whether the landlord has experienced change in the landownership in the last five years (1=change, 0=no change)
Conflict	Whether the landlord has experienced any conflict regarding the land
Dependent	**Variables**
Productivity	The value of production per ha.
Contract renewal	Whether the contract will be renewed or not in the next production year (1=renewal; 0=non-renewal)
Lease out	The lease status of the plot (1= Leased, 0=owner operated)

Table 2: Summary statistics of variables used in the regressions

	Mean	St.Dev.	Minimum	Maximum
Education	1.581	0.871	1	3
Female	0.348	0.477	0	1
Age	55.902	18.191	13	95
Adult male	0.534	1.055	0	9
Adult female	0.414	0.900	0	9
Livestock	4.009	13.572	0	394
Oxen	1.095	1.904	0	13
Fertile plot	0.344	0.475	0	1
Medium fertile plot	0.421	0.494	0	1
Black soil	0.344	0.475	0	1
Red soil	0.520	0.500	0	1
Flat slope plot	0.633	0.482	0	1
Moderate slope plot	0.239	0.427	0	1
Plot distance plot	20.6	41.3	0	900
Plot size	0.255	0.169	0	1
Farm size	1.330	0.808	0	4
Addisgudguadit	0.093	0.290	0	1
Chorisa	0.022	0.145	0	1
Addismeder	0.040	0.196	0	1
Yamed	0.079	0.270	0	1
Ambamariam	0.078	0.269	0	1
Kete	0.092	0.289	0	1
Sekeladebir	0.093	0.290	0	1
Telima	0.087	0.282	0	1
Wolekie	0.084	0.278	0	1
Kebi	0.117	0.322	0	1
Manure	166.3	583.0	0	7600
Fertilizer	49.8	127.1	0	2381
Tenant's age	2.315	0.803	1	3
Tenant's oxen	1.977	1.074	0	8
Blood relation	0.427	0.495	0	1
Spouse relation	0.129	0.335	0	1
Spouse relation*female	0.053	0.224	0	1
Blood relation*female	0.160	0.367	0	1
Inability to monitor	0.083	0.276	0	1
Inability to monitor*female	0.033	0.179	0	1
Satisfaction	0.638	0.481	0	1
Satisfaction*female	0.239	0.426	0	1
Security	1.829	0.866	1	3
Changeland	0.132	0.339	0	1
Conflict	0.196	0.397	0	1
Contract duration	4.696	3.763	1	20
Contract duration*female	2.267	3.861	0	20
Contract choice	3.991	0.991	1	5
Predicted survival	0.925	0.161	0	1
Survival	0.806	0.396	0	1
Logvalue (yield)	6.858	1.233	0	11
Lease	0.645	0.479	0	1

Land owning farm households may or may not engage in the land lease market. Accordingly, they are categorized as ‘autarkic’, ‘landlords’ or ‘tenants’. For those who engage in the land lease market, they might do so partially or fully i.e. by renting out all/part of the plots. Table 3 presents the nature and extent of participation in the land lease market by gender category.

Table 3: Socioeconomic and endowment characteristics by household head gender

Socioeconomic characteristics						
	Age	Education	Family size	Adult family members	Oxen	Livestock (tlu)
Female	52.71 (16.48)	1.21 (0.61)	4.05 (2.11)	2.64 (1.28)	0.34 (1.05)	1.13 (1.86)
Male	55.67 (18.48)	1.85 (0.95)	6.00 (2.27)	3.88 (1.69)	0.80 (1.23)	2.71 (3.01)

Tenure security indicators			
	Conflict	Certificate	Security
Female	0.20 (0.41)	1.19 (0.57)	2.5 (0.88)
Male	0.19 (3.97)	1.17 (0.56)	2.56 (0.94)

Land market participation							
	Farm size	Plot size	Non leased plot	Shared in plot	Shared out plot	Rented in plot	Rented out plot
Female	1.04 (0.61)	0.25 (0.19)	0.32 (0.46)	0	0.62 (0.48)	0	0.07 (0.08)
Male	1.79 (1.03)	0.24 (0.08)	0.45 (0.49)	0.02 (0.14)	0.47 (0.49)	0.004 (0.64)	0.015 (0.12)

5. Results

5.1.The existence of gender gaps in productivity

Table 4 presents the Ordinary Least Squares and Treatment Effects estimation results for the pooled leased and non leased plots along with selection equation results for the plot’s lease status.

In the productivity equation, plots owned by female-headed households are significantly less productive. This is in line with previous studies which have shown that there is a gender gap in land productivity. This is so even after controlling for the effect of leasing out (using a dummy for leased plots), and the possibility that female and male households might not benefit equally from land leasing. Plot size is a significant negative determinant of productivity, while the impact of farm size is not significant, likely because that of plot size picks up the effect of farm size. Male adult per unit of land is a significant positive determinant of productivity while tropical livestock units and oxen (all measured per unit of land), are insignificant. Education and age of the household head are insignificant. Zone is insignificant while many of the village variables are significant. This conforms to the expectation that agroecological and institutional (market) characteristics, which are likely to be different across villages, affect productivity in a significant manner.

The selection equation results for plot lease status indicate that female owned plots are more likely to be leased out. However, other socioeconomic characteristics like education and the number of male and female members per ha. are not significant. As would be expected, households with more oxen per ha are less likely to lease out land while the total tropical livestock units of the household per ha., which we use to proxy for wealth is not a significant determinant of the decision to rent out. Larger total land area decreases the probability of leasing out land, while a larger plot size increases the likelihood of leasing out. Plots distant to the homestead are not significantly more likely leased to be rented out. Plots with moderate slope are likely to be rented out while other plot characteristics are not significant.

Table 4: Ordinary Least Squares and Treatment effects Estimates of Pooled Plot level Productivity

Variable	OLS estimates of productivity		Treatment effects estimates of productivity		Plot rent equation	
	Coefficient	Std.dev	Coefficient	Std.dev	Coefficient	Std.dev
Zone	0.471	1.174	0.574	1.438		
Plot size	-2.594***	0.376	-2.901***	0.672	1.336***	0.458
Farm size	-0.297**	0.148	-0.129	0.225	-0.397***	0.094
Livestock	-0.001	0.009	-0.000	0.011	0.017	0.015
Oxen	0.017	0.055	0.021	0.063	-0.081**	0.038
Adult male	0.080	0.059	0.113*	0.065	-0.002	0.045
Adult female	-0.028	0.057	-0.041	0.060	-0.053	0.035
Female	-0.486**	0.189	-0.451*	0.270	1.047***	0.129
Age	0.009**	0.004	0.007	0.005	0.005	0.004
Education	0.174*	0.091	0.106	0.109	0.087	0.063
Fertile plot	0.082	0.247	0.132	0.266	-0.201	0.148
Medium fertile plot	-0.039	0.234	-0.011	0.252	-0.157	0.139
Black soil	-0.649*	0.347	-0.694	0.463	0.023	0.223
Red soil	-0.594	0.371	-0.605	0.487	-0.176	0.208
Flat slope plot	0.501	0.359	0.400	0.334	0.263	0.213
Moderate slope plot	0.481	0.341	0.343	0.369	0.413*	0.221
Manure	0.000**	0.000	0.000**	0.000		
Fertilizer	0.002*	0.001	0.002*	0.001		
Lease	0.054	0.178				
Plot distance					0.004	0.003
Constant	0.269***	0.082	1.140	0.967	0.437	0.008***
Number of Observations	981					
* significant at 10%, ** significant at 5%, ***significant at 1%						

Note: 1. Dependent variable is the value of yield per hectare (‘000).

2. Kebele Dummies are included in the productivity but not in the plot rent equations. Some are significant.

3. Standard errors are bootstrapped.

5.2. Contract renewal

Table 5 presents the results from the survival analysis along with the selection equation representing the lease status of the plot. Female heads are not less likely to continue contracts with the same tenant than male heads. However, it should be noted that the magnitude of the coefficient is large and negative. On the other hand, female-headed households that are unable to monitor are less likely to renew contracts. Among the kinship variables, male tenants are less likely to renew contracts with blood relatives, while other kinship variables are found to be insignificant for both male and female household heads. The landlord’s experience of land gain or loss and expectations of future changes in the land size are significant and negative determinants of contract renewal, among the tenure security variables. However, expectation of future land redistribution and experience of conflict are insignificant.

Older and more educated households are more likely to renew contracts. Of the tenant characteristics included, the number of oxen the tenant has is not a significant determinant of contract renewal. Older tenants are less likely to get their contracts renewed.

In addition, results from the lease status selection equation follow the same pattern as the selection equation result in Section 5.1. except that the likelihood of renting out does not significantly differ between female and male owned plots, in this case.

Table 5: Bivariate Probit Model with Selection Estimation Results for the Likelihood of Contract Renewal on Rented Plots

Variable	Contract Renewal Equation		Selection Equation	
	Coefficient	Std. Err.	Coefficient	Std. Err.
Security	-0.041	0.091		
Changeland	-0.677**	0.268		
Conflict	-0.026	0.221		
Female	-1.509	2.377	0.142	0.118
Age	0.012**	0.005	0.012**	0.005
Education	0.229*	0.124	0.166***	0.062
Blood relation	-0.392*	0.209		
Blood relation*female	0.202	0.314		
Spouse relation	-0.181	2.358		
Spouse relation *female	-0.284	2.413		
Tenant’s age	-0.321***	0.115		
Tenant’s oxen	-0.006	0.089		
Inability to monitor	0.290	0.264		
Inability to monitor*female	-0.767*	0.459		
Satisfaction	0.793***	0.268		
Satisfaction*female	0.456	0.720		
Ability to find another tenant	0.013	0.181		
Ability to find another tenant*female	0.348	0.762		
Contract renewal*female	0.061	0.077		
Contract renewal	0.017	0.038		
Male adult			-0.074*	0.041
Female adult			0.002	0.033
Livestock			-0.006	0.011
Oxen			-0.081**	0.035
Farm size			-0.409***	0.085
Plot size			1.041***	0.402
Flat slope plot			0.194	0.219
Moderate slope plot			-0.001	0.261
Black soil			0.216	0.218
Red soil			0.282	0.262
Plot distance			0.004*	0.002
Fertile plot			-0.211	0.177
Moderate fertile plot			-0.115	0.146
Constant	2.925***	0.076	0.717	0.693
Number of Observations	981			
* significant at 10%, ** significant at 5%, ***significant at 1%				

Note: Standard errors are bootstrapped.

5.3.Productivity analysis including land leasing behavior

Table 6 presents the endogenous switching regression estimation for the determinants of productivity. The gender dummy variable is not significant in the leased regime. However, it is negative and significant in the non-leased regime confirming our hypothesis that female owned plots exhibit lower productivity. However, contract renewal[1], the link via which land owner's tenure insecurity is linked to tenant's level of effort, is insignificant. Since tenure insecurity and contract renewal are likely to be strongly correlated, the insignificance of contract renewal might be explained by its effect being picked up by the tenure insecurity variables.

In addition, in the leased regime, plot size is a negative determinant of productivity while farm size has a weaker but significantly negative impact. The effect of previous experience of conflict and expectations of reductions in the size of holdings both have negative effects on productivity of leased plots. This indicates that tenure insecurity indeed has a negative impact on the productivity of lased plots. The number of oxen the tenant has is a negative and significant determinant of productivity. The number of oxen the tenant has is a negative and significant determinant of productivity. This is a likely result in our case where the production environment is constrained by oxen availability and the more oxen a tenant has, the more number of lease arrangements the tenant may take up.

Total livestock ownership and oxen ownership are positive and significant determinants of productivity in the non-leased regime. While the other tenure security measures are insignificant, experience of change in the size of holdings has a positive impact on the productivity of non-leased plots. However, the impacts of plot level fertility, soil type and slope are generally weak. In addition, socioeconomic characteristics like age and education of the household and are insignificant.

The lease selection equation results are similar to the selection equation estimations in the previous sections. One major difference is that plot distance is a significant determinant of leasing out indicating that distant plots are more likely to be leased out.

[1] Contract renewal is for the coming production year while productivity is for the current production year. It should also be noted that, since contract renewal is likely to be endogenous, we used the predicted contract renewal in the regression

Table 6: Endogenous switching regression results of the determinants of productivity

	Lease out equation		Productivity Equation: Non leased pots		Productivity Equation: Leased plots	
Plot distance	0.002**	0.001				
Plot size	-1.311***	0.307	-4.191***	1.011	-2.314***	0.582
Farm size	-0.266***	0.079	0.576*	0.340	-0.339**	0.149
Livestock	0.064	0.021	0.218**	0.083		
Male adult	0.020	0.038	-0.056	0.137		
Female adult	-0.023	0.022	0.070	0.108		
Oxen	-0.101**	0.048	0.427**	0.202		
Female	0.423	0.132	-1.386***	0.433	-0.310	0.206
Age	0.005	0.003	-0.001	0.011	0.012**	0.005
Education	0.077	0.056	-0.038	0.191	0.061	0.114
Fertile plot	-0.169	0.141	0.416	0.444	0.145	0.259
Merium fertile plot	-0.193	0.138	0.282	0.462	0.036	0.251
Black soil	0.234	0.171	-0.924*	0.544	-0.546*	0.329
Red soil	-0.038	0.152	-0.277	0.500	-0.533*	0.320
Flat slope plot	-0.049	0.186	0.496	0.543	-0.092	0.381
Moderate slope plot	0.180	0.196	-0.177	0.598	0.200	0.398
Fertilizer			0.052	0.105	-0.048	0.061
Manure			-0.134	0.401	-0.573**	0.217
Security			0.035	0.290	-0.504***	0.167
Changeland			4.192***	0.519	0.471*	0.255
Conflict			0.340	1.731	-2.076***	0.449
Tenant's age					0.056	0.066
Tenant's oxen					-0.250**	0.108
Predicted survival					-0.434	0.299
Constant			-0.605	0.789	2.685***	0.341
Sigma(0)					-0.747***	0.235
RHO(0.u)					1.407***	0.097
Sigma(1)					0.661**	0.244
RHO(1.u)						
Number of observations	981					
* significant at 10%. ** significant at 5%. ***significant at 1%						

Note: Standard errors are bootstrapped.

6. Conclusions

Does gender discrimination have an impact on earnings and economic performance? This question has been widely examined in labor market studies where possibilities for differential wage payment exist. This paper assesses the possibility of discrimination against women and its impact on their productivity in a poor small farm setting where women are factor owners and employers. Because the main agricultural activities are undertaken by men, there are tendencies in such settings to disregard the role of women as farmers. This might undermine their landownership and weaken their bargaining position in the land lease market. Hence, we argue that women might be more tenure insecure and might have lower bargaining positions in the land lease market compared to their male counterparts and this would have a negative impact on tenant's effort and productivity.

In order to assess the role of women's tenure insecurity and bargaining power in maintaining the gender gap in productivity, we set up a double moral hazard model of a landlord and a tenant that allowed us to show the importance of landlord tenure (in)security in the determination of the optimal current level of tenant effort. The model also predicts that a high tenure security of a landlord leads to a higher probability of contract renewal. In turn, a lower probability of contract renewal leads to lower levels of tenant's effort, and vice versa.

The empirical analysis started out by establishing that female owned plots exhibit significantly lower productivity, which is in line with the findings by other studies. Tenure insecurity is shown to reduce the likelihood of contract renewal while contract renewal is not less likely for plots leased out by female landlords. As per the theoretical predictions, productivity is positively affected by tenure insecurity; however the impact of contract renewal is insignificant.

In sum, given the long history of women's lack of property rights over their land, an important policy progress has been made by formally entitling them to land rights. One important implication of our result is that a full stride towards empowering rural women and in land rights requires their proper recognition as farmers. This would enable them to feel more tenure secure and have better bargaining power in the land lease market and would eventually lead to closing the gender gap in productivity. At a more general level, this indicates that ensuring that informal grounds are leveled is important in order to obtain the expected results from a policy change.

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Heterogeneous Risk Preferences, Transaction Costs and Land Contract Choice

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Abstract

The paper analyzes how heterogeneities in risk preferences, rate of time preferences and transaction costs affect the choice of contracts among participants in the land lease market. The analysis draws from both agency and transaction cost theories, which propose alternative explanations of contract choice. Unique data from Ethiopia, containing experimental risk, rate of time preference measures and transaction costs are employed in the analysis. Tenant characteristics are more important than those of landlords in explaining contract choice. The results do not support the risk-sharing hypothesis of the agency theory as a motivation for contract choice while there is some support that discount rates and transaction costs affect contract choice. The results also indicate that the land lease market serves as a resource pooling mechanism by bringing poorer landlords and tenants into sharing arrangements.

JEL Classification: C93, D00, Q02

Key Words: Contract Choice**,** Risk Preferences, Transaction Cost, Rate of Time Preferences

1. Introduction

The organization of agricultural land transactions through contracts and the coexistence of multiple contracts has been the subject of much discourse in the economics literature. One reason for this pertains to the need to understand the prevalence of sharecropping with its perceived inefficiency *vis-à-vis* other contract forms (Hayami and Otsuka, 1993) as well as the distributional and access implications. However, despite immense academic and policy interest, contract choice studies have remained largely inconclusive. This study is an endeavor to contribute to understanding of land leasing[1] contractual arrangements by incorporating simultaneous heterogeneity with respect to risk preferences, time preferences and transaction costs into previous theories and explanations to contract choice.

In particular, our analysis draws from the two major streams of the broad literature that attempts to explain the coexistence of multiple contracts and their efficiency implications. A pioneering explanation is what is commonly called the agency theory, which claims that attempts to balance risk bearing and production incentives dictate contract choice and sharecropping comes out as an arrangement that addresses the two concerns optimally. However, a later approach, the transaction cost theory, counters the assertion by the agency theorists, arguing that uncertainty provides wider space for opportunistic behavior by tenants, which makes rental contracts optimal incentive mechanisms under uncertainty. In addition, our approach also borrows from recent empirical studies regarding the role of imperfect markets in contract choice that attempt to bridge the gap in theoretical and empirical findings by the agency and transaction cost explanations.

We argue that combined individual heterogeneity with respect to attitude towards risk and risk sharing, ability to curb opportunistic behavior, and liquidity constraints offers a more comprehensive explanation to the patterns of existing land contracts. In line with

[1] Land lease in this paper includes all land transactions that take place between a household in a farming community, who gives (part of) his/her land to another household in exchange for money or share of output, for a short period of time. The alternative land lease arrangements (contracts) considered in this study are rent, pure sharecropping and cost sharing.

this, the objective of this study is to assess the combined impact of risk-sharing, transaction costs, and liquidity constraint/discount rate. We have a number of hypotheses. In poor rural communities where production is weather dependent, output risk becomes an important concern. For a landlord, less input/output sharing means less production risk. Thus, risk averse landlords are expected to have a stronger preference for rental contracts than other landlords. In addition, an inability to contribute to inputs due to liquidity constraints and high discount rates make rental contracts attractive. Thus, landlords with a higher rate of time preference are more likely to go for rental arrangements.

However, consumption-smoothing concerns might make sharing arrangements superior to rental payments. Consumption smoothing concerns are associated with the fact that collecting upfront payments at the beginning of the season[2] leaves the landlord with no income to expect at the end of the season[3] and hence with no income for the rest of the year. An additional argument could be that the value of rentals is very low compared to the present value equivalent of sharecropping. Moreover, the landlord loses money if he/she uses the money collected from rental to buy crops, since crops are more expensive in the off-season (when rental money is collected) than in the on-season (during and after harvest). While the money from rental could be saved to buy cheap on-season crops, the months from May to October is a period where households struggle to feed themselves[4], making it hard to save the money. Landlords are also aware of the downside of sharecropping, the classical inefficiency it induces with respect to tenant effort. For landlords inclined to go for sharecropping, ensuring an optimal level of effort requires effective supervision of tenant labor. Thus, landlords with a higher ability to search are more likely to go for sharing contracts. This would make the landlord's ability to search, screen and monitor an important determinant of contract choice.

[2] In the setting we are studying, main season harvests take place November-January. Contractual agreements take place around April. Since rental agreements involve upfront payment, the landlord collects the money in April, while under sharing agreements the output is given to the landlord the following January.
[3] This was revealed to us upon discussion with some of the respondents. Fixed rent contracts are even referred to as yebelto-*tenesh*, which literally means an arrangement that involves emptying the plate.
[4] The period mentioned is popularly known as *the hungry season* across the poor developing world (See Hoddinott and Yohannes, 2002) in which households exhaust the stock of harvest but have highest nutritional needs due to the need to undertake the labor-demanding agricultural activities during that period.

From the tenant's point of view, rate of time preference may be important since upfront payment and input contribution are related to liquidity and credit constraints. In addition, risk-averse tenants would prefer pure sharecropping/cost sharing as a risk-sharing alternative. However, because of the supervision requirements of contracts involving input/output sharing, tenant characteristics become critical for sharing contracts. Thus, whether tenants with more preference for sharing get such contracts depends on their ability to search and to send signals that they are worthy tenants.

The empirical analysis assesses contract choice decisions by introducing the possibility of heterogeneity of transacting agents with respect to both risk preferences, time preferences and transaction costs simultaneously. While assessment of the effects of risk, discount rate and transaction cost are not new in the contract choice literature, this study is the first attempt to simultaneously look at these factors. Moreover, previous studies rely on proxies as measures of these factors. According to Akerberg and Botticini (2002) proxies[5] for both risk and market imperfection measures lead to matching errors and biased estimation results. Similarly, transaction cost studies focus on measures of transaction costs related to the nature of inputs or the nature of crops, and so far no study in agricultural contract studies has looked into individual level transaction costs. [6]

Section 2 presents a review of existing studies on land leasing contractual arrangements. The data and the context of analysis along with definition and construction of variables are given in Section 3. This is followed by section 4 where the econometric framework is discussed. The hypotheses stated in Section 1 will be empirically tested in section 5. Section 6 concludes the paper.

2. A Review of Alternative Contractual Arrangement Explanations

Studies regarding the choice of alternative agricultural land leasing arrangements are mainly based on two streams of literature: the agency and transaction cost explanations.

[5] Wealth and crop riskiness are used as risk aversion and market imperfection measures in the studies.
[6] Examples of individual-level transaction cost studies include Gebremadhin's (2003) work on the impact of individual level transaction costs on the choice of brokerage and Atkins and Dye's(1997) work on stock market exchange.

According to the agency theory, concerns over alignment of risk bearing and production incentives are what dictate an agent's choice of one contract over another (Matsen & Saussier, 2002). Marshall (1890) put forward the inefficient-sharecropping argument later known as the Marshallian inefficiency. It suggests that with sharecropping arrangements, it is in the best interest of a profit maximizing tenant to under-provide effort since he is not the full claimant of the residual effort. In this regard, rental arrangements give the first best results since the tenant has the full incentive to provide an optimal level of effort. On the other hand, without supervision, the tenant has the lowest incentive to provide effort under wage contract. Thus wage contracts give the lowest level of effort compared to the other contract forms.

However, under rental/wage contract, production risk is borne by the tenant/landlord respectively. Sharecropping could in this sense become a risk-sharing arrangement where production risk is shared between the tenant and the landlord. In line with this, Stiglitz (1974) shows that given a risk averse tenant and non-observability or costly monitoring of effort, sharecropping might dominate wage contract because of its incentive advantage and dominate fixed rental because of its risk pooling advantage.

On the other hand, according to the transaction cost theory, unobservability of the implementation of contractual agreements provides incentives for opportunism on the tenant's part. The landlord is, therefore, expected to opt for rental contract as a caution against this opportunism. The reason is that opportunism includes efforts to evade performance, to engage in asset damaging activities, to cheat on input application, and to under-report output, all of which impose costs to the landlord (Allen and Lueck, 1995). This apparently contradicts the risk sharing theory, which predicts that uncertainty in the production environment favours sharecropping due to its optimal alignment of incentives and risk.

While transaction costs with respect to search, screening and monitoring are central in the respective arguments, the essential deviation lies in the way the costs are perceived. For the agency theorists, moral hazard represents deviation from joint maximizing behavior due to the disincentives induced by sharing. Transactions cost theorists, on the other hand, see the opportunism to be akin to efforts to gain the maximum out of the distribution of gains or asset abuses (Matssen & Saussier, 2002). Empirical studies of actual contract choice also remain equally inconclusive with some supporting the risk sharing (e.g. Shaban, 1987) and others supporting transaction costs explanations (e.g. Allen and Leuck, 1999).

Recent studies focus on notoriously imperfect credit markets and their resulting liquidity implications as additional determinants of contract choice. Tikabo (2003) argues that rural communities are characterized by severe credit constraints leading to high discount rates. [7] As a result, in order to carry out cash-related transactions in the land lease market, tenants (for rent and input contribution) and landlords (for input contribution), would have to rely on their individual liquidity. Thus, liquidity constraints and the associated discount rates become important determinants of contract choice. [8] In addition, in early 19th century Italy, where credit markets were arguably under-developed, Akerberg and Botticini (2002) find evidence where poorer tenants matched with better off landlords pointing to the role of the land lease markets in relaxing credit constraints.

3. Empirical setting, data collection and variable description

The pattern of land ownership and distribution in Ethiopia has largely been shaped by the radical Land Reform of 1975 which made all land state property and introduced an egalitarian distribution[9] of user rights to land based on household size. The two decades following the reform were characterized by frequent redistributions in order to adjust operational holdings to family size and to accommodate new landless families. Moreover, the abolishment of outright land sales that occurred in the 1970s still holds, and until the early 1990s, any kind of land rental was prohibited.

In the study area, redistribution has been generally banned since 1997. Thus, land leasing has been the only viable way of accessing land for those who do not own (enough) land (Teklu and Lemi, 2004). Similarly, those who have excess (operational) land relative

[7] Credit market imperfections make individuals discount consumption at abnormally high rates. Thus discount rates could measure the degree of credit market/liquidity constraints (Pender, 1996).
[8] Tikabo (2003) used wealth as a proxy for discount rate.
[9] The land redistribution was generally more effectively egalitarian in the traditionally non-land owning and tributary mass of the South than traditionally land-owning mass of the North. Moreover, Kebede (2003) argues that some Pre-Land Reform inequalities are considerably carried over to post reform inequalities.

to other factors they own have also relied on the land lease market to balance their factor endowments in production (Tikabo, 2003).

An average land holding in the study area is a little more than one hectare. Ploughing land of that size takes roughly four oxen days, which creates a huge extra demand for land even for a farmer with an average land size and only a pair of oxen. This is compounded by landlessness leading to serious land scarcity. Thus, the decision to rent out and what contract type to choose is largely determined by the landlord. Since land is scarce, landlords generally have the upper hand in setting the terms of the contract.

However, there could be situations where the landlord is in a weaker bargaining position either due to either financial reasons (Bellemare and Barrett, 2003) or to the landlord being a female-headed household (Bezabih and Holden, 2006).

The data contain information on 125 pairs of land lease contracts in East Gojjam, a *zone* in the Amhara National Regional State of Ethiopia. The pairing is based on a sub-sample of land owners included in the third round of the Ethiopian Environmental Household Survey. The survey was conducted during the 2005/06 production year.

The survey consists of details of socioeconomic characteristics of both landlord and tenant households. Contracts contain information on the type of crop, who makes decisions and/or contributions on the type of crop, the amount of fertilizer applied, and crop/residue sharing rule. In addition to items stipulated in the contract, information on the search process, social capital and local market interactions as well as previous contracting experiences was collected.

The observed choice of contractual arrangements is a function of factors that are identified in risk sharing and transaction cost theories, and background socioeconomic and physical farm characteristics of the household. As per our hypothesis in Section 1, the main determinants of contract choice are the risk preferences and discount rates as well as the individual transaction costs of both landlords and tenants. We hypothesize that the landlord's risk preference is negatively related to the increase in the share of output that goes to the landlord. The impact of rate of time preferences on the landlord's choice of contract is mixed. On the one hand, poverty and credit market imperfections increase the landlord's desire to have immediate cash and hence increase the tendency to go for rental arrangements, which involve upfront payment. On the other hand, the risk of foregoing consumption during the coming year and receiving lower amounts in terms of rent, both of which are related to credit market imperfections and high discounting, make rental arrangements less attractive. We also hypothesize that a higher search ability of the landlord increase the tendency to go for sharing contracts. This is because finding a trustworthy tenant with low tendencies to shirk on effort relies on the landlord ability to search for such a tenant.

To the tenant, high risk aversion increases the tendency to go for sharing contracts since such contracts lead to sharing output risk. In addition, sharing contracts are more likely to be favored by tenants with high rate of time preferences. This is because these tenants are likely to be liquidity and credit constrained, and sharing avoids the burden of paying cash upfront. Tenants with high search and signaling ability are more likely to go for sharing contracts, since the type of tenant is more critical in sharing than rental contracts.

Contractual arrangements are also functions of socioeconomic and physical farm characteristics of a farm household, which determine the household's preferences of one form of contract over another. We base our choice of such variables on contractual studies (e.g. Tikabo, 2003). Definitions and summary statistics of the variables used in our analysis are presented in Tables 1and 2 respectively.

Table 1: Variable definitions and descriptions

Variables	Description
LANDLORD SOCIOECONOMIC & FARM	**CHARACTERISTICS**
Education	Head's formal education (1=read and write; 2= read only; 3=none)
Age	Age of household head
Female	Gender of the household head
Male adult	The number of male working-age family member of the landlord per ha
Female adult	The number of female working-age family member of the landlord per ha
Livestock	The number of livestock per ha
Oxen	The number of oxen per ha
Flat slope plot	Flat slope of the plot (1=flat; 0=not flat)
Medium slope plot	Medium slope of the plot (1=medium; 0=not medium)
Fertile plot	Fertile plot (1=fertile; 0=not fertile)
Medium fertile plot	Medium fertile plot (1=medium fertile; 0=not medium fertile)
Black soil	Plot with black soil color (1=black; 0=not black)
Red soil	Plot with red soil color (1=red; 0=not red)
Plot size	Total farm size (ha)
Farm size	Plot size (ha)
Plot distance	Distance of the plot from homestead (minutes)
TENANT	**CHARACTERISTICS**
Tenant's age	Tenant's age
Tenant's oxen	The number of oxen owned by the tenant
RISK&TIME PREFERENCE	**VARIABLES**
Landlord's risk preference	An experimental measure of landowner's risk aversion
Landlord's rate of time preference	An experimental measure of landowner's rate of time preference
Tenant's risk preference	An experimental measure of tenant's risk aversion
Tenant's rate of time preference	An experimental measure of landowner's rate of time preference
SEARCH &SIGNALING	**VARIABLES**
Tenant's access to local factor market	An index of variables indicating the tenant's ability to acquire oxen and labor in the local market
Landlord's access to local factor market	An index of variables indicating the landowner's ability to acquire oxen and labor in the local market
Tenant's ability to acquire help when needed	A dummy variable indicating tenant's ability to mobilize free labor and money in case of emergency
Landlord's ability to get credit in kind	A dummy variable indicating whether the landlord would be able to acquire credit in kind
Tenant's commitment to other landlords	A dummy variable indicating whether the tenant has contractual agreements with other landlords
Tenant's land ownership	A dummy variable indicating whether the tenant owns any land of his own
DEPENDENT	**VARIABLES**
Contract choice	A categorical variable with three levels where 1=rent; 2=pure sharecropping & 3= cost sharing
Lease out	A dummy variable indicating whether a plot is leased out or not

Table 2: Summary statistics of variables used in the regression

Variables	Mean	Std.Dev.	Minimum	Maximum
LANDLORD SOCIOECONOMIC & FARM CHARACTERISTICS				
Education	1.403	0.773	1	3
Female	0.412	0.494	0	1
Age	55.56	17.57	22	95
Adult male	1.295	1.341	0	8.6
Adult female	1.958	1.357	0	7.1
Livestock	2.879	4.409	0	20.7
Oxen	1.021	1.837	0	10.8
Fertile	0.306	0.461	0	1
Medium fertile	0.362	0.480	0	1
Black soil	0.264	0.441	0	1
Red soil	0.555	0.497	0	1
Flat slope plot	0.545	0.498	0	1
Medium slope plot	0.257	0.437	0	1
Plot distance	17.6	71.2	0	900
Plot size	0.312	0.194	0.003	1.356
Farm size	2.162	1.099	0.1	4.929
TENANT CHARACTERISTICS				
Tenant's age	1.982	0.758	1	3
Tenant's oxen	2.034	1.118	0	0
RISK&TIME PREFERENCE MEASURES				
Tenant's risk	4.32	1.994	1	6
Tenant's rate of time preference	0.398	0.183	0.117	0.963
Landlord's risk	4.008	2.081	1	6
Landlord's rate of time preference	0.364	0.172	0.117	0.963
SEARCH &SIGNALING				
Tenant's ability to acquire help when needed	4.823	1.418	1	6
Tenant's access to local factor markets	4.700	2.511	1	8
Landlord's access to local factor markets	2.857	2.132	0	8
Landlord's ability to acquire credit in kind	0.766	0.423	0	1
Tenant's commitment to other landlords	0.452	0.498	0	1

Below we present the dependent and independent variables used in the analysis.

Contract Choice

The dependent variable is a categorical variable with three levels. The categories include pure rent, pure sharecropping and cost sharing. Under rental arrangements, the tenant gives the landlord an upfront cash payment for the period of the contract, and all input costs are borne by the tenant. The other two are variants of sharecropping, where pure sharecropping involves output sharing at the end of the production period. In addition, under sharecropping, inputs like fertilizer and seed are fully contributed by the tenant. Likewise cost sharing arrangements involve end-of-period output sharing. But under cost sharing, the landlord contributes to inputs like seeds and fertilizer. [1]

Household socioeconomic and physical farm characteristics

Socioeconomic variables include the household head's age and level of education, and oxen ownership for both the landlords and the tenants. In addition wealth and labor availability measures were included for the landlords. Plot-level fertility, slope, and soil type, for plots owned by the landlords are also included as physical farm variables.

Search ability

Since it is difficult to get an ideal measure of search ability for the landlord and the tenant, we use proxies as measures. In particular, we chose the household's access to other (parallel) local factor markets as one measure of search ability. This variable is constructed by aggregating the household's participation in the local markets. Households were asked whether they would be able to rent in/out oxen, hire in/out agricultural labor and borrow/lend grains when needed. The yes/ no answers were aggregated to form an index measuring the household's access to the local factor markets. Another measure of search ability that we used is the ability to access help upon emergency which is measured as a dummy variable.

Signaling ability

Because of the difficulty to objectively measure signaling ability, we opted for proxies. One is whether the tenant has signed a contract with other landlord(s). The rationale for choosing this as a measure of signaling ability is that it indicates the tenant's reputation as a good farmer. The other measure of signaling ability used is the tenant's land ownership since landless tenants will generally be less experienced with farming activity.

Rate of time preferences and risk aversion

The time preference experiment was set up following Pender (1996). The experiment was described to households as a hypothetical game consisting of six choice sets. In

[1] Sometimes pure sharecropping involves an upfront fixed payment in addition to output sharing at the end of the production period. The upfront payment in this case is usually repaid later (upon harvest or when the landlord gives cash) or in some cases it is never repaid. As per our discussion with some of the respondents, we got the impression that non-repayable upfront payments were given to households with good plots while repayable upfront payments were given as an interlinked credit arrangement for cash-stressed households.

each choice set, the households were offered a choice between a specific amount of money to be received the same day and an alternative amount to be received on an alternative future date. The choice sets were arranged in such a way that the gap between the amounts to be received the same day and an alternative amount to be received on an alternative future date were randomly sequenced. All choice sets offered choices between Br. 50[2] to be received the same day and an amount ranging from Br. 65 to Br. 195 to be received on the same day next year. The choice set with the smallest difference was given by an early reward of Br. 50 and a later reward of Br. 65. The choice set with the largest difference was given by an early reward of Br. 50 and a later reward of Br. 195. The range of rate of time preference was inferred when the respondent crossed over from preference for an early reward to preference for a later reward. The obtained response was used to compute an interval measure of rate of time preference for each respondent. The structure of the rate of time preference experiment is presented in Appendix 1.

The risk preference experiment was set up following Yesuf (2004), where the standard risk preference experiment is modified to fit into the real life experiences of farmer choosing between alternative levels of agricultural yields. The experiment was also described to the households as a hypothetical game consisting of six choice sets. Each choice represented two alternative farming systems with identical costs but with different output levels. The realization of each outcome/each farming system carried a 50% probability of a good or a bad harvest. For each outcome, the expected gains are calculated as the average of the good and bad harvest, while the spreads are calculated as the differences between the good and bad harvest. The choice sets were arranged in a tree structure where the choice made in the first choice set determines whether one branches into more/ less risky choice alternatives. A bad harvest ranged from 0kg output to 100kg output while a good harvest ranged between 100kg to 400kg. The expected gain from a combination of bad-good harvest outcomes ranged from 100 to 200kg, while the spread ranged between 0 and 400kg. An extreme outcome consisted of an expected gain of 100kg and a spread of 0kg, while a neutral outcome consisted of an expected gain of 200kg and a spread of 400kg. Accordingly, the households were subjected to one choice at a time, in order to determine their risk preferences. The

[2] Br. is the Ethiopian currency and USD. 1 is equivalent to about Br. 8.6.

obtained response was used to compute an interval measure of risk preference for each respondent. The structure of the risk preference experiment is given in Appendix 2. Table 3 presents a summary of the main variables with the expected signs.

Table 3: Variable relationships and expected signs

Dependent	Explanatory	Expected sign
Contract choice	Landlord Variables	
Pure rent=1 Pure sharecropping=2 Cost sharing=3	Risk preference Rate of time preference Access to local factor market Ability to acquire help when needed	- +/- +/- +/-
	Tenant Variables	
	Risk preference Rate of time preference Access to local factor market Ability to acquire help when needed	+ - +/- +/-

4. Empirical Specification

Households make contract choices on plots they are leasing out. Since plots that are leased out are likely to be systematically different from plots that are not leased out, the possible selection bias needs to be addressed for proper analysis of the determinants of contract choice. To that effect, the following selection equation is specified:

$$P_i = \begin{cases} 1 \text{ if } \alpha + \gamma * dem + \mu * farm + u > 0, \\ 0 \quad otherwise \end{cases} \quad (1)$$

where P_i is a binary variable which takes the value one if the plot is leased out and zero if the plot is managed by the landlord him/herself, *dem* is the vector of socioeconomic variables of the landlord, *farm* is the vector of physical farm characteristics of the landlord, $\alpha, \gamma \; \& \; \mu$ are coefficients, and u is the error term. The contract choice equation is given by:

$$Contract = \omega + \beta * dem + \theta * farm + \iota * tcxs + \gamma * risk + \lambda * rtp + \vartheta * search + \psi * SIG + \upsilon \quad (2)$$

where contract stands for $\begin{cases} 1: rent \\ 2: \text{ pure sharecropping} \\ 3: costsharing \end{cases}$

tcxs is the vector of socioeconomic and physical farm characteristics of the tenant, *risk* is risk aversion variables for the landowner and the tenant, *rtp* stands for rate of time preference variables for the landowner and the tenant, *search* stands for the vector of search ability variables for the landowner and the tenant, *sig* stands for the variable measuring the signaling ability of the tenant, $\omega, \beta, \gamma, \lambda, \vartheta, \iota \, \& \, \psi$ are coefficients, and *v* is the error term.

As we argued in Section 3, when we go from rental contracts to pure sharecropping and cost sharing, then the tenant's output share and output risk decrease and vice versa. Given this and following Tikabo (2003), we opt for an ordered probit model of contract choice. To address the selection bias, we follow Heckman (1979) and employ Heckman's two-stage estimation.

According to Heckman's specification, the error terms, *u* and *v* are assumed to follow a bivariate normal distribution where $v \sim N(0,1)$ and $E(u/v) = \gamma v$; γ is a constant and where $\gamma = 0$ indicates that *u* and *v* are uncorrelated. For non-zero γ values, *u* and *v* are correlated and the following relationship holds:

$$\begin{aligned} E(y_1 \mid x_2, y_2) &= x_1\beta_1 + \gamma_1 E(v \mid x_2, y_2) \\ &= x_1\beta_1 + \gamma_1 h(x_2, y_2) \end{aligned} \tag{3}$$

where x_1, y_1 x_2, y_2 represent the independent and dependent variables in equations (1) and (2) respectively. Since $h(x_2, y_2) = E(v \mid v > -\delta x_2) = \lambda(\delta x_2)$ where $\lambda(.) \equiv \phi(.)\Phi(.)$ is the inverse Mill's ratio, the estimable form of equation (3) could be equivalently written as:

$$E(y_1 \mid x_2, y_2 = 1) x_1\beta_1 + \gamma_1\lambda(\delta x_2) \tag{4}$$

The procedure estimates equation (1), which is the leasing decision equation in the first stage. The second stage in this estimation procedure is the ordered probit equation of contract choice that incorporates the inverse Mills ratio as a correcting term.

5. Results

We present the results from Heckman's two-stage estimation of the determinants of contract choice in Table 4. The first stage represents selection equation for the lease status of the plot and in the second stage ordered probit model of contract choice is estimated.

In the contract choice estimation, the rate of time preference for the tenant is not significant while that of the landlord is positive and significant, which indicates that landlords with higher discount rates tend to go for more sharing. The risk measure is also not significant neither for the tenant nor for the landlord. This indicates that there is no support for the risk-sharing hypothesis.

Tenant's current engagement with other landlord(s), which we used as a measure of tenant signaling ability, is significant and negative, indicating that tenants with more landlord(s) than the current landlord are likely to get more incentive-contracts like rent. Tenant and landlord ability to get help when needed, and access to local factor markets, which we used as proxies for landlord and tenant search ability are insignificant. Although the transaction costs measures are mainly insignificant, the fact that tenant characteristics are significant may indicate that those pick up the effects of transaction costs.

Many of the socio-economic and physical farm characteristics of the landlord are not significant. However, households with more educated heads are significantly less likely to go for sharing contracts. This could be because more educated households might be going to school and thus have less time for farming activities, which may make less sharing easier both in terms of possible labor contribution as well as supervision. In addition, more fertile plots are likely to be leased out under sharing arrangements. This could be due to the landlord's strategy to reduce asset abuse by the tenant, and is in line with the finding by Dubois (2002).

Older tenants are more likely to go for sharing contracts probably due to the possibility of getting labor help from landlords. On the other hand, tenants with more oxen are likely to go for less sharing contracts. This result may be due to the high correlation of wealth and liquidity with oxen ownership and hence oxen ownership might be picking up the effects of discount rate on contract choice.[3]

A further assessment of our results indicates that there is a tendency for landlords and tenants to match along certain characteristics. Particularly, the results show that landlords with a high rate of time preferences and less wealthy tenants tend to go for sharing contracts. This indicates that the land lease market is a mechanism for

[3] Higher discount rates are associated with lower oxen ownership and vice versa (Yesuf, 2004).

poor tenants and landlords to pool resources together for production. Similarly, wealthier tenants/landlords go for less sharing contracts.

The lease-out selection equation results show systematic differences between leased and non-leased plots, which is in line with Dubois (2002) who also found similar selection biases in the decision to lease out. Many of the physical plot characteristics are insignificant except for larger size plots, which are significantly more likely to be leased out. This may be a strategy by landlord households who are oxen and labor constrained: to keep and manage smaller plots more efficiently but to lease out bigger plots to relatively more oxen and/or labor endowed tenants. The household head's levels of education and per hectare oxen and livestock ownership are not significant determinants of leasing out. Households headed by a female or those with more adult male family members are more likely to rent out their land.

Table 4: Heckman's two-stage estimates of determinants of contract choice

	Contract choice equation		Lease out equation	
	Dep. Variable : 1=rent; 2=pure sharecropping; 3=cost sharing			
Landlord characteristics	coefficient	Std.err.	coefficient	Std.err.
Plot size	0.936	0.834	1.604***	0.320
Farm size	-0.138	0.092	-0.159	0.037
Livestock	0.003	0.037	-0.001	0.034
Oxen	0.081	0.099	-0.013	0.081
Male adult	-0.380**	0.166	0.181**	0.063
Female adult	0.553**	0.132	-0.093	0.061
Female	-0.118	0.202	0.321**	0.158
Age	-0.002	0.005	0.001	0.003
Education	-0.268*	0.136	-0.025	0.084
Fertile plot	0.485**	0.212	-0.066	0.162
Medium fertile plot	0.190	0.197	-0.060	0.158
Black soil	0.311	0.345	0.025	0.077
Red soil	0.119	0.337	-0.034	0.158
Flat slope plot	-0.119	0.236	0.232	0.282
Moderate slope plot	-0.389	0.239	0.243	0.253
Plot distance			-0.008	0.005
Tenure security	-0.191	0.134		
Tenant characteristics				
Tenant’s age	-0.018**	0.007		
Tenant’s oxen	-0.222**	0.095		
Rate of time preference and risk				
Landlord’s rate of time preference	0.732*	0.396		
Landlord’s risk	0.017	0.069		
Tenant’s risk	-0.076	0.067		
Tenant’s rate of time preference	0.256	0.428		
Search and screening				
Tenant’s ability to acquire favour in need	0.109	0.074		
Tenant’s access to local factor market	-0.037	0.045		
Landlord’s ability to get informal credit	0.267	0.198		
Landlord’s access to local factor market	0.032	0.049		
Tenant’s commitment to other landlords	-0.403**	0.207		
Tenant’s land ownership	-0.303	0.249		
Constant	0.936	0.834	0.431	0.951
Inverse Mill’s Ratio	1.988	.0003***		
Number of Obervations (609)		396	609	
Standard errors in Parentheses : * significant at 10%, ** significant at 5%, ***significant at 1%				

6. Conclusions

Our interest here is in trying to see if landlord-tenant characteristics with respect to risk sharing, discount rates and transaction cost in the land lease market influence contract choice. Based on the explanations from the agency and transaction cost theories, and complementary market imperfections that characterize rural factor markets, we expect that transaction costs, risk and rate of time preference are important and simultaneous determinants of contract choice.

We employ data from the Central-Western Highlands of Ethiopia that consists of information on contractual arrangements and socioeconomic and physical farm characteristics of landlords and matching tenants. Risk and time preferences and search abilities for both land owners and tenants, and tenant's signaling ability as well as relevant demographic information are used.

The results show that tenant characteristics are more important in explaining contract choice than those of landlords. Landlord rate of time preference is a significant determinant of contract choice indicating that credit constraints matter. However, risk preferences are not significant for tenants or landlords. Hence, the risk-sharing hypothesis of the agency theory as a motivation for contract choice while there is some support that discount rates and transaction cost considerations affect contract choice.

In addition, the results from the binary lease out decision equation indicate that landlords make the decision to lease out based on certain considerations. Our finding that plots with bigger sizes are likely to be rented out might be associated with the inverse farm-size productivity results that are consistently found across smallholder agricultural efficiency studies. If owner-operators manage smaller plots, to the extent that tenants manage leased-in plots less efficiently, then landlords with bigger leased out plots may be the ones with overall farm inefficiency. Further studies that look into such links could lead to a better understanding of farm size-efficiency relationships. Consistent with expectations, female headed households are also more likely to rent out.

One important implication of the results is that there is a tendency for landlords and tenants to match along certain characteristics. Particularly, our results indicate that the land lease market serves as a resource pooling mechanism by bringing together poor landlords and tenants into sharing arrangements. Further studies are needed to examine the characteristics of landlords and tenants that are matched by assessing leasing in/out decisions directly.

While our study is one of the few land lease market studies that include matching of landlords and tenants, our sample is based on landlords and tenants who are currently observed in the market. It does not include potential tenants and landlords who do not currently take part in the land lease market but who are possibly screened out due to constraints faced in the land lease market. Future studies that include such information could illuminate our understanding of agricultural contract choice and the workings of the rural land lease market at large.

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Appendix

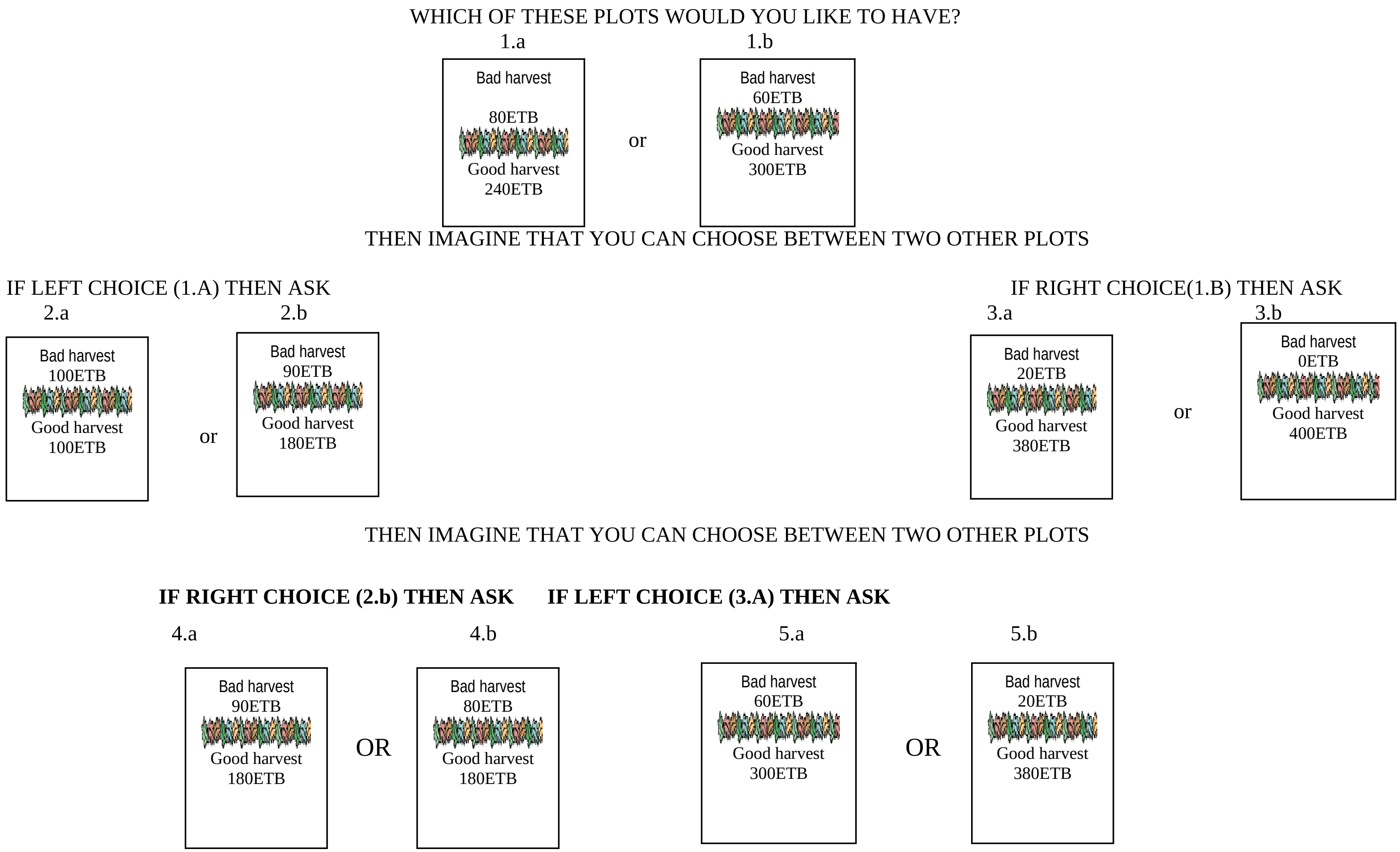
Appendix 1: The time preference experiment

We would like to ask you questions regarding how you feel about money today compared to money exactly one year from now. Imagine that you can choose between receiving 50 ETB today or a larger sum one year from now. Which would you choose?

Choice set1	50 ETB Now	Or	65 ETB after 12 months
Choice set2	50 ETB Now	Or	105 ETB after 12 months
Choice set3	50 ETB Now	Or	195 ETB after 12 months
Choice set4	50 ETB Now	Or	80 ETB after 12 months
Choice set5	50 ETB Now	Or	160 ETB after 12 months
Choice set6	50 ETB Now	Or	130 ETB after 12 months

Appendix 2: The risk preference experiment

We would now like to know how you would choose between different agricultural plots with different characteristics. Imagine that you have two plots. The production on the plots differ depending on if the rains are good or bad. There are equal chances (50%) of good or bad rains.



Agrobiodiversity Conservation under an Imperfect Seed System: the Role of Community Seed Banking Scheme

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Abstract

The study is an empirical investigation of agrobiodiversity conservation decisions of small farmers in the central highlands of Ethiopia. The primary objective is to measure the effectiveness of Community Seed Banking (CSB) in enhancing diversity while providing productivity incentives. Our results indicate a significant impact of participation in CSB on farm-level agrobiodiversity. However, the level biodiversity conservation was not found to have the expected reinforcing impact on participation indicating no support for simultaneity. CSB participation also led to increase in productivity consistent with the need for such incentives to enhance diversity at a farm level. Our assessment of the performance of the GLS estimator yielded a significant discrepancy between the GLS and bootstrap estimates. This led to the conclusion that bootstrapping asymptotic estimations might be required for appropriate inference.

JEL classification: C35, Q12, Q29

Key words: Agrobiodiversity; Seed system imperfection; Amemiya's GLS; Bootstrapping

1. Introduction

The provision of public goods is commonly financed by taxation or subsidies to private expenditure or action (Roberts, 1987). However, in poor developing countries, imposing taxes on individuals based on the 'polluter pay principle' may be questionable, as it would enhance poverty (Holden et al., 2005). On the other hand, state subsidy is, in many cases, justified for a very narrow range of public goods due to priority reasons. In cases where the goods do not fall into this range, one way of ensuring their provision is through exploiting possible synergies between private incentives and public good generation (e.g. Lamb, 2002).

In line with this, the study focuses on agrobiodiversity[1] as a quasi-public good and assesses possible synergies between improvement in the working of the local seed system, and its conservation. Since the provision of agrobiodiversity is largely *in-situ*[2], the level of conservation is highly dependent on individual farmers' decisions. Under the condition of imperfectly working seed system, an easy-access seed source will provide incentives for adoption of seeds from the particular source. If the farmer's decision is such that the seeds adopted add to the existing seed portfolio, farm-level diversity will be enhanced.

The aim of the paper is to assess the potential of a scheme called Community Seed Banking (CSB), which intends to correct for imperfections in the local seed system by availing easy access to local seeds, and to enhance farm level agrobiodiversity (Lewis and Mulvany, 1997; Demissie and Tanto, 2000). The efficacy of CSB is based on two premises. One is that the CSB seed system expands the availability of local varieties to individual farmers, and therefore, increases diversity. The other premise is that given imperfections in the already existing seed system, the provision of seed varieties would ease constraints to seed access. In turn, this would lead to improved resource allocation and increased productivity. However, for the increase in productivity to be realised, the varieties need not be inherently more productive than the other available varieties; the productivity increase comes about

[1] The component of biodiversity that contributes to food and agriculture production (European Environmental Agency, 2005).

[2] In situ conservation is the conservation of ecosystems and natural habitats and the maintenance and recovery of viable population and species in their natural surrounding or in surroundings where they have developed their distinctive properties (UNEP, 1994).

because of improvement in access to seeds and the resulting improvement in the allocation of resources.

Based on this, we set out to investigate the role of CSB in enhancing agrobiodiversity and in increasing farm-level productivity. We hypothesize that CSB participation will have a positive impact on biodiversity. Also, its impact on productivity will be positive.

Previous studies analyzing participation in agri-environmental schemes looked into farmer (e.g. Wilson, 1997) and scheme factors (e.g. Vanslembrouk et al., 2002) as important determinants of the decision to participate and of the degree of participation. In addition, other aspects not captured by 'farmer' and 'scheme' factors are also indicated to be important in explaining participation in such programmes. Wossink and van Wenum (2003) found that perception of environmental risks is an important additional reason to participate in agri-environmental schemes. In their analysis of the determinants of participation in unsprayed crop edges program in the Netherlands, Van der Muleun et al. (1996) found that perceptions regarding the environment significantly differ between participants and non-participants.

In the case of CSB intervention, we argue that in addition to 'farmer', 'scheme', and other behavioral factors, previous knowledge and experience in managing biodiversity affect participation in CSB. Since knowledge and experience in managing biodiversity are directly related with the level of diversity, this implies that diversity will be a determinant of participation. This, together with our main hypothesis that participation is a determinant of diversity, implies that there is simultaneity between diversity and participation. Thus, assessment of the impact of CSB on agrobiodiversity requires a simultaneous estimation of an equation system with participation and biodiversity measures as endogenous variables.

The rest of the paper is organized as follows. In Section 2, we present description of seed systems and the mechanisms by which CSB would work to enhance diversity and increase productivity. Section 3 follows with a description of the setting and sampling procedure. Section 4 presents the econometric model and estimation techniques. The results and discussion are presented in section 5. Section 6 concludes the paper.

2. CSB, Seed System Imperfection and Agrobiodiversity

In poor, smallholder agriculture, a number of seed sources comprise the seed system which farmers access planting materials from. These include savings from own harvest, farmer-farmer exchange/borrowing, purchases from the local market, provision via projects and NGOs, other informal seed sources, as well as distribution of seeds via national seed distribution programs, which are present in many developing countries. At the village level, most farmers consistently obtain seeds from own harvest, from neighbors and from village markets (Ndjeunga, 2002). In addition, in Mexico, for instance, farmer-farmer seed exchange is highly frequent both in terms of modern and traditional varieties (Rice and Smale, 1998).

If farmers have to rely on own-source, they would have to save from previous harvests. In poor, subsistence agriculture, this would entail that only those capable of saving from previous harvests could access planting materials from own-harvest. In addition such seed sources are characterized by storage problems associated with pest infestations and deterioration in seed quality (Lewis and Mulvany, 1997). Seed exchange and borrowing among farmers also tends to have limited scope. According to Sperling et al. (1996) the seed diffusion among farmers happens within a narrow social circle–not every one who asks for seed obtains it and seeds targeted for stressful environments move more slowly than highly productive seeds

Another component of the seed system is the formal/modern component, which is either under national seed distribution programs or the private seed multiplication and distribution sector. The coverage of public sector seed schemes has been very low either due to ill-implementations or structural adoption problems. There has also been little interest in multiplying and distributing seed by the private sector since there is limited market potential. A combination of poor public sector performance and lack of private sector interest makes formal seed systems less reliable sources of seed (Ndjeunga, 2002). In addition, the modern component of the seed system is also characterized by positive transaction costs to access, indicated by factors like costly supplementary inputs, costly experimentation, seasonal liquidity and family labour constraints (Moser and Barrett, 2003).

Imperfections in both the traditional/informal and the modern seed sources constitute positive transaction costs in the already existing seed system, which leaves room for improvement in terms of provision of a relatively easily accessible source. Given this, projects/programs with objectives of increasing seed materials to farmers through farmer participatory methods could be one way of availing seeds that are desired by and affordable to farmers.

CSB is a scheme, which aims at improving the working of the existing seed system by availing easy-access seeds. The scheme is part of the Global Environment Facility initiative to strengthen *in situ* conservation of farmers' traditional landraces with their natural competitors such as pests, predators, and pathogens together with the associated farmers' traditional knowledge on these landraces which can be instrumental in utilization and development of new crop varieties from farmers original landraces. Through a method of establishing community seed banks, the project links farm communities and their landraces with the existing genetic resource conservation efforts of central Gene Banks (Demissie and Tanto, 2000).

The scheme involves identification, collection, multiplication, storage and distribution of local seeds. Farmer groups engage in the task of identifying local varieties that are desired by farmers. The selection criteria are based on the local availability and distribution of the identified variety, availability of the variety in other localities or in the central gene bank and assessment of the individual farmer's demand for it. The selected varieties will be collected and multiplied on rented plots and stored in the CSB storehouse. Participants can borrow local seeds of available types and amounts. Participants are also entitled to interest on deposited seeds (Demissie and Tanto, 2000).

In our study, the main source of CSB varieties is the central gene bank of the Institute of Biodiversity Conservation and Research. Another source of CSB seeds is deposit and storage by CSB participants. The varieties from CSB will be of such a nature that they are either currently planted by some farmers but others do not have access to them or they are varieties that are not currently planted by farmers in the locality but are either available in other localities or in the central gene bank (Lewis and Mulvany, 1997).

While participation might include attending trainings, farmer-days, taking part in on farm seed multiplication, seed selection, seed collection, seed storage and borrowing seed, we only focus on borrowing seed. We also refer as participants only those who were engaged in borrowing seeds during the period of the data collection.

By increasing the availability of local seeds to farmers, CSB facilitates easier seed flow among farmers, thereby widening their varietal choice. It also expands the variety basket available at the village level since CSB varieties could originate from other localities or the central gene bank storage. In addition, CSB provides farmers with modern storages, which give the seeds longer shelf life and better protection against pests and diseases.

Thus, provision of CSB seeds would increase productivity given the imperfections in the already existing seed system. In line with this we hypothesize CSB to be a seed source, which improves the already existing seed system, thereby enhancing productivity.

Since CSB seeds are local varieties, there are reasons to believe that their adoption could lead to increased farm-level diversity. Within-farm heterogeneity with respect to physical farm characteristics is one reason. Given appropriate combinations, planting a diverse set of varieties would lead to higher overall productivity. Particularly, local varieties do well on marginal fields. In line with this, Meng et al. (1998b) found that households managing farms with diverse characteristics tend to grow more landrace varieties.

Another reason for the association between local varieties and diversity could be the transaction costs of accessing varieties with particular qualities. Smale (1995) noted that Malawian maize farmers tend to grow local varieties for quality reasons (since the local maize varieties have superior consumption qualities) and especially because it is not certain that the particular local varieties will be available in the market. Thus, households who face higher transaction costs of accessing a wide range of varieties tend to diversify production. This is in line with Meng et al. (1998b) observation that quality issues become relatively unimportant for households that have given up traditional varieties, while high transaction costs of obtaining desired qualities in a particular variety contribute to the continued cultivation of landrace varieties.

In sum, we hypothesize that CSB would relax seed access constraints and increase productivity. In addition, since CSB provides local varieties, it contributes to increased farm-level biodiversity.

3. Setting, Sampling Procedure and Data Used

The study was conducted in an area within the broad agro ecological zonation of Ethiopia known as the Central Highlands in May 2004. The study site is Chefedonsa, a *woreda*[3] with 30 *kebeles*, located in the Eastern Oromiya Zone of the Oromiya National Regional State. The site is a center of origin and diversity for many wheat and pulse varieties. Therefore, one of the eleven community seed banks across the country is located in the woreda. Agroecologically, the study area has a good agricultural potential and is located on a plateau as high as 2800m above sea level, which makes it frost prone. Main produces include durum and bread wheat, *teff*[4] and pulses.

The CSB is located in the southeast corner of the woreda. While the scheme targets twelve of the thirty kebeles in the *Woreda*, we only focused on six of them. The reason is that the other six had too few participants which, according to the staff managing the Bank, could be due to lack of participation in farmer days, training days or lack of informal information flow. Using a stratified random sampling, where the proportion of the population in each of the six kebeles are used as strata, a sample of 381 households were interviewed.

The dependent variables in our analysis are participation in the CSB, diversity in crop choice and the level of productivity. Participation is a dichotomously observed variable representing whether or not the respondent household has borrowed seeds from the CSB in the current production year.

Diversity is measured by the Shannon index[5] as $D = -\sum \alpha_i \ln \alpha_i$, where α_i is the share of area occupied by the i^{th} crop variety in a household. Following Rice and Smale (1998), we refer to a variety as a crop population as recognized and named by farmers. Traditional varieties are those that are selected and maintained by farmers while modern/improved varieties are those varieties which are developed by the

[3] Woreda corresponds to a district while kebele corresponds to a village.
[4] *Teff* is a cereal with tiny grains and is used for making Injera, a staple for Ethiopians.
[5] Since diversity has many dimensions, a number of measures have been used to represent it. In this study, we started by using two measures: the count (representing richness) and Shannon indices (representing richness and relative abundance). However, since the results were similar, we opted to report the results based on the Shannon index.

international or national plant breeding programs. Both traditional and modern varieties are included in the diversity index. Our analysis included eight types of crops and their varieties. For details on crops and varieties included in the analysis, see table 1.

Table1: Varieties Planted by Households by Crop Category

	Crop type								
	Wheat	Teff	Peas	Lentil	Barley	Chickpea	Beans	Vetch	All crops
Total Number of varieties	37	29	21	14	5	10	6	5	127
Average number of varieties planted per household	2.31	0.64	0.75	0.24	0.02	0.29	0.07	0.16	4.58
Standard Deviation	1.06	0.69	0.57	0.49	0.16	0.47	0.26	0.38	1.91
Minimum	0	0	0	0	0	0	0	0	1
Maximum	8	3	3	3	1	2	2	2	14

Commonly used farm level-diversity measures are based on inter-specific and infra specific concepts. Inter-specific diversity is the diversity among crop species, while infra-specific diversity is the repertoire of varieties of a crop that farmers grow simultaneously (Bellon, 1996). While both concepts diversity are widely used in the agrobiodiversity literature, we found the concepts less suitable for our purpose for the following reasons.

Using interspecific diversity to assess the impact of participation in CSB as a measure of household level diversity could underestimate the impact of participation on diversity. For instance, the diversity of a household who is already growing a wheat variety and who has adopted another CSB wheat variety will be underestimated in this case since both wheat varieties belong to the same crop category. This way, it will be a significant proportion of the households whose farm-level diversity will be underestimated (and the impact of participation in CSB as well) since around 51% of the plots are planted with wheat varieties.

Focusing on infraspecific diversity also has its own limitations. Analyzing the impact of CSB on based on infraspecific diversity would limit the analysis to households growing the crops that the CSB varieties are included in. This might overestimate the impact of CSB on diversity if the households excluded are diverse households than the ones included and vice versa.

Given this, we follow the argument by Meng et al. (1998a) that the appropriateness of the concept that is chosen is largely a function of the objectives of the study and of the level at which the analysis takes place. Accordingly, we construct our diversity measure based on a variety as a unit, disregarding whether the particular variety belongs in the same crop category as the other variety(ies) or in a different crop category. For instance, a household growing three wheat varieties and two teff varities will be considered as growing five varieties. Based on this diversity concept, an average of 4.58 varieties is grown per household, the most diverse household growing 14 varieties and the least diverse just one.

Wheat is the most widely grown crop covering (51%) of the total number of plots. Teff is the next most widely grown crop followed by pulses and other cereals, which represent smaller proportion of the total number of plots compared to the two crops.

The third dependent variable in our analysis, productivity is defined as the value of output per hectare. The value of output is calculated by multiplying output (in kg.) from each plot with the corresponding price per kg. By summing the output values from each plot, the farm-level output is obtained. The ratio of farm level output to farm size (in ha.) gave the value of output per ha.

The price for the different varieties was collected from three sources. The main source of price information was the local market. We also had price information for all varieties reported by the households. The price information for varieties not available in the local market was filled in with the household- reported price information. For those that were not reported by the household, we used the average price of the crop by averaging the price of all the varieties within the crop. Although that might not correctly measure the value of the variety, we found that to be the least biased way of doing so.

Socio-economic and physical farm characteristics are among the variables that are included in the participation, diversity and productivity equations. Specifically, we consider age, gender of the household head, and whether the household head has attended any religious or formal education as important measures of demographic characteristics in the participation equation. We also include livestock ownership, converted into the number of tropical livestock units, as a proxy for wealth[1]. Radio ownership and whether the head received any training during the year, are included as measures of access to information.

Location of the CSB, measured by distance from homestead to town, is included in the participation equation as a feature of the CSB. Access to improved seed and fertilizer as well as other sources of seed are included as seed system characteristics.

The diversity equation also includes kebele dummies, intended to capture factors that systematically differ across kebeles and that are left uncaptured by any of the variables used at the household level. One set of such factors concerns agro ecological conditions which include general soil fertility conditions, precipitation, temperature,

[1] Endogeneity between variety choice and livestock could be possible since the choice of certain local varieties might depend on the quality and quantity of crop residue that is used as animal fodder. However, since our diversity index includes both improved and local varities, the effect of endogeneity is likely not to be strong.

elevation, disease, pest/frost incidence and the like. Market access and transaction cost comprise another set of factors that could systematically vary across villages (kebeles).

In the productivity equation we have the different sources of seeds as explanatory variables. In addition, we include age, gender of the household head, wealth and oxen ownership as socioeconomic characteristics. The categories of physical farm and agroecological variables included in the diversity equation are included in the productivity equation.

Table 2 contains descriptive statistics of the variables used in the analysis.

Table 2: Descriptive Statistics of the Variables used in the Regressions

Variables	Description	Mean	Standard deviation
SOCIOECONOMIC	VARIABLES		
TRAINING	Head with any training (1=yes; 0=otherwise)	.234	.424
WEALTH	Livestock holdings (in tropical livestock unit)	6.748	3.417
OXEN	Number of oxen	2.495	1.478
AGE	Age of the household head	45.45	12.015
FEMALE	Sex of household head (1=female; 0=male)	0.029	0.167
RADIO	Radio ownership (1=yes; 0=otherwise)	0.567	0.186
FORMAL EDUCATION	Head's formal education (1=yes; 0=otherwise)	0.076	0.265
RELIGIOUS EDUCATION	Head's religious education (1=yes; 0=otherwise)	0.389	0.488
SCHEME	VARIABLE		
LOCATION OF CSB	Location of the Bank (measured in terms of Distance from homestead to the Bank (minutes)	73.744	36.920
PHYSICAL FARM	VARIBLES		
FARM SIZE	Farm size (ha)	2.115	2.316
FLAT LAND	Proportion of flat land in the total farm area	0.761	0.326
MEDIUM SLOPE	Proportion of hilly land in the total farm area	0.117	0.216
STEEP SLOPE	Proportion of gorgy land in the total farm area	0.119	0.251
FERTILE	Proportion of land with good fertility	0.537	0.351
MODERATELY FERTILE	Proportion of land with moderate fertility	0.217	0.306
INFERTILE	Proportion of infertile land	0.243	0.298
AGROECOLOGICAL	VARIABLES		
GORO	Kebele dummy (1=Goro)	0.297	0.457
ADDADI GOLE	Kebele dummy (1=Addadi Gole)	0.241	0.428
BUAE TENGEGO	Kebele dummy (1=Buae Tengego)	0.122	0.327
KERSA	Kebele dummy (1=Kersa)	0.082	0.275
MENJIKSO	Kebele dummy (1=Menjikso)	0.161	0.368
KOREMTA	Kebele dummy (1=Koremta)	0.090	0.287
SEED SYSTEM	VARIABLES		
IMPROVED SEED	Amount of improved seeds purchased on credit in year 2003 (kg)	26.82	84.126
FERTILIZER	Amount of modern fertilizer purchased on credit year 2003 (kg)	234	453
SEED SOURCE	Number of sources a household has secured seeds from (both traditional and modern)	1.339	0.543
OWN SEED	Proportion seeds from own storage in the total farm	.216	0.388
CSB SEED	Proportion seeds from CSB in the total farm	.072	0.196
BORROWED SEED	Proportion seeds borrowed from farmers	.040	0.179
EXCHANGED SEED	proportion seeds exchanged with fellow farmers	0.016	0.111
EXTENSION SEED	Proportion seeds from the extension system	0.217	0.359
MARKET SEED	Proportion seeds from the market	0.437	0.422
DEPENDENT	VARIABLES		
PARTICIPATION	Participation in CSB (1=yes;0=otherwise)	0.271	0.445
SHANON	Richness measured in terms of Shannon index	1.251	0.464
YIELD	Value of total yield per ha (Br[2]/ha)	8574	6643

[2] 1 US dollar is about 8.76 Ethiopian Birr (Br.)

4. The Econometric Framework and Estimation Procedure

Our analysis of the impact of CSB participation on the level of diversity maintained by households is based on a simultaneous estimation of diversity and participation equations. The level of diversity maintained by the ith household is, given by:

$$D_i = \beta^D X_i + \gamma^D P_i + \eta_i \tag{1}$$

Where D_i is the level of crop diversity; P_i is an indicator variable equal to 1 if the respondent participates in the CSB, X_i is a vector of socio-economic and physical farm characteristics, and η_i is an error term.

For the i^{th} individual, the participation equation is given by:

$$P_i = \begin{cases} 1 \; if \;\; \beta^P X_i + \gamma^P D_i + u_i > 0, \\ 0 \quad otherwise \end{cases} \tag{2}$$

and u_i is an error term. We assume that the errors in the two equations are independently, identically and normally distributed error terms with zero means.

The productivity analysis is intended to analyse the impact of CSB participation on productivity. In an imperfect seed system, productivity will not only be a function of farm and socio-economic characteristics, but also which source(s) the household accesses seeds from. Thus, the different seed sources as well as the number of seed sources will be determinants of productivity. In addition, there is also evidence that diversity is a determining factor in the level of productivity (Di Falco and Perrings, 2003), so we include diversity as an additional determinant of productivity.

Translog, log-linear and CES specifications are widely used in agricultural productivity analysis. Log-linear specification is common in cases where a considerable number of the independent variables are categorical/ dummy variables (Holden et al., 2001). Accordingly, we adopt a log-linear specification where, for the ith household, the productivity equation becomes[3]:

[3] Since we do not have information on labour input, we have not controlled for it although its effect may be crucial in the productivity analysis.

$$Y_i = \beta^Y X_i + \lambda P_i + \psi S_i + \vartheta D_i + \zeta_i \qquad (3)$$

where Y_i is the value of total yield per ha and S_i stands for the different seed sources, D_i stands for the level of diversity; β^P, γ^P, β^D, γ^D, β^Y, λ, ϑ and ψ are sets of coefficients to be estimated; and u_i η and ζ_i are error terms corresponding to the three equations. It should be noted that Y_i and the continuous variables in X_i are in logarithmic forms.

Equation (3) is estimated using OLS[4]. However, because the endogenous variables appear as regressors in equations (1) and (2), equation-by-equation estimation results in biased and inconsistent estimates of the parameters (Greene, 2000).

The two equations could be considered as a mixed simultaneous system of equations since the dependent variable in equation (1) is discrete and that in equation (2) is continuous. Heckman (1978) suggested a two-stage estimation procedure where the structural parameters are consistently estimated in two stages. While Heckman's estimator is consistent, an alternative estimator was suggested by Amemiya (1978), which is shown by Lee (1981) to be the most efficient of the class of mixed simultaneous equation estimators (Zepeda, 1994). The procedure involves four stages where in the first stage the reduced form parameters are estimated using OLS and maximum likelihood respectively. The second stage recovers the starting value structural parameter estimates. The third stage obtains the asymptotic covariance matrix from estimates in the first and second stages. The Generalized Probit GLS estimates are obtained in the last stage using the starting value structural parameters and the variance covariance matrices. Details on the GPGLS estimation are found in Amemiya (1978), Zepeda (1994) and Dies and Hill (1998).

Amemiya's estimator, like any instrumental variable estimator, has the properties of asymptotic estimators[5] which generally suffer from the problem of accuracy. In order to assess the performance of the Amemiya's estimator, we follow the procedure in Deis and Hill (1998) where Amemiya's (asymptotic) estimates are

[4] It should be noted that there are no reasons to believe a priori that productivity affects participation in CSB or diversity directly. Thus, the productivity equation which assesses the productivity impact of CSB participation is not part of the simultaneity.
[5] Asymptotic estimators are estimators with known properties that apply to large samples and whose finite sample behavior is approximated by what is known about their large sample properties (Greene, 2000).

bootstrapped and the results from the original estimates and the bootstrapped estimates are compared[6]. A comparison of the asymptotic and bootstrapping results is done using percentage differences in each of the statistics where percentage differences are calculated as the ratio of (bootstrap) statistics - (asymptotic) statistics to the absolute value of the asymptotic statistic. The 'bias t-statistics' is calculated as the ratio of coefficient (asymptotic)- coefficient (bootstrap) to standard error (bootstrap)/10, and measures the statistical significance of an estimated coefficient's bias.

5. Results

In Table 3, we present the estimation results for the diversity equation. The first part of the table shows the results from Amemiya's GLS estimator and in the second, the results based on bootstraping are reported. Comparison of Amemiya's and the bootstrap results is given in the third part of the table. The discussion of the results is based on the second part of the table.

Socio-economic characterisics such as age, gender and education of the household head, appear to bear no relationship to the level of diversity maintained by households. This is in line with the findings by Benin et al. (2003) in their study of the determinants of cereal diversity in the Ethiopian Highlands where different measures of diversity and physical farm characteristics were found to be weak in explaining the level of diversity maintained by households. The only socio-economic factor significant in explaining diversity is wealth, which has a positive impact. Benin et al. (2003) observed a similar effect of wealth. They attributed the positive impact of wealth to the ability of less poor households to better use diverse set of resources.

The village level dummies also had insignificant impact on the level of diversity. This could be for two reasons. One is the condensed nature of our sampling. The sampled villages are close to where the community seed bank is located which means that the villages are close to each other. That naturally dampens the agroecological and infrastructure variation. Furthermore, there can be counteracting effects of the village dummies. For example, villages with agroecological conditions favouring monocropping could be diversifying because of unfavourable market access.

[6] The software package LIMDEP 8.0 was used to estimate both the asymptotic and bootstrap statistics.

We found diversity to be increasing with the amount of fertilizer applied. This result might appear counter intuitive given that fertilizer application is associated with use of improved seeds and reduced level of diversity. Smale et al. (1994), however, observed that, at very low (but not high) levels of fertilizer use, it pays to diversify as with moderate fertilizer application, local varieties might perform better than improved varieties. This indicates there could be a threshold to the effect of fertilizer use on the level of diversity where our case is likely to be below the threshold (where fertilizer use enhances diversity).

The impact of CSB participation on diversity is positive and consistently significant across estimates. This indicates the effectiveness of CSB scheme in enhancing diversity. As we argued earlier, the modern seed system has a negative impact on participation. Thus, given present constraints to accessing modern varieties, the impact of CSB scheme as an effective instrument would be primarily deterred by a push for expanding the commercial seed system.

Comparison of Amemiya's and bootstrap estimations shows that unlike like in the participation equation, many of the coefficient estimates are equally significant /insignificant across estimations. However, like the participation equation, the bias–t statistic is significant for some coefficients indicating significant bias in the coefficients estimated using Amemyia's GLS.

Table 3: Simultaneous Equations Estimation Results with and without Bootstrap of the Diversity Equation

Variable	Amemiya's GLS simultaneous equation estimation			Bootstrapping Amemiya's GLS estimator			Comparison of Amemiya's and Bootstrap estimates		
	AGLS	T-STAT	T-crit (α=0.10)	BGLS	T-STAT	BT-crit (α=0.10)	%Δ in BETA	%Δ in T	Bias_T
Wealth	0,029 [ab]	2,906	2,481	0,026 [a]	2,294	3,436	-0,223	-0,211	0,647
Oxen	0,004	0,186	3,097	0,009	0,258	2,556	9,348	0,383	3,169 [ab]
Age	0,001	0,208	4,594	0,000	0,091	2,632	-16,212	-1,440	5,151 [ab]
Female	0,283 [a]	2,195	5,345	0,326	1,104	4,007	-0,184	-0,497	0,835
Radio	-0,072	1,493	2,001	-0,078	1,293	2,843	0,043	0,134	1,785
Formal education	0,007	0,087	2,500	-0,007	0,066	2,561	10,433	-1,762	6,466
Religious education	-0,004	0,089	2,273	0,000	0,004	2,428	2.557	0,960	-0,093
Improved seed	0,016 [a]	1,752	4,784	0,020 [a]	1,829	3,774	0,907	0,044	-3,338 [ab]
Farm size	-0,001[ab]	2,108	1,751	0,001	1,259	2,844	0,293	0,403	-5,210 [ab]
Medium slope	-0,103	1,175	6,252	-0,120	0,986	3,090	-0,450	0,161	1,375
Steep slope	0,011	0,149	20,845	0,035	0,463	2,528	-2,390	2,109	-3,157 [ab]
Moderately fertile	0,092	1,405	7,948	0,085	1,017	2,750	5,002	-0,276	0,910
Infertile	0,108	1,573	5,682	0,149	1,422	3,262	3,015	-0,096	-3,914 [ab]
Goro	-0,170 [a]	2,000	2,282	-0,209	0,619	3,743	1,263	0,690	1,151
Addadi Gole	-0,131	1,539	2,564	-0,171	0,509	3,589	0,054	0,669	1,176
Buae Tengego	-0,097	1,076	2,022	-0,125	0,379	3,050	-0,588	0,647	0,847
Kersa	-0,154	1,515	2,348	-0,180	0,530	3,296	0,182	0,650	0,758
Menjikso	-0,004	0,047	5,301	0,341	0,337	7487	152,799	8,107	-3,415 [a]
Fertilizer	0,004 [ab]	5,015	2,170	0,001 [a]	3,136	5,394	0,0423	-0,375	-0,276
Constant	0,948 [a]	6,032	4,333	0,955 [a]	2,215	3,783	0,180	-0,633	-0,172
Participation	0,106 [ab]	5,830	2,147	0,095 [ab]	4,231	2,664	-0,108	-0,274	4,711 [ab]

[a] Significant at 10% level, using the standard critical value (i.e. t=1.64)
[b] Significant at 10% level, using the critical values derived from the empirical distribution of bootstrap t-values.

Table 4 presents the results from the simultaneous equation estimation of the CSB participation equation.

Wealth and gender of the household head turn out to be significant socioeconomic determinants of participation. CSB varieties which are local generally have less/no fertilizer demand which makes them more attractive to the poor[1]. Compared to female-headed households, male-headed households are more likely to participate in CSB. However, other socio economic characteristics, such as training received within the year and education are not significant. The only scheme feature in our study, location of the CSB, also has a significantly negative impact on the likelihood of participation. Although distance to the CSB is the only factor that is associated with CSB and that varies between participants and non-participants in our data set, Smale et al. (2003) has shown that participation in a similar scheme would entail and transaction costs in terms of time and resources which we acknowledge to be a fairly important omission.

The amount of improved seeds purchased on credit and total fertilizer used have a significantly negative impact on participation. The impact of diversity, representing knowledge and experience, is also positive and significant.

The amount of improved seeds comes out as the only significant variable across estimations. This indicates substitutability between CSB varieties and those from the commercial seed system. Due to its perceived productivity advantages, there is and there will continue to be a push for increased adoption of the modern input package from the government's side. Given the negative relationship, the continued push for adoption of improved varieties would lead to improvement in access to commercial seeds. In turn, this would lead to reduction in participation in the CSB.

Comparison of the two methods shows that the bias-t is significant for almost all the coefficients giving evidence that Amemiya's estimator suffers from inaccuracy in this case also.

[1] An alternative interpretation here is that richer households could go for improved varieties that would give higher yields when combined with fertilizer.

Table 4: Simultaneous Equations Estimation Results with and without Bootstrap of the Participation Equation

Variable	Amemiya's GLS simultaneous equation estimation			Bootstrapping Amemiya's GLS estimator			Comparison of Amemiya's and Bootstrap estimates		
	AGLS	T-STAT	t- crit[1] (α=0.10)	BGLS	BT-STAT	Bt- crit[2] (α=0.10)	%Δ in BETA	%Δ in T	BIAS-T
Training	0,144	0,267	1,857	0,466	0,784	2,700	4,482	3,112	-5,418 [ab]
Wealth	-0,263[a]	2,697	4,207	-0,173	1,143	5,269	0,792	-1,066	-5,910 [ab]
Age	-0,0004	0,019	3,244	0,013	0,533	2,767	125,072	45,599	-5,473 [ab]
Female	-2,860 [a]	2,376	5,674	-3,298	1,024	4,653	0,182	-1,157	1,361
Radio	0,747[b]	1,595	1,287	0,751	1,431	3,698	0,076	0,149	-0,077
Formal education	-0,161	0,202	1,728	-0,002	0,002	2,729	-3,379	-4,083	-1,664
Religious education	-0,020	0,041	1,507	-0,136	0,267	2,375	-13,431	-15,101	2,281 [ab]
Location of CSB	-0,165 [a]	1,860	2,092	-0,138	1,154	4,412	0,651	-1,163	-2,231
Improved seed	-0,019 [a]	2,828	3,327	-0,019 [ab]	2,192	1,611	0,626	-1,139	0,446
Farm size	0,006 [a]	1,766	2,874	0,002	0,342	2,685	-0,853	-0,947	6,860 [ab]
Medium slope	-0,047	0,061	21,472	-0,052	0,069	2,525	-3,380	-1,258	0,057
Steep slope	-0,607	0,935	4,815	-0,334	0,414	2,417	-1,039	-1,440	-3,388 [ab]
Moderately fertile	-0,662	0,911	4,976	-1,158	1,236	3,427	-1,956	-1,663	5,295 [ab]
Infertile	0,202	0,375	1,469	0,406	0,685	3,045	0,117	-0,146	-3,435 [ab]
Fertilizer	-6,614 [a]	2,736	7,657	-4,376	0,987	2,918	0,579	-1,091	-5,047 [ab]
Seed source	-0,004 [a]	2,706	4,298	-0,002	1,153	6,870	0,805	-1,061	-4,796 [ab]
Constant	-0,234	0,278	3,763	0,497	0,367	5,104	8,232	1,178	-5,397 [ab]
Shannon	9,581 [a]	2,730	4,979	6,280	1,116	5,551	-0,915	-0,974	5,867

[1] The critical values are obtained from the empirical distribution of the bootstrap t-values where each t value corresponds to a bootstrap replication (following Dies and Hill, 1998). We used 100 bootstrap replications for the results.
[2] The bootstrap t-critical values are obtained from bootstrapping the bootstrapped samples. The bootstrap replications in the second bootstrap are 10.
[a] Significant at 10% level, using the standard critical value (i.e. t=1.64)

Table (5) presents the results from the OLS estimates of the productivity equation. The productivity equation relates the value of production per ha to the different seed sources, diversity measure, socio-economic, physical farm and agro ecological characteristics.

The socio-economic factors, namely gender and wealth of the household head, have turned out to be insignificant in explaining productivity. However, productivity is found to significantly decline with age. The number of oxen, measuring access to traction power, is an insignificant determinant of productivity. The coefficient for total area is negative, lending support the inverse farm size-productivity relationship. Productivity was shown not to significantly vary with the proportions of hillside and infertile plots. The impact of fertilizer application is positive and significant.

The impact of own seed on productivity is significant. The positive impact of own seeds on productivity is intuitive since own storage indicates the ability to save a portion of previous harvest and reduces the cost of accessing seeds from other sources. Access to informal seed sources, particularly borrowing from fellow farmers has significant positive impact on productivity. This indicates the importance and the role of informal links in reducing transaction costs in accessing seeds. Access to the commercial seed varieties does not have significant impact on productivity. This might appear counter intuitive since the commercial varieties are tipped to be of superior productive quality. Borrowing from CSB has significant impact on productivity indicating that CSB as a seed source improves the working of the existing seed system. This is also in line with the findings by Sperling et al. (1996) where improvement in seed system led to increase in productivity.

Diversity, as measured by the Shannon index was shown to be a positive determinant of productivity consistent with the theoretical and empirical findings by Di Falco and Perrings (2003)[1].

[1] The total number of seed sources households accessed seeds from was found to be correlated to the other seed sources and diversity so it was dropped out of the productivity analysis.

Table 5: Estimation Results for the Determinants of Productivity

Variable	Log Value of total yield per ha.	Standard error
Own seed	0.359	0.084***
CSB seed	0.253	0.155*
Borrowed seed	0.161	0.167
Exchanged seed	0.095	0.296
Extension seed	0.104	0.091
Female	-0.204	0.174
Log(age)	-0.258	0.120**
Formal Education	0.036	0.115
Religious Education	-0.079	0.065
Log(oxen)	-0.022	0.014
Log(wealth)	0.270	0.068***
Log(Farm size)	-0.398	0.061***
Log(Fertilizer)	0.005	0.003*
Medium slope	-0.346	0.237
Steep slope	-0.020	0.020
Moderately fertile	0.002	2.083
Infertile	0.009	0.005*
Goro	0.003	0.116
Addadi Gole	-0.008	0.118
Buae Tengego	-0.166	0.126
Kersa	-0.222	0.142
Menjikso	0.021	0.120
Log(Shanon)	0.018	0.010*
Constant	9.324	0.635***
Adjusted R- squared	0.56	

Note: *** stands for significance at 1% level and ** stands for significance at 5% level.

6. Conclusions

Biodiversity conservation initiatives in large monocropped farms have been associated with monetary compensation to 'conservator' farmers who choose to engage in the particular program (see for e.g. Wossink and Wenum, 2003). However, in small multicropping farming systems with imperfections in the seed system, expanding the provision of local seeds sources might improve seed access and enhance farm level diversity.

In line with this, the study examines a scheme called Community Seed Banking (CSB), which aims at increasing biodiversity of individual farms through improving the local seed supply system. The particular objectives of the study have been to assess the potential of the CSB in enhancing diversity and in improving access to local seeds.

We hypothesized that participation in CSB leads to enhancement of agrobiodiversity. We also argued that provision of local varieties in the CSB alleviates the problem of seed access and thus CSB participation would improve productivity. In addition, we proposed that the existing level of biodiversity would have a positively enforcing impact on participation in CSB. The relationships we proposed implied endogeniety of diversity and CSB participation measures. To assess the possible simultaneity, we employed the Generalized Probit GLS estimator, which was developed by Amemiya (1978) to handle simultaneous equations with mixed endogenous variables. The performance of the GLS estimator is also examined using the bootstrapping technique.

Our results confirm a significant impact of participation in CSB on farm level biodiversity. Holding other factors constant, a CSB participant household has around 10% higher diversity than a non-participant household. The effect of participation on diversity is the strongest effect compared to other determinants of diversity. This indicates that expansion of CSB and in a manner that targets likely participants better would be an effective mechanism of enhancing biodiversity.

Furthermore, CSB participation was shown to significantly increase the productivity of participant farmers. The implication is that agrobiodiversity conservation could be enhanced through provision of desirable local varieties. On the other hand, the level of diversity did not have a significant impact on participation implying that participation is not necessarily conditioned by previous knowledge and experience with respect to maintaining diversity. The number of seed sources farmers access seeds from did not significantly explain participation. However, access to improved varieties, which comprise the modern seed system, was shown to reduce the likelihood of participation in the CSB. This implies that given the current working of the seed system, CSB could work as a conservation instrument for seed-poor farmers who have less access to the commercial seed system. On the other hand, with improvement in the working of the commercial seed system, overall participation in the CSB would reduce. This further leads to reduction in the potential of CSB as a mechanism enhancing conservation.

This implies that while CSB participation is an instrument to enhancing diversity, increased improved seed use seems to deter participation. As a result, instruments, which explicitly reward ‘conservator’ farmers, should be in place for sustainable agrobiodiversity conservation in light of improved access to the modern seed system. Projects that enhance the current use value of local varieties could be such additional instruments. In their evaluation of a participatory crop improvement project which aimed at encouraging landrace maize conservation in Mexico, Smale et al. (2003) found that availing better yielding/ higher fodder quality landrace varieties encouraged farmers to grow them.

The results also show that plot-level productivity is affected by seed sources, with own-source and CSB seeds making a significant positive impact. This indicates that seeds channeled through such sources are likely to be effective in enhancing the productivity of farm households. However, the study does not assess the particular nature of the seeds accessed from the different sources, the type of households that access seed largely from these sources or the transaction costs involved in getting seed from these sources. Future research may be needed to analyze these factors to identify the most effective way(s) of availing seeds to farmers.

Older households were also shown to have lower productivity, which might be due to labour constraints which leads them to farm their land under suboptimal labour/rental arrangement. As per results from productivity analysis in Ethiopia and many similar places, wealth of the household is a significant and positive determinant of productivity. However, seed from the national seed distribution (extension system) does not seem to significantly contribute to productivity. Fertilizer use has a positive and significant impact but a very weak one. A percentage increase in fertilizer only increases productivity by 1%. In addition, the impact of fertilizer use is only significant at 10%. This indicates that the national extension system which is responsible for delivering external inputs like fertilizer and improved seeds to enhance productivity is not a very effective instrument of doing so and further research is needed to evaluate and improve its performance.

Diversity is found to be a positive determinant of productivity indicating that in farming systems characterized by low-market access and risky production environment, favoring multicropping and biodiversity would enhance productivity. Moreover, this also supports obervations that biodiverse systems are actually more productive than monocropped systems.

Our investigation of the performance of the GLS estimator vis-à-vis the bootstrap yielded that the asymptotic results were significantly different from the bootstrapped results. This is in line with previous studies, which compared asymptotic and bootstrapping estimates. The implication is that techniques like bootstrapping should be used to get accurate estimations when asymptotic estimators are employed.

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Environmental Change, Species Coping Ability and the Insurance Value of Biodiversity

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Abstract

This paper develops a measure of the value of biodiversity by incorporating a stochastic change in the environmental factor into an economy-ecosystem model of biodiversity. The analysis draws from an ecological model specifying the relationship between aggregate productivity, responsiveness to environmental change, and diversity. The value of biodiversity is derived as the contribution of diversity in enhancing the ecosystem's adaptive response to environmental change. The results are relevant to biodiversity conservation efforts that target areas with differing degrees of environmental variation. In addition, our analysis of some features of global warming the results imply that with increased concerns of global warming, more needs to be invested in biodiversity.

JEL codes: C61, C88, Q51, Q57

Key words: Biodiversity valuation, Ecological model, Hamilton-Jacobi-Bellman Equation, Simulations

1. Introduction

The desire to conserve biodiversity[1] is essentially motivated by two major concerns. One is that when a species becomes extinct, the social value associated with its possible future use is lost. In addition, as Blockstein (1998) argues, the loss of species could lead to cascading changes, since natural ecosystems are complex and highly interdependent, and small perturbations can lead to far-reaching changes with unexpected repercussions (Heal, 2004). Thus, individual species possess not only social benefits of their own; they also carry a joint value shared with other species, which is associated with an uncertainty in the functioning of an ecosystem composed of different species (Fromm, 2000). Measuring and assessing this joint value has attracted considerable interest and this paper is one such endeavor to add to this effort. The major contribution of our approach is its reliance on an ecological framework that objectively specifies species interrelationships and accounts for species' dynamic responsiveness to stochastic environmental change[2] in an aggregate manner. This realistic yet aggregate representation gives us the advantage of assessing the contribution of diversity to environmental adaptation in the context of complex species relationships and without relying on simplifying assumptions.

When valuing individual species, the focus has been on attaching values to benefits related to the use and existence of each species. Since use and existence values are inherent to people's preferences and hence to their willingness to pay (Moran and Bann, 2000), conceptualization of the values has been less difficult. Stated preference methods have been popular, assigning monetary values to threatened or extinct species and their habitats (e.g. Loomis and White, 1996; Montgomery et al., 1999). On the other hand, valuing diversity with respect to species interdependencies has been characterized by wide-ranging definitions and metrics. One explanation to this is that there are many different assumptions about species inter-relationships and their interaction with the environment. A unifying approach could be having a comprehensive account of such

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[1] Biodiversity is defined as the variety of life at all levels of organization, from the level of genetic variation within and among species to the level of variation within and among ecosystems and biomes (Tilman, 1997).

[2] In the context used in this study, the environmental factor represents an exogenous phenomenon which conditions the performance of the ecosystem, and which exhibits an unpredictable change over time. Norberg et al. (2001) use temperature or predator abundance as examples.

relationships. However, Crepin (2002) argues that with such approaches, species multiplicity and richness, and the resulting non-linearities in the relationships, make valuation exercises cumbersome and practically unmanageable.

Thus, appropriate biodiversity valuation calls for a framework that balances off the need to account for complex species interrelationships on the one hand, and to be simple enough to analyze theoretically, on the other.

In line with this, earlier approaches focus on specific species relationships. Examples include Principe (1989) where species values are additive; Solow et al. (1993) where adjustments should be made to possible redundancies in species use; and Polasky and Solow (1995) where species interdependences should also be valued.

Incorporating ecological information to the measurement of biodiversity value has been increasingly popular in recent studies. A pioneering work in this regard is Weitzman (1998) who used a genetic distance concept in deriving a diversity function. Brock and Xepapadeas (2003) refined this measure by integrating the genetic distance concept to an economically desirable measure of species responsiveness to environmental stress. However, in their analysis, the evolution of the environmental factor (pest) follows a predictable pattern and species' response to environmental stress is fixed i.e. an underperforming species will remain so even when the environmental factor changes. On the other hand, Kassar and Lasserre (2004) argue that environmental changes are uncertain and species value evolves following the impetus from the environment in continuous evolution. However, their analysis is restricted to species that are perfectly substitutable in their use. Other studies which employ ecological models to assess the role of diversity in ecosystem functioning include Tilman et al. (2005) and Eichner and Pethig (2006).

In light of this, our approach employs an ecological model of diversity developed by Norberg et al. (2001), which aggregates the behavior of a group of species with respect to overall productivity, diversity, and the group's ability to respond to environmental stress. The model has a thorough specification of species interdependencies and incorporates explicit species-environmental factor relationships in a manner that allows dynamic species responses to environmental stress. Thus, our approach has the advantage of not only specifying complex species interrelationships objectively, but also of accounting for their changing performances with respect to changes in the environment. In addition to its thorough specification, it explains the behavior of the ecosystem using aggregate measures making it theoretically manageable to analyze.

We derive the gain (loss) from biodiversity by considering outcomes under myopic and full information management regimes. This approach borrows from Brock and Xepapadeas (2003) where the difference between two species and one species value functions gives the endogenous value of biodiversity.

Section 2 presents the ecological model, which is the basis of our analysis. In Section 3, we set up the optimization problems and obtain the corresponding solutions under myopic and fully foresighted management regimes. Simulation results are given in Section 4, and Section 5 concludes the paper.

2. The ecological model and its relation to biodiversity value

As mentioned in the introduction, we base our analysis on an ecological model developed by Norberg et al. (2001), which defines species interrelationships and their responsiveness to environmental change. By using moment approximation methods, the model captures the dynamics of the macroscopic/aggregate characteristics of the group of species in terms of total biomass, average phenotype[3] and phenotypic variance. The total biomass aggregates the productivity of all the different species at a given point in time. Similarly, the average phenotype measures the average successional response of all the species to environmental change. The phenotypic variance, which we use as a measure of diversity,[4] represents the spread of individual. species phenotypes around the mean.

The resulting model provides a framework that is simple enough to analyze theoretically but which captures essential aspects such adaptive complex systems. The model also has an intuitive economic appeal since the total biomass, average phenotype, and phenotypic variance represent overall productivity, responsiveness to environmental stress, and a measure of diversity of the ecosystem, respectively.

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[3] Phenotype is defined as the morphological, physiological, biochemical, behavioural, and other properties of an organism that develop through the interaction of genes and environment (World Resources Institute, 1992).

[4] While there are other measures of diversity, Norberg et al. (2001) argue that phenotypic variance may be a more appropriate measure of diversity when relating diversity to ecosystem functioning.

The mathematical formulation of the model is given as:

$$\frac{dQ}{dt} = (f_o + vf_2)Q + a \quad (1)$$

$$\frac{dX}{dt} = vf_1 + b \quad (2)$$

where Q is the total biomass; $\frac{dQ}{dt}$ is the rate of change of biomass; X is the average phenotype of the whole group of species; $\frac{dX}{dt}$ is the rate of change of the average phenotype; f_o is the aggregate growth function of the different species; f_1 and f_2 are the first and second derivatives of the growth function with respect to X; v is the phenotypic variance; a is a constant representing the amount of biomass immigrating from the external environment; and b is the corresponding average phenotype of the immigrating species.[5]

The growth function, f_o, and its first and second derivatives with respect to X, f_1, and f_2 are specified as: [6]

$$f_o = (1 - \frac{Q}{K})(1 - (E - X)^2) \quad (3)$$

$$f_1 = 2(1 - \frac{Q}{K})(E - X) \quad (4)$$

$$f_2 = -2(1 - \frac{Q}{K}) \quad (5)$$

where E is the environmental factor and K is the carrying capacity.

Substituting the expressions for f_o, f_1, and f_2 into equations (1) and (2) gives:

$$\frac{dQ}{dt} = [(1 - \frac{Q}{K})(1 - (E - X)^2) - 2v(1 - \frac{Q}{K})]Q + a \quad (6)$$

$$\frac{dX}{dt} = 2v(1 - \frac{Q}{K})(E - X) + b \quad (7)$$

[5]Unlike the original model, we assumed the addition of external input of biomass to be a constant. Thus, expressions related to external input of biomass that appear in the original model are not included here. In addition, in the original model, the value of the phenotypic variance changes over time due environmentally determined immigration of species from the surroundings. In our case, phenotypic variance is constant since we assume immigration of species to be constant.

[6] The specification of the growth function was kindly given to us by Jon Norberg.

(7)

Equation (3) specifies the growth equation f_o as a logistic growth equation extended to incorporate the role of the environmental factor, diversity, and responses to environmental change. The first bracket represents a standard logistic growth equation. The second bracket is an expression for the difference between the optimal average phenotype and the current average phenotype.[7] Thus, the larger the expression $(E-X)^2$ is, the farther the system is from optimal performance with respect to the environmental condition, and vice versa.

Equation (4) gives an expression for the first derivative of the growth equation, f_1. The slope of the growth function increases, f_1, when $(E-X)$ is positive, or when the average phenotype is moving towards the environmental optimum. Similarly, f_1 decreases when $(E-X)$ is negative, i.e. when the average phenotype is moving away from the environmental optimum. Equation (5) gives the expression for the second derivative of the growth function, f_2, which is always negative.

This approach essentially decomposes the impact of biodiversity on ecosystem functioning into two components. The first component, which corresponds to equation (1) relates the growth of the total biomass, $\frac{dQ}{dt}$, to the diversity measure, v, holding the average phenotype, X, constant. The second component is represented by equation (2), which relates the dynamics of the average phenotype, $\frac{dX}{dt}$, to the diversity measure, v, where the total biomass, Q, is held constant.

As can be seen in equation (1), the growth of the total biomass, $\frac{dQ}{dt}$, decreases with diversity, v, since the second derivative of the growth equation, f_2, is always negative. The negative relationship between biomass growth, $\frac{dQ}{dt}$, and the diversity measure, v, indicates that higher diversity reduces the growth of total biomass, holding

[7] The current state of the environment, *E*, corresponds to the environmentally determined optimal average phenotype, X_{opt}. A positive change in X corresponds to a movement towards the environmental optimum, X_{opt} while a negative change in X corresponds to a movement away from it.

the average phenotype, X, constant, among other factors. In other words, for a given value of the environmental factor and the average phenotype, there will be one species outperforming all the others. With diversity, the presence of underperforming species increases, which decreases the overall productivity of the system. Intuitively, diversity would imply that there is one outperforming species (corresponding to the given environmental factor), while all the other species are underperforming. The suboptimal species take up space and resources, which could be used more efficiently by the outperforming species. As a result, the more diverse the ecosystem, the slower the rate at which its productivity increases. Thus, equation (1) depicts the cost of diversity to the productivity of the system.

Equation (2) specifies the relationship between the rate of change in the average phenotype of the whole species, $\frac{dX}{dt}$, and the diversity measure, v, holding the total biomass, Q, constant. According to this relationship, the rate of change of the average phenotype, $\frac{dX}{dt}$, falls when f_1 decreases. Similarly, the rate of growth of the average phenotype increases when f_1 increases. A positive change in the average phenotype, $\frac{dX}{dt}$, corresponds to movement towards the environmentally determined optimum average phenotype and vice versa. This implies that the system moves away from an environmentally determined optimum when f_1 is positive, while it moves towards the environmentally determined optimum when f_1 is negative. Since diversity, v, multiplies f_1 in the equation, it determines the rate at which the system moves towards/away from the environmental optimum.

Intuitively, since the dynamics of the average phenotype captures the system's adaptive response to environmental stress, the ecosystem may be in a state where it is negatively or positively responding to the stress. Higher diversity enhances the ecosystem's ability to have positive adaptive responses if the system is moving towards the optimal average phenotype. If the system is moving away from the optimum, diversity further dampens the coping ability of the system. In sum, while equation (1) depicts the cost of having diversity at any point in time, equation (2) depicts the responsiveness of species to the environmental factor which is conditioned by diversity.

Our approach is to measure the value of diversity in terms of the gain in the present value of harvest (from the total biomass) from having diversity. In order to derive the value of diversity this way, we consider two management regimes that give alternative values for the present value of harvest. We call the management regime that only considers the dynamics of the biomass only (i.e. equation 1) myopic management. The second regime is a fully foresighted management, where both the dynamics of the biomass (equation 1) and the dynamics of the average phenotype (equation 2) are considered. Our premise is that since biomass is a source of harvest, its dynamics is of direct economic interest. On the other hand, the dynamics of the average phenotype depicts the system's responsiveness to environmental change, which represents its adaptation to the environment and hence the system's long term productivity. Since average phenotype is not a direct factor in the system's immediate productivity and harvest does not (directly) depend on it, it is not of direct economic importance. If optimization only considers biomass dynamics, then it leaves out an important indirect effect. Thus, by disregarding the dynamics of the average phenotype, the myopic management fails to account for the indirect effect, which captures the ecosystem's adaptive response to environmental stress. On the other hand, fully foresighted management takes into account both the dynamics of the total biomass and the average phenotype. Based on this, this paper intends to obtain the gain (loss) of biodiversity as the difference in outcomes under the two management regimes.

In the ecological model, E is a time varying factor that could be characterized by a constant or variable rate of change over time. The variable rate E leads to more complicated dynamics (Norberg et al., 2001: p11377), [8] but is also more interesting since it can accommodate unpredictable changes in the environment.

Based on this, we take E to be a stochastic variable, and consider a random value of the environmental factor with a Brownian motion. Accordingly, the following stochastic differential equation specification is chosen.

$$dE = \alpha dt + \sigma(t) dz(t) \tag{8}$$

[8] Their analysis involving variable rates of environmental change considered seasonally oscillatory and reddened noise time series types of environmental behaviour.

where α could take a zero value or could be a non-zero constant[9], σ is the instantaneous standard deviation of the environmental variable, and $dz(t)$ is the increment to a standard Gauss-Weiner process.

3. Alternative management outcomes

This section develops a framework that enables derivation of the value of biodiversity. The basis of our analysis is the ecological model (discussed in Section 2), which specifies that short term productivity is reduced by diversity due to the presence of suboptimal species, while long term productivity may be enhanced by diversity due to its possible contribution to environmental adaptation. Accordingly, the first management regime we consider, myopic management, takes into account the impact of diversity on short-term productivity. The full-foresighted management regime incorporates impacts of diversity both on short and long-term productivity.

Our approach is to evaluate the outcomes of the two management regimes by computing the corresponding present values of harvest. Each of the management outcomes are assessed using a bio-economic model that consists of a sole owner-manager who maximizes the present net value of benefits from harvesting part of the biomass.

The benefit from harvesting is a function of price, p, and biomass harvest, q. Harvest is a function of harvesting effort, y, and total biomass, Q. The total benefit from harvesting is, thus, pyQ. The cost of harvesting is given as sy^2, where s is a constant. The net benefit from harvesting at a specific point in time (where the time index is omitted) is the difference between the total benefit and the cost of harvesting, $pyQ - sy^2$.[10] The sole manager would seek to maximize the sum of the discounted stream of net benefit from harvesting the biomass with the a risk-free, positive discount rate given by r.

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[9] With $\alpha(t) = 0$, the pattern of the environmental variable will be purely random. Any other positive and constant value of $\alpha(t)$, the pattern exhibits an increasing trend.

[10] By doing so we have assumed a quadratic objective function.

It should be noted that, to come up with such a net benefit function, we relied on certain assumptions with respect to harvest and prices. We assumed a harvest function linear in effort and aggregate biomass. Given that harvest functions are commonly specified as quadratic (e.g. Crepin, 2002), our choice of the functional form is a simplification.

To value the harvest, we have assumed a single price corresponding to the total biomass. As we argued in the introduction, our focus is on the contribution of biodiversity to ecosystem functioning. In our analysis, species derive their distinct features from their individual contribution to the total biomass[11] and their individual response to environmental stress. Thus, different species contribute different amounts of biomass and have different levels of environmental responsiveness, at every point in time. An additional difference could be that the qualities of biomass contributed by different species may be different leading to different market prices of the biomass corresponding to the different species (Tilman and Polasky, 2006)[12]. While the value of biomass for the different species could be different, we assumed away the price differences. Our analytical framework, which is realistic in many respects and hence complex, did not allow us to incorporate the possible price differences of the species with respect to biomass.

Below, we present our analysis of alternative management strategies of a biologically diverse ecosystem. The outcomes of the two strategies are evaluated in terms of the respective present net benefits from harvest. Our objective is to find the insurance value of biodiversity by computing the difference in the values of harvest under full-foresighted and myopic management regimes.

3.1. Myopic management

The myopic manager maximizes the present value of net benefits from harvest, subject to the growth of biomass over time. However, she disregards the impact of a changing environment on the performance of each of the different species. In other words, she does perceive the environmental factor as a variable that has an impact on the dynamics

[11] Note that the total biomass is the sum of individual species biomasses.

[12] It should be noted that the ecological model conveniently aggregates the amounts of biomass contributed by the different species, for each period of time. In addition it also aggregates the contribution to environmental responsiveness by each species. What is not taken into account in the model is, as opposed to the biomass amounts, the quality of biomass contributed by each species.

of the biomass. However, she treats the average phenotype of the different species in the system as a constant, with no dynamics as a response to the change in the environmental factor over time. Mathematically, the problem is stated as:

$$W(0, Q_o, E_o, T) = \max_y \int_0^T e^{-rt} (pyQ - sy^2) dt \qquad (10)$$

s.t.

$$\frac{dC_T}{dt} = [(1 - \frac{Q}{K})(1 - (E - X)^2) - 2v(1 - \frac{Q}{K})]Q + a - yQ \qquad (11)$$

$$dE = \alpha dt + \sigma(t) dz(t) \qquad (12)$$

where $Q(0) = Q_o$, $E(0) = E_o$, T represents the end time and W is the value of the opportunity to exploit the multispecies ecosystem. Following Malliaris and Brock (1982), the Hamilton-Jacobi-Bellman's equation for the above problem is given by:

$$-W_t = \max_y \{(pyQ - sy^2) + W_Q \left[(1 - \frac{Q}{K})(1 - (E - X)^2) - 2v((1 - \frac{Q}{K}))Q + a - yQ \right] + W_E \alpha + \frac{1}{2} W_{EE} \sigma^2 \qquad (13)$$

From (13), the solution to the optimal level of effort, y, is:

$$y^* = \frac{pQ - W_Q Q}{2s} \qquad (14)$$

Substituting the optimal effort into the HJB equation transforms the expression into:

$$-W_t = (py^* Q - sy^{*2}) + W_Q \left[((1 - \frac{Q}{K})(1 - (E - X)^2) - 2v(1 - \frac{Q}{K}))Q + a - y^* Q \right]^* + W_E \alpha + \frac{1}{2} W_{EE} \sigma^2 \qquad (15)$$

It should be noted that the functional form of the value function, W, is not known, which also implies that its derivatives, W_t, W_Q, W_E, and W_{EE} are not known either. Since our problem is not in the class of stochastic optimization problems that are quadratic in the objective function and linear in the constraints, the functional form cannot also be approximated (Dockner, 2000). Thus, we find a numerical solution for *W* that is piece-wise linear[13]. The program C++ was have to obtain the numerical solution in a number of discrete points. The program Matlab was then used to do linear interpolations between the discrete points to get a solution for *W* that is piecewise linear. With a solution for *W*, equation (15) could be used to solve for W_Q, which transforms expression (14) into

[13] I would like to thank Tobias Göbak, for his help in coding the problem in C++ and Matlab.

$$y^* = \frac{pQ - W_Q^* Q}{2s} \quad (16)$$

The solution for Q that corresponds to the optimal effort, y^*, is obtained by solving the following system of differential equations

$$\frac{dQ}{dt} = [(1 - \frac{Q}{K})(1 - (E - X)^2) - 2v(1 - \frac{Q}{K})]Q + a - y^* Q \quad (17)$$

$$dE = \alpha dt + \sigma(t) dz(t) \quad (18)$$

$$\frac{dX}{dt} = 2v(1 - \frac{Q}{K})(E - X) + b \quad (19)$$

It should also be noted that although the rate of change of the average phenotype is not taken into account in the manager's decision making, its evolution would naturally impact upon the evolution of the biomass. Thus, the solution for Q for would also incorporate the solution to X. The corresponding numerical solution is coded using Matlab.

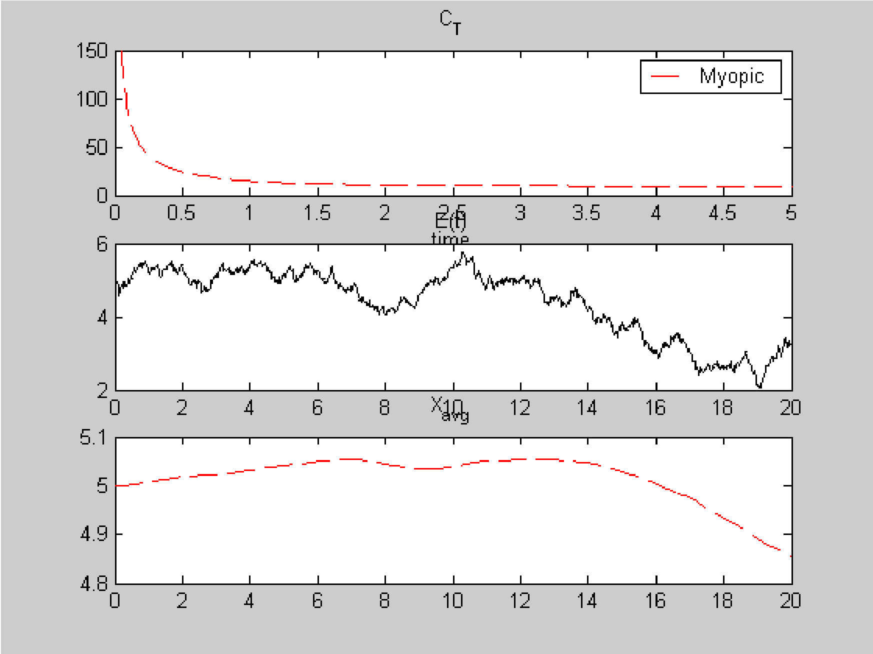
The parameters in the systems of equations are given in the Appendix. Our choice of many of the parameters is closely based on Norberg et al. (2001). These include parameters like the initial values for the total biomass and the average phenotype, and the external inputs of biomass and phenotype.[14] Due to the nature of the growth function and the resulting equations for the dynamics of the total biomass and the average phenotype, we were restricted to using a diversity measure less than 1. We chose the price, interest rate, and carrying capacity values arbitrarily but in a manner that allowed for convergence.

Figure 1 shows the patterns of environmental change over time when the growth of the average phenotype is not taken into account in the planner's decision making. Hence the figure depicts the myopic management scenario. The first panel in the figure shows the dynamics of the total biomass over time, where the end time is 20 units. The second panel depicts the movement of the environmental variable over time, while the third panel shows the pattern of the dynamics of the average phenotype over time. The environmental variable, *E*, depicts an environmental change with Brownian motion

[14] It should be noted that, in the case of Norberg et al. [14] the simulations were run for individual species to study the aggregate characteristics.

which also follows a roughly cyclical pattern with a slightly upward pattern followed by a downward pattern. The average phenotype roughly follows a similar direction as the environmental variable albeit with a smoother pattern. The total biomass follows a steadily falling trend.

Figure 1: Behaviors of Q, E, and X under random environmental change with Brownian motion



3.2. The fully foresighted management

Under this management regime, the dynamics of the average phenotype, or the responsiveness of the multispecies ecosystem to environmental stress, is considered in addition to the dynamics of the total biomass. Thus, the average phenotype of the group of species is (correctly) perceived to be evolving over time. This is the difference between this management scenario and the myopic scenario, where the average phenotype is perceived to be a constant and not responsive to environmental changes. Given a perfect foresight scenario, the manager's problem is stated as:

$$W(0, Q_o, X_o, E_o, T) = \max_y \int_0^T e^{-rt}(pyQ - sy^2)dt \qquad (18)$$

s.t.

$$\frac{dC_T}{dt} = [(1 - \frac{Q}{K})(1 - (E - X)^2) - 2v(1 - \frac{Q}{K})]Q + a - yQ \qquad (19)$$

$$\frac{dX}{dt} = 2v(1 - \frac{Q}{K})(E - X) + b \qquad (20)$$

$$dE = \alpha dt + \sigma(t)dz(t) \tag{21}$$

where $Q(0) = Q_o$, $E(0) = E_o$, T represents the end time and W is the value of the opportunity to exploit the multispecies ecosystem. The corresponding Hamilton-Jacobi-Bellman equation becomes:

$$-W_t = \max_y\{(pyQ - sy^2) + W_Q\left[(1-\frac{Q}{K})(1-(E-X)^2) - 2v((1-\frac{Q}{K})) + a - yQ\right] + W_X[2v(1-\frac{Q}{K})(E-X)+b] + W_E\alpha + \frac{1}{2}W_{EE}\sigma^2 \tag{22}$$

From equation (22), we solve for y, which is the optimal level of effort corresponding to the optimal harvesting rule:

$$y^* = \frac{pQ - W_Q Q}{2s} \tag{23}$$

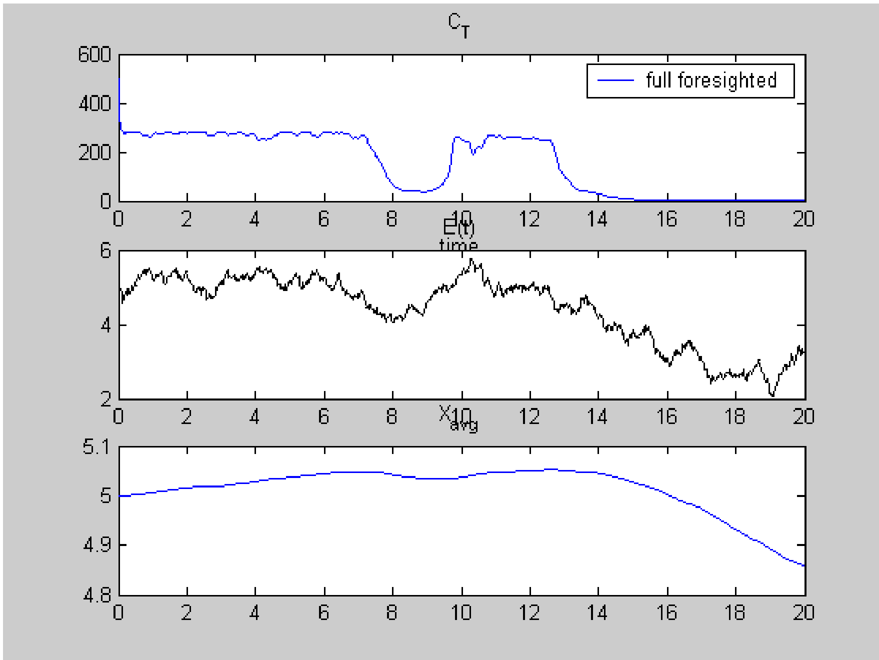
Substituting the optimal effort into the HJB equation transforms the expression into:

$$-W_t = py^*Q - sy^{*2} + W_Q\left[(1-\frac{Q}{K})(1-(E-X)^2) - 2v((1-\frac{Q}{K})) + a - y^*Q\right] + W_X[2v(1-\frac{Q}{K})(E-X)+b] + W_E\alpha + \frac{1}{2}W_{EE}\sigma^2 \tag{24}$$

Figure (2) analyzes the dynamics of the biologically diverse ecosystem under fully foresighted management. The pattern of the environmental change is similar to the myopic case because the environmental change is exogenous and is not affected by the dynamics within the model. Similarly, the pattern of the dynamics of the average phenotype is similar to that under myopia. As can be seen in equation (18), the average phenotype is not a function of the total biomass, Q, or harvest, y. Thus the harvest decisions that differ between the myopic and the full foresight management regimes do not affect the evolution of the average phenotype. Due to this, the patterns of the average phenotype under the two management regimes (i.e. in Figures 1 and 2) are identical.

The dynamics of the total biomass follow an interaction of the pattern of the environmental factor and the average phenotype: when the environmental factor and the average phenotype move close to each other, the total biomass tends to increase over time and decrease whenever the environmental factor and the average phenotype move apart.

Figure 2: Behaviors of Q, E and X under random environmental change with Brownian motion (high standard deviation).



4. Biodiversity value based on simulation results

As explained earlier, the value of biodiversity is computed as the difference between the present values of harvest under fully foresighted and myopic management regimes. For each regime, optimal harvest/effort and the corresponding total biomass values at each point in time are computed, which are, in turn, used to calculate the stream of net benefits from harvest. Discounting and summing up the net benefit values gives the present values of harvest under each management scenario.

The basis of our analysis is the case where the environmental variable exhibits a random value with a Brownian motion. Since the environmental factor is a stochastic variable, its realized value is one out of the many possible random values. In order to account for the randomness, we run ten simulations, each representing (an arbitrarily) low environmental variation. Each simulation is run for myopia and full foresightedness, under a given environmental outcome, and the results provide the present value of harvest corresponding to the two management regimes. Table 1 presents the present value of harvest for the myopic and fully foresighted management under (an arbitrarily) low environmental variation. The first column gives the present value of harvest under myopia; hence the results represent the harvest value of the ecosystem disregarding its responsiveness to environmental stress. The second column corresponds to the present value of harvest under full foresight, i.e. when the ecosystem's responsiveness to environmental stress is taken into account. The difference between the two values is computed to give the value of diversity. The average of the differences gives the expected value of diversity, and the standard deviation of the differences gives the spread of the actual diversity values around the expected value of diversity.

The result shows that the biodiversity value is positive for all the considered cases, and hence diversity enhances the system's adaptive response to environmental stress. This is in line with Brock and Xepapadeas[3], who found that biodiversity increases productivity through providing an insurance mechanism that controls the system's adaptation to pest dynamics.

However, the value of diversity for given environmental outcomes differ from very high to zero depending on how close/far apart the present values of harvest are from each other under the two management regimes.

Table 1: Comparison of Fully Foresighted and Myopic Management Regimes under Low-Variation Environmental Change (Low Standard Deviation)

Present value of harvest (Full foresight)	**Present value of harvest (Myopia)**	**Difference**
88.90	0.29	88.61
1.30	1.30	0.00
216.20	0.81	215.39
0.77	0.73	0.04
0.48	0.48	0.00
0.88	0.86	0.02
175.80	0.68	175.12
1.90	1.90	0.00
1.40	1.10	0.30
0.88	0.87	0.02
	Mean	47.95
	Standard Deviation	62.65

In order to assess the impact of the magnitude of environmental uncertainty, we consider a case where the standard deviation of the environmental variable is higher.

We compute the value of biodiversity based on the same set of parameters as in the earlier case (see Appendix) but with a higher standard deviation of the environmental change. Table 2 presents the corresponding simulation results. In this case too, the difference between the present values of harvest under full-foresighted and myopic regimes is positive, indicating that biodiversity has a positive value. Comparing biodiversity values under high and low standard deviation (mean values in Table 1 & 2), however, the average biodiversity value is higher with a higher standard deviation. Thus, biodiversity is more valuable when the environmental variability is higher. Similarly, comparing the standard deviation of biodiversity values in Tables 1 & 2, it is shown that the standard deviation of the value of biodiversity is higher when the environmental factor has a higher standard deviation. This implies that, for a given environmental pattern, the value of biodiversity will be far higher or lower than the average when the environmental variation is greater. This result is in line with the finding by Kassar and Lasserre (2004) which shows that environmental volatility raises the value of diversity by increasing species' option value and by expanding the target conservation area through substitution of currently used species for unused ones.

Table 2: Comparison of Fully Foresighted and Myopic Management Regimes under High-Variation Environmental Change (High Standard Deviation)

Present value of harvest (Full foresight)	**Present value of harvest (Myopia)**	**Difference**
1.10	0.82	0.28
146.20	1.80	144.40
0.99	0.79	0.20
111.70	1.00	110.70
1.20	0.84	0.36
157.80	1.50	156.30
1.80	1.60	0.20
27.90	0.66	27.24
0.59	0.57	0.03
115.90	0.82	115.08
	Mean	55.48
	Standard Deviation	81.18

In order to assess the possible impact of global warming on biodiversity value, we consider additional patterns of the environmental factor. We assume that, with global warming, environmental variables like temperature exhibit increased higher volatility and assume positive trends, and consider a case where the average value of the environmental variable has an increasing trend and its standard deviation is (arbitrarily) high.

Table 3 presents the results for our assessment of the impact of global warming on biodiversity value. The results show that the average value of biodiversity increases when the average environmental variable increases combined with a higher standard deviation. This indicates that with global warming, biodiversity becomes more valuable. This suggests that, with global warming concerns, biodiversity conservation might deserve a special attention where features of global warming make biodiversity more valuable.

Table 3: Comparison of Fully Foresighted and Myopic Management Regimes under High-Variation Environmental Change (High Standard Deviation)

Present value of harvest (Full foresight)	Present value of harvest (Myopia)	Difference
62.20	0.82	61.38
1.20	0.89	0.31
0.59	0.59	0.00
170.10	1.30	168.80
134.40	1.70	132.70
135.80	1.10	134.70
0.96	0.80	0.15
1.10	1.00	0.10
1.20	0.70	0.50
166.70	1.70	165.00
	Mean	66.36
	Standard Deviation	73.27

5. Conclusions

Biodiversity conservation has been one of the great global environmental concerns due to the tremendous loss of diversity (Thrupp, 2000), the threat of rapid future depletion and huge uncertainty about the consequences (Heal et al., 2004). Designing sound conservation policies and wise use of funds calls for a proper understanding of the value of biodiversity. The focus of this paper is on assessing the value of biodiversity with respect to the joint value shared by different species by emphasizing on species inter-relationships and their interaction to the environment.

Following recent trends in incorporating ecological information into a biodiversity valuation framework, this study employs a unique ecological model that gives an aggregate characterization of a multiple species ecosystem in terms of measures of productivity, responsiveness to environmental change and diversity. The model depicts that diversity reduces instant productivity of the system because of the presence of suboptimal species under a given environmental condition. On the other hand, higher diversity may enhance the ability of the ecosystem to have positive adaptive responses to changes in the environment.

Following Brock and Xepapadeas (2003), our approach develops a measure of the value of diversity in terms of the gain in the present value of harvest by comparing alternative management regimes. The myopic management corresponds to optimization, which takes into account the cost of diversity only. The fully foresighted management considers both the costs and potential benefits of diversity. Using techniques of stochastic dynamic optimization, the optimal effort (harvest) rules corresponding to myopic and fully foresighted management are obtained. The value of biodiversity is calculated as the difference in the discounted stream of net benefits from harvest between the two management regimes. Analytical computation of the solutions was not possible due to non-linearities and unknown form of the value function. Hence, the solutions are based on numerical simulation.

In existing analyses, biodiversity was shown to have a positive insurance value in the presence of environmental stress. Our analysis, which is based on stochastic environmental change, also supports this result. In a similar manner, our results show that biodiversity assumes a higher value with increase in environmental variability. This implies that the positive correlation between biodiversity value and environmental volatility is not restricted to species with substitutability in their current use value, as shown in previous studies; environmental uncertainty raises the biodiversity value irrespective of whether species are compliments and substitutes in their use.

The principal implication of our analysis is that biodiversity conservation efforts should target high environmental-variation areas. This paper has also suggested that with global warming concerns, biodiversity conservation might deserve a special attention where features of global warming make biodiversity more valuable.

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Appendix

Appendix1: Parameter Values Used in the Simulations

Parameter	Base case	Higher environmental uncertainty	Global warming
r	0.01	0.01	0.01
p	0.0001	0.0001	0.0001
s	0.05	0.05	0.05
K	1000	1000	1000
a	0.1	0.1	0.1
b	0.005	0.005	0.005
v	0.01	0.01	0.01
Emean	5	5	5
Estd	**0.25**	**0.5**	**0.5**
Aamp	0.5	0.5	0.5
Aper	10	10	10
CT0	0.5	0.5	0.5
Xavg0	5	5	5
Tend	20	20	20
epsilon	0.008	0.008	0.008
const	**0.00**	**0.00**	**0.01**

Appendix 2: Codes for the simulation results

A. Solution codes for the patterns of total biomass, average phenotype and environmental change over time

```
% Parameter values
global p s K a b v E Xavg0 dt Ccrd Ecrd Tcrd Xcrd dWC;
r = 0.01;
p = 0.0001;
s = 0.05;
K = 1000;
a = 0.1;
b = 0.005;
v = 0.1;
Emean = 5;
Estd = 0.5;
Aamp = 0.0;
Aper = 10;
CT0 = 0.5;
Xavg0 = 5;
Tend = 20;
epsilon=0.008;

verbose=1;
% Generate E (Brownian motion with mean Emean and stdev Estd)
seed = sum(100*clock);
randn('state',seed) % set the state of randn
N = 1024;
dt = Tend/N;
dE = Estd*sqrt(dt)*randn(1,N); % increments
E = Emean + [0 cumsum(dE)]; % cumulative sum => Brownian motion
E = Aamp * sin(2*pi/Aper*(0:dt:Tend)) + E;  % Add oscillatory function
E = max(E,0);  % remove negative values

% solve HJB-equation for myopic case
disp('Solving HJB-equation, myopic case')
params=[p*K s 0.0 1.0 Xavg0 v a/K b Aamp Aper Estd epsilon];
times=[0.0 1.0 Tend 1];  % Solution times: T0 Tstep Tend saveint
NC=50; NE=40;
Cbnd=[-1.0 2.0];
Ebnd=[0.0 10.0];
mshm=unbmesh([Cbnd Ebnd],[NC NE]);
wm=callsolver('myopic',times,params,mshm,verbose);
Ccrd=getxvals(mshm);
Ecrd=getyvals(mshm);
Tcrd=times(1):times(2)*times(4):times(3);
% compute dW/dC
dWC = zeros(size(wm));
dWC(2:end,:,:) = (wm(2:end,:,:)-wm(1:end-1,:,:))/mshm.h(1);
figure(3)
[CC,EE]=ndgrid(Ccrd,Ecrd);
mesh(CC,EE,dWC(:,:,1))
title('myopic W_C, at t=0')


% solve dynamical system, using HJB solution
disp('Solving ODEs, myopic case')
```

```
[Tm,u] = ode15s('FunMyoHJB',[0 Tend],[CT0; Xavg0]);

% Compute optimal values
CTm = u(:,1);
Xavgm = u(:,2);
ETm = interp1(0:dt:Tend,E,Tm);
wcm = interp3(Ecrd,Ccrd,Tcrd,dWC,ETm,CTm,Tm);
qm = (p*K-wcm)/(2*s).*CTm;
Mm = p*K*qm.*CTm-s*qm.^2;

%% Full foresight model %%
% solve HJB-equation for full foresight case
disp('Solving HJB-equation, full foresight case')
epsilon = 0.02;
params=[p*K s 0.0 1.0 Xavg0 v a/K b Aamp Aper Estd epsilon];
times=[0.0 1.0 Tend 1];  % Solution times: T0 Tstep Tend saveint
NC=30; NE=28; NX=28;
Xbnd=[0.0 10.0];
mshf=unbmesh([Cbnd Ebnd Xbnd],[NC NE NX]);
wf=callsolver('full foresight',times,params,mshf,verbose);
Ccrd=getxvals(mshf);
Ecrd=getyvals(mshf);
Xcrd=getzvals(mshf);
Tcrd=times(1):times(2)*times(4):times(3);
% compute dW/dC
dWC = zeros(size(wf));
dWC(2:end,:,:,:) = (wf(2:end,:,:,:)-wf(1:end-1,:,:,:))/mshf.h(1);
figure(4)
[CC,EE]=ndgrid(Ccrd,Ecrd);
mesh(CC,EE,dWC(:,:,NX/2,1))
title(sprintf('full foresight W_C, at X=%.1f, t=0',Xbnd(2)/2))

% Solve dynamical system, using HJB-solution
disp('Solving ODEs, full foresight')
[Tf,u] = ode15s('FunFullHJB',[0 Tend],[CT0; Xavg0]);

% compute optimal values
CTf=u(:,1);
Xavgf = u(:,2);
ETf = interp1(0:dt:Tend,E,Tf);
wcf = interpn(Ccrd,Ecrd,Xcrd,Tcrd,dWC,CTf,ETf,Xavgf,Tf);
qf = (p*K-wcf)/(2*s).*CTf;

Mf = p*K*qf.*CTf-s*qf.^2;


% Plot results
figure(1)
subplot(3,1,1)
plot(Tf,K*CTf,'b',Tm,K*CTm,'r--')
title('C_T');
xlabel('time')
legend('Full foresight','Myopic');

subplot(3,1,2)
plot(0:dt:Tend,E,'k')
title('E(t)')

subplot(3,1,3)
```

```
plot(Tf,Xavgf,'b',Tm,Xavgm,'r--')
title('X_{avg}')

figure(2)
plot(Tf,Mf,'b',Tm,Mm,'r--')
title('M')

figure(5)
plot(Tf,wcf,'b',Tm,wcm,'r--')
title('W_C')

% compute integral from 0 to Tm (Tf)
Intm = trapz(Tm,exp(-r*Tm).*Mm)
Intf = trapz(Tf,exp(-r*Tf).*Mf)
```

B. Codes for recalling the discrete solution

```
function w=callsolver(ptype,times,params,msh,verbose)
fh=fopen('tmpin.txt','wt');
if (fh==-1)
 error('Could not open file tmpin.txt');
end fprintf(fh,'%s\n',ptype);
fprintf(fh,'n: %d ',length(msh.n));
fprintf(fh,'%d ',msh.n);
fprintf(fh,'\n');
fprintf(fh,'bounds: %d ',length(msh.bounds));
fprintf(fh,'%g ',msh.bounds);
fprintf(fh,'\n');
fprintf(fh,'times: %d ',length(times));
fprintf(fh,'%g ',times);
fprintf(fh,'\n');
fprintf(fh,'params: %d ',length(params));
fprintf(fh,'%g ',params);
fprintf(fh,'\n');
% options (tolf tolrel tolst maxit tolsol maxitsol verbose)
fprintf(fh,'options: 7 %g %g %g %d %g %d %d\n',1.e-6,0.0,1.e-6,20,1.e-
5,1000,verbose);
fclose(fh);
% Call solver
if ispc,
!hjb tmpin.txt tmpout.dat
Else
!./hjb tmpin.txt tmpout.dat
End
```

```
W=loadcmat('tmpout.dat');
Nt=size(W,2);
w = reshape(W,[msh.n Nt]);
function M=loadcmat(filename)
if ischar(filename),
  f=fopen(filename,'r');
  if f==-1,
    error(['Could not open ' filename]);
  end
else
  f=filename;
end
```

```
m=fread(f,1,'int32');
n=fread(f,1,'int32');
[M,cnt]=fread(f,[m n],'double');
if cnt~=m*n,
  error(ferror(f));
end

if ischar(filename),
  fclose(f);
end
```

C. Codes for interpoliation and solving the differential equations

```
function y=FunFullHJB(t,u);

global p s K a b v E dt dWC Ecrd Ccrd Tcrd Xcrd;   % global parameters
set in main file

if length(E)==1
  ev=E;
else
  ev = E(floor(t/dt)+1);
end
% find dW/dC(E,C,X,t)
wc = interpn(Ccrd,Ecrd,Xcrd,Tcrd,dWC,u(1),ev,u(2),t);

% rescaled equation ( C = C_T/K )
y = [(1-2*v-(ev-u(2)).^2)*(1-u(1)).*u(1) + a/K - (p*K-
wc)/(2*s)*u(1).^2; ...
     2*v*(1-u(1))*(ev-u(2)) + b];
```

```
function y=FunMyoHJB(t,u)

global p s K Q a b v Xavg0 E dt dWC Ecrd Ccrd Tcrd;   % global
parameters set in main file

if length(E)==1
  ev=E;
else
  ev = E(floor(t/dt)+1);
end
% find dW/dC(E,C,t)
wc = interp3(Ecrd,Ccrd,Tcrd,dWC,ev,u(1),t);

% rescaled equation (C = C_T/K)
y = [(Q-2*v-(ev-u(2)).^2)*(1-u(1)).*u(1) + a/K - 100*(p*K-
wc)/(2*s)*u(1).^2; ...
     2*v*(1-u(1))*(ev-u(2)) + b];
```

D. Codes used for plotting the value function

```
function [X,Y,Z]=getcoordmat(m)

x=getxvals(m);
y=getyvals(m);

if length(m.n)==2,
```

```
  [X,Y]=ndgrid(x,y);
else
  z=getzvals(m);
  [X,Y,Z]=ndgrid(x,y,z);
End
```

```
function c=getnodecoords(m,idx)

% Gets coordinates of mesh points in row vector idx
% coords in columns of c, with mesh points along rows

switch length(m.n)
  case 2
    kx=mod(idx-1,m.n(1));
    ky=(idx-kx-1)/m.n(1);
    c(1,:)=m.bounds(1)+(kx+1)*m.h(1);
    c(2,:)=m.bounds(3)+(ky+1)*m.h(2);
  case 3
    n0=m.n(1)*m.n(2);
    kxy=mod(idx-1,n0);
    kz=(idx-1-kxy)/n0;
    kx=mod(kxy,m.n(1));
    ky=(kxy-kx)/m.n(1);
    c(1,:)=m.bounds(1)+(kx+1)*m.h(1);
    c(2,:)=m.bounds(3)+(ky+1)*m.h(2);
    c(3,:)=m.bounds(5)+(kz+1)*m.h(3);
end
```

```
function x=getxvals(m)

%Returns x-values of mesh points

x=m.bounds(1)+m.h(1):m.h(1):m.bounds(2)-m.h(1);
```

```
function y=getyvals(m)

%Returns y-values of mesh points

y=m.bounds(3)+m.h(2):m.h(2):m.bounds(4)-m.h(2);
```

```
function z=getzvals(m)

%Returns z-values of mesh points

z=m.bounds(5)+m.h(3):m.h(3):m.bounds(6)-m.h(3);
```

```
unction v = subsref(m,index)
%SUBSREF Define field name indexing for unbmesh objects
%Allows direct indexing into member arrays, e.g. m.bounds(2)
switch index(1).type
  case '()'
    error('Array indexing not supported by mesh objects')
  case '.'
```

```
    switch index(1).subs
      case 'bounds'
      if length(index)>1,
        if index(2).type=='()',
          v = m.bounds(index(2).subs{1});
        end
      else
        v = m.bounds;
      end
      case 'n'
      if length(index)>1,
        if index(2).type=='()',
          v = m.n(index(2).subs{1});
        end
      else
        v = m.n;
      end
      case 'h'
      if length(index)>1,
        if index(2).type=='()',
          v = m.h(index(2).subs{1});
        end
      else
        v = m.h;
      end
      case 'N'
      v = m.N;
   % Additional indexing to 'virtual' properties
      case 'xmin'
      v = m.bounds(1);
      case 'xmax'
      v = m.bounds(2);
      case 'ymin'
      v = m.bounds(3);
      case 'ymax'
      v = m.bounds(4);
      case 'zmin'
      v = m.bounds(5);
      case 'zmax'
      v = m.bounds(6);
      case 'nx'
      v = m.n(1);
      case 'ny'
      v = m.n(2);
      case 'nz'
      v = m.n(3);
      case 'hx'
      v = m.h(1);
      case 'hy'
      v = m.h(2);
      case 'hz'
      v = m.h(3);
      otherwise
      error('Invalid field name')
    end
  case '{}'
    error('Cell array indexing not supported by unbmesh objects')
end
```

```
function m=unbmesh(varargin)

% UNBMESH constructor, umesh(bounds,[nx ny nz])
%
% Class unbmesh:
%   A uniform mesh in which the boundaries are NOT included
%
% Properties:
%
% m.bounds  : [xmin xmax ymin ymax (zmin zmax)]
%             m.xmin, etc. may also be accessed independently
% m.h       : [hx hy (hz)] mesh size in different directions
% m.n       : [nx ny (nz)] nr of mesh points in diff. dirs
% m.N       : The total number of mesh points.
%
% Methods:
%
% v=IsEdgeNode(m,[i]) : Determines if mesh nodes in vector [i] are on
edge.
%                       Returns boolean vector v.
% v=GetEdgeNodes(m)   : returns nrs of all edge nodes in v.
% v=GetNodeCoords(m,[i]) : Returns node coords of nodes in [i].
%                          Coords in colums.
% v=GetXVals(m)       : Returns the x-values of mesh points
% v=GetYVals(m)
% v=GetZVals(m)
% [i j]=FindAdjMeshPts(m,iip) : Finds adjacent mesh points to iip.
%
%

switch nargin,
  case 0
    m.bounds = zeros(1,4);
    m.n = zeros(1,2);
    m.h = zeros(1,2);
    m.N = 0;
    m = class(m,'unbmesh');
  case 1
    if isa(varargin{1},'unbmesh')
      m=varargin{1};
    else
      error('Wrong argument type')
    end
  case 2
    m.bounds = varargin{1};
    m.n = varargin{2};
    m.h(1)=(m.bounds(2)-m.bounds(1))/(m.n(1)+1);
    m.h(2)=(m.bounds(4)-m.bounds(3))/(m.n(2)+1);
    m.N = m.n(1)*m.n(2);
    if length(m.n)==3,
      m.h(3)=(m.bounds(6)-m.bounds(5))/(m.n(3)+1);
      m.N = m.N*m.n(3);
    end
    m=class(m,'unbmesh');
  otherwise
    error('Wrong number of arguments')
end
```