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Allocation of Payments for Environmental Services through auctions & the role of social interaction

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Abstract

This thesis contributes to the study of the use of auctions in the allocation of contracts of payments for environmental services. The focus of the research is on the role of social interaction as a learning source for bidders in repeated auctions. Bidders learn over time and adapt their bidding strategies accordingly in order to increase their rents. Two different payments schemes are considered; payments for biodiversity conservation and payments for carbon sequestration. In order to evaluate the performance of repeated auctions, the implementation of these payments schemes is simulated by means of agent-based modeling. Agent-based models allow simulating interactions among heterogeneous individuals, their learning effects and their strategies, such that the effects that emerge from these dynamics can be analyzed. This study confirms that the cost-effectiveness of auctions to provide biodiversity conservation decreases with the learning effects of land users. Nevertheless, contrary to the expectations, learning through social interaction can dampen the deterioration of the cost-effectiveness of auctions, such that despite of learning effects, discriminatory auctions can be more cost-effective than fixed payments. Moreover, this study shows that these learning effects can contribute to the goal of poverty alleviation, which is especially relevant for the implementation of these schemes in low income countries. Repeated discriminatory auctions can provide "pro-poor conservation" effectively, especially in the presence of uncertainty about the income of alternative sources and in settings of high competition among potential participants. This thesis also explores the problem of asset specificity in the provision of environmental services, taking as an example schemes of payments for carbon sequestration where land users are expected to plant trees on their land. It assesses the design possibilities of payments schemes in order to overcome this problem, and it explores the use of auctions to allocate contracts requiring specific investments. The results provide evidence for losses in cost-effectiveness through non-compliance when one-shot auctions are used to allocate long-term contracts if land users face high time preferences. However, repeated discriminatory auctions can allow the agency to allocate short-term contracts cost-effectively because the contract terms can be renewed and adapted to changes in opportunity costs, such that compliance is not compromised in the long-run.

Zusammenfassung

Diese Dissertation ist ein Beitrag zur Analyse der Nutzung von Auktionen im Rahmen der Allokation von Verträgen für Agrar- und Klimamaßnahmen. Hierbei geht es um Programme, in denen Landnutzern direkte Zahlungen für ihre Leistungen angeboten werden. Diese Forschungsarbeit fokussiert sich auf die Rolle der sozialen Interaktion als Lernquelle für potentielle Teilnehmer in wiederholten Auktionen. Landnutzer lernen und verändern ihre Strategien entsprechend, um höhere Renten zu erzielen. Zwei Arten von Programmen werden einer näheren Betrachtung unterzogen; Bezahlungen für die Erhaltung von Biodiversität sowie Bezahlungen für Kohlenstoffspeicherung. Um die Leistung von wiederholten Auktionen zu evaluieren, werden verschiedene Programme durch eine Agenten-basierte Modellierung simuliert. Diese erlaubt die Simulation von Interaktionen zwischen heterogenen Individuen sowie deren Lerneffekte und Strategien, so dass die Effekte der daraus resultierenden Dynamiken analysiert und bewertet werden können. Diese Studie zeigt, dass eine höhere Konnektivität zwischen den Landnutzern einen höheren Informationsaustausch zur Folge hat und sich daher die Bereitstellung von Biodiversitätserhaltung weniger kosteneffizient gestaltet. Anders als erwartet, mindern die durch soziale Interaktion induzierten Lerneffekte die Verschlechterung der Kosteneffektivität von Auktionen, so dass diese trotzdem kosteneffektiver als fixe Bezahlungen sein können. Diese Studie zeigt auch, dass diese Lerneffekte zum Ziel der Armutsbekämpfung beitragen können, und damit eine Relevanz für ärmer Länder aufweisen. Wiederholte diskriminierende Auktionen können eine pro-arm Biodiversitätserhaltung induzieren, besonders wenn Landnutzer Unsicherheit bezüglich ihrer zukünftigen Einkommensquellen von alternativen Landnutzungen haben, und wenn diese Programme unter hoher Konkurrenz implementiert werden. Diese Dissertation erforscht auch das Problem der Faktorspezifität in der Implementierung dieser Programme anhand des Beispiels der Wiederaufforstung für die Speicherung von Kohlenstoff. Die Gestaltungsmöglichkeiten dieser Programme, hinsichtlich des Umgangs mit dem Problem der Faktorspezifität werden analysiert. Zudem wird der Einsatz von Auktionen als Instrument zur Allokation von Verträgen mit faktorspezifischen Investitionen untersucht. Die Ergebnisse liefern Evidenz für Kosteneffektivitätsgewinne durch diskriminierende Auktionen, sofern kurzfristige Verträge angeboten werden. Diese erlauben eine kosteneffektive Anpassung der Vertragsbestimmungen gemäß den Änderun-

gen der Opportunitätskosten, so dass die Einhaltung der Verträge auf lange Sicht nicht gefährdet wird. Allerdings können einmalig implementierte Auktionen zur Allokation von langfristigen Verträgen dazu führen, dass Landnutzer mit hohen Zeitpräferenzen zu niedrige zukünftige Bezahlungen annehmen, so dass diese später nicht den Anreiz haben die gepflanzten Bäume zu erhalten.

Contents

List of Figures

List of Tables

Abbreviations

CDM Clean Development Mechanism.

EBI Environmental Benefits Index.

ESI Environmental Services Index.

MWK Malawi Kwacha.

PES Payments for Environmental Services.

PROFAFOR Programa Face de Forestación.

PSA Pagos por Servicios Ambientales.

SAF Systemas Agroforestales.

USD US Dollars.

1

Thesis introduction

> *"Wir leben in einem gefährlichen Zeitalter. Der Mensch beherrscht die Natur, bevor er gelernt hat, sich selbst zu beherrschen."*
>
> – Albert Schweitzer

1.1 Background

Forests produce environmental services, such as hydrological benefits, reduced sedimentation, the prevention of floods and landslides, biodiversity conservation and carbon sequestration, among others (Pagiola & Platais 2002). These services have a great value to human society, however, their provision is often less profitable for land users compared to alternative economic activities. This can lead to a natural capital depletion that is not socially optimal (Engel *et al.* 2008, p.664). This calls for measures to avoid deforestation, but also to induce the restoration of ecosystems.

An instrument that has raised considerable interest in the last decades is the compensation of land users through schemes of Payments for Environmental Services (PES). These schemes imply an internalization of externalities according to the Coasean theorem (Engel *et al.* 2008, p.665). They give land users an incentive to provide environmental services, considered to be positive environmental externalities (Engel *et al.* 2008, p.664). Wunder (2005) describes them as *voluntary transactions where a well-defined environmental service, or a land use likely to secure that service, is bought by at least one service buyer from at least one service provider, conditional on the provision* (p.3).

Procurement auctions are claimed to increase the budgetary cost-effectiveness of such payment schemes. These auctions are a mechanism through which the environmental agency invites bids from potential providers of environmental services for a specific contract. By means of market competition and bidding rules, auctions allow agencies to disclose information about the opportunity costs of land users, and thus to reduce overcompensation (Ferraro 2008, p.813).

The objective of this thesis is to investigate the potential of procurement auctions to allocate contracts in payment schemes, considering that social interaction affects their performance over time through learning effects. The following section provides an overview of the aspects of the design of payment schemes that are relevant for this research. The third section introduces the research questions addressed, and the last section describes the structure of the thesis.

1.2 Payments for Environmental Services

The logic behind payment schemes, as shown in figure 1.1, is the compensation of land users for the provision of environmental services, provided that the latter is socially desirable. This figure shows the private benefits of a land user from two different land uses; forest conservation and the conversion to pasture. As long as the private benefits from the conversion of the forest to pasture are higher, a land user will not have an incentive to conserve the forest. This would induce negative environmental externalities, implying costs incurred by the society or users of environmental services. Examples of these externalities are a reduction of water services, the loss of biodiversity and carbon emissions, just to mention some (Pagiola & Platais 2002, p.2). As long as the value of the avoided environmental external costs exceed the value needed to induce forest conservation, the implementation of these schemes is socially desirable. Compensation payments have to exceed the opportunity costs of land users in order to make forest conservation more attractive than the conversion to pasture.

Payment schemes are often implemented for the conservation of forests, but they are not restricted to that purpose. Payments can also be offered for restoration and establishment of any land use inducing external environmental benefits, including even agricultural land uses (Engel *et al.* 2008, p.665). In this thesis two main environmental services are considered; biodiversity and carbon sequestration.

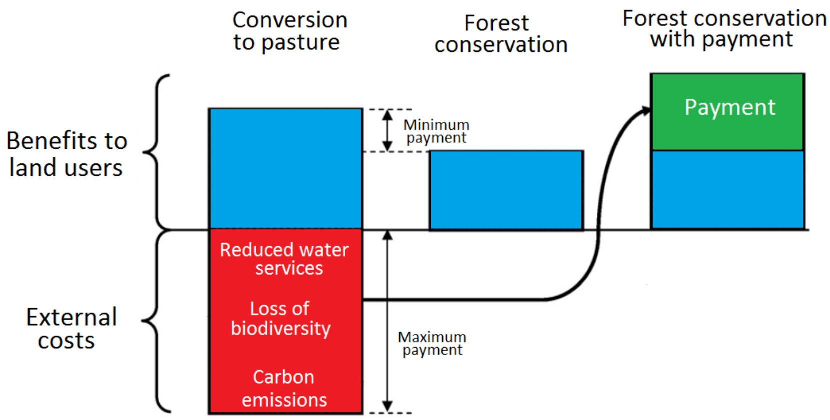

Figure 1.1: The logic of payment schemes adapted from Pagiola and Platais(2007)

Biodiversity conservation relies on the contribution of biodiversity to the provision of environmental services, and on the idea that other land uses can lead to irreversible losses of biodiversity (Millenium Ecosystem Assessment,2005). If biodiversity is given a monetary value, biodiversity conservation can be converted into a profitable land use (Ferraro & Kiss 2002, p. 1719). The latter requires the proper management and protection of ecosystems. Examples of schemes offering payments for biodiversity conservation are the Bolivian scheme in Los Negros, where land users are paid for forest and páramo conservation, the Costa Rican PSA scheme, which compensates land users for the conservation of their forests, and the CAMPFIRE scheme in Zimbabwe, which offers compensations for the conservation of natural landscapes (Wunder *et al.* 2008, pp.836-837).

Carbon sequestration is an environmental service related to the goal of mitigating climate change. Forests are key components of the global carbon cycle. They are estimated to absorb billions of tons of carbon every year through net growth, thus emissions can be mitigated through reforestation (Canadell & Raupach 2008, p.1456). Examples of schemes offering payments for carbon sequestration are the Ecuadorian scheme PROFAFOR, where land users are paid for re- and afforestation, the PSA scheme in Costa Rica, where land users are paid for timber plantations and agroforestry activities, and the Conservation Reserve Program in the US, where land users are paid for the retirement of marginal land from agricultural production (Wunder *et al.* 2008, pp.836-837).

Payment schemes have been already implemented all over the world for many different types of land uses, in both developing and developed countries, differing one from the other. There are user-financed schemes, as well as schemes in which the government acts on behalf of the users of environmental services (Wunder *et al.* 2008, pp.836-837). Each scheme has a specific target, according to which the scheme is designed. The design of payment schemes comprises aspects like the allocation of contracts, monitoring, sanctions, and conditionality (Wunder *et al.* 2008, pp.840), the mode of payment, the amount paid, the timing of the payment and the contract duration (Wunder *et al.* 2008, pp.842). This section gives an overview on the design of these schemes.

1.2.1 Targets, requirements and payment design

Each payment scheme has a specific target to be achieved. An environmental agency offers land users payments for an activity assumed to meet that target, or for successfully meeting that target. These are referred to as input and outcome-based payments, respectively. If the provision of environmental services cannot be observed, agencies cannot offer outcome-based payments. In such cases input-based payments can be offered based on the area enrolled in the scheme, or on alternative metrics used to measure inputs (Engel *et al.* 2008, p.668).

Participation can imply keeping the existing land use, such as in the case of forest conservation, changing practices in the current land use, or even changing the land use, such as in the case of reforestation and afforestation (Engel *et al.* 2008, pp.667-668). So are land users in Bolivia and Ecuador paid for forest and páramo conservation in schemes whose goal is the watershed and biodiversity protection. Land users in Ecuador are also paid for re- and afforestation in another scheme that targets carbon sequestration. Vittel pays land users for the implementation of certain practices in dairy farming that lead to a better water quality. Land users in the US are offered payments for the retirement of agricultural land in a scheme that targets the quality of water, air and soil, as well as wildlife protection and carbon sequestration, just to mention some examples (Wunder *et al.* 2008, pp.836-837).

Participation in a payment schemes can also imply in-kind benefits for land users (Engel *et al.* 2008, p.668). The benefits they would derive from participation must exceed their opportunity costs in order to induce their participation. Deciding on the amount to be paid for participation can be however challenging for an environmental agency whenever land users have private information regarding their opportunity costs. The higher the overcompensation paid to land users, the fewer the amount of contracts that can be allocated given a certain fixed budget. If opportunity costs would be observable, the agency could decrease the level of overcompensation and provide more environmental services (Ferraro 2008, p.811).

The requirements vary across schemes. Some require land users to submit a management plan in order to apply for payments. Participation can imply technical requirements and initial investments. The latter are often barriers to participation, because of lacking access to information, because of liquidity constraints (Pagiola *et al.* 2005, pp.244-245), or because of the presence of asset specificity. Asset specificity implies that investments are non-redeployable in an alternative use without losses. This can imply a "hold up" situation for land users (Ducos & Dupraz 2007, p.5), characterized by the existence of quasi-rents that could be potentially appropriated by the environmental agency (Ducos & Dupraz 2007, p.7). Higher initial payments would be necessary to overcome these participation barriers. These could help land users finance initial implementation costs (Pagiola *et al.* 2005, p.245), and in the case of asset specificity, these would prevent land users from exposing their quasi-rents. In this context, trust plays an important role. Land users would agree to make specific investments in the absence of initial payments if they trusted the intentions of the agency to compensate them ex post for their investments (Ducos & Dupraz 2007, p.23).

Although payment schemes are conceptualized as a mechanism to improve efficiency in the provision of environmental services, and are not thought to be an instrument for poverty alleviation, it is often argued that they can also induce pro-poor effects. This effects can be a result of the payments themselves, if these are made to poor land users. There are even schemes that specifically target them (Pagiola *et al.* 2005, p.239). In fact, the need to improve the welfare of the poor is one of the reasons why governments decide to choose these incentive-based policies (Rosa da Conceição *et al.* 2015, p.250).

1.2.2 Scheme evaluation

Payment schemes are evaluated according to their budgetary cost-effectiveness. For budget-constrained schemes, budgetary cost-effectiveness refers to the potential of the scheme to maximize the provision of environmental services given a certain budget constraint. Conditionality is in this respect an important aspect of the design of payment schemes. It has to be verified whether the target of the scheme has been met. This can be done through the definition of certain indicators, and through the establishment of a baseline in order to determine whether the scheme induced additionality (Engel *et al.* 2008, p.668). Leakage and other spillover effects should also be considered when evaluating the scheme (Engel *et al.* 2008, p.670). A further criterion is permanence, which refers to the ability of the payments to generate long-run environmental benefits even beyond the period of the contract. However, this is often dependent on the continued flow of financing (Engel *et al.* 2008, p.671).

1.2.3 Contract design

Payment schemes have to be developed for the particular environmental, economic, social, and political context in which they are going to be implemented. The context has a significant influence on the design of the scheme (Engel *et al.* 2008, p.668).

The payment amount, the mode of payment, the timing and the contract duration differ among schemes. Agencies can moreover make differentiations according to space or other characteristics. So are for example long-term contracts offered for reforestation in the US and Ecuador, and short-term contracts for conservation in Costa Rica. Some schemes offer initial ex ante payments, such as the payments for conservation in Bolivia, and others ex post payments which are subject to compliance, like the payments in Costa Rica. Many schemes offer annual payments and land users are paid in cash (Wunder *et al.* 2008, p.842). All contracts include sanctions in case of non compliance. This could be in form of a temporary exclusion from participation as it is in the schemes in Bolivia and Ecuador, in form of losses of future payments like in the Costa Rican scheme, or in form of repayment as in the CRP scheme in the US (Wunder *et al.* 2008, p.840).

1.2.4 Allocation of contracts

The dominant forms of price setting are bilateral bargaining and fixed payments, however, these allocation mechanisms can lead to inefficiencies because of the information asymmetry between contract buyers and sellers. Land users can use their private information as a source of market power to extract rents (Ferraro 2008, p.818).

Procurement auctions are claimed to improve the cost-effectiveness of a scheme by reducing overcompensation, and thus allowing to increase the number of contracts. The environmental agency invites bids from land users that are potential suppliers of the targeted environmental services, and then contracts those offering the highest cost to benefit ratios. Bidding rules and market competition reduce the incentive for sellers to inflate their payments (Ferraro 2008, p.813). Nevertheless, the implementation costs of each allocation mechanism should be taken into account in order to compare their net gains (Ferraro 2008, p.819). So far, the best-known scheme where contracts are allocated by means of procurement auctions is the Conservation Reserve Program (CRP) in the US (Ferraro 2008, p.814).

The bidding strategies, and thus the cost-effectiveness of the auctions, depend on their design. Auctions can be discriminatory, meaning that contracted land users receive a payment equal to their bid. Alternatively, all winners can receive uniform payments, determined by the lowest rejected bid or the highest accepted one. Auctions can be conducted only once, or can be repeated. The offers can be sealed or open, and thus observable (Ferraro 2008, p.813).

The dominant strategy in discriminatory auctions is overbidding, the bid depends on the opportunity costs of participation and on the bidders' expectation about the cut off payment (bid cap) (Latacz-Lohmann & Van der Hamsvoort, Carel 1997, p.411). On the contrary, in uniform auctions the dominant strategy is to offer a bid equal to the opportunity costs because bids only determine the chance of winning a contract but not the payment (Latacz-Lohmann & Schilizzi 2005, pp. 21-22).

The potential of auctions to provide services more cost-effectively than fixed payments has been questioned in repeated auctions because repetition allows land users to learn. Land users adapt their bids accordingly in order to secure higher rents over time (Latacz-Lohmann & Schilizzi 2005, p.29). On the other hand, repeated auctions generate asymmetries among bidders in terms of learning effects, specific assets, and social capital. This might lead to a favorable effect in the provision of services through long-term solid and trustful contractual relationships (Vogt & Bizer 2013, p.12).

There have been many efforts to investigate the learning effects of bidders and their influence on the performance of auctions. Auction theory is less well developed for repeated procurement auctions as a result of the level of complexity involved (Schilizzi & Latacz-Lohmann 2007, p.499), therefore studies comprise laboratory experiments (Cason & Gangadharan 2004; Latacz-Lohmann & Schilizzi 2007) and agent-based modeling (Hailu & Schilizzi 2004; Hailu & Thoyer 2006, 2010; Hailu *et al.* 2010; Lundberg *et al.* 2018). Agent-based models allow simulating interactions between heterogeneous individuals, so that the macro-scale effects that emerge from these dynamics, can be analyzed (Axelrod & Tesfatsion 2006). This allows the understanding of how learning, strategizing, and interaction over time affects the outcome of payment schemes in the presence of bounded rationality (Hailu & Schilizzi 2004, pp.153-154). Moreover, they allow analyzing the outcomes resulting from the implementation in different scenarios, and under different assumptions.

Studies using agent-based modeling provide evidence for the deterioration of the cost-effectiveness of auctions over time. While most of these models include the assumption that bidders learn from their own experiences through reinforcement learning algorithms, only one study recognized the fact that learning can be the result of social interaction. Lundberg et al. (2018) introduce a learning algorithm where bidders exchange information with their neighbors in order to adapt their strategies over time. As long as bidders have information about a higher successful bid, they will have an incentive to increase their offers (p.351). Nevertheless, to date there is no study assessing the effect of the connectivity of land users in a social network on the cost-effectiveness of payments.

Although the use of auctions to reveal private information could be important in low-income countries where markets do not function well, so far auctions in low-income countries have only been implemented in some piloting projects. One reason for this is the pro-poor effect that payments are expected to induce, and the concern that auctions may reduce the monetary transfer to the poor (Ajayi *et al.* 2012, p.3). However, if auctions are used in a setting where poor land users are those with the lowest opportunity costs, auctions could help reduce poverty while still providing services cost-effectively because they target low-cost land users (Ajayi *et al.* 2012, p.4). On the contrary, the participation of the poor in fixed payment schemes can only be ensured with additional targeting. One aspect that contributes to pro-poor effects is the fact that fixed payments are not volatile as crop prices are (Pagiola *et al.* 2005, p. 247), which might not be the case in procurement auctions. More evidence is lacking in order to evaluate the benefits of implementing auctions in low income countries.

1.3 Research questions

This thesis explores the use of auctions in the allocation of contracts in payment schemes, taking into account the role of social interaction. Social interaction is considered as a means for land users to inform themselves in order to optimize their strategies. Social interaction affects their expectations and perceptions. Thus, personal social networks are an important determinant of participation (Sun & Müller 2012, p.2). The thesis addresses four different research questions, which are explained in the following.

The first research question is whether discriminatory auctions can be more cost-effective than fixed payments when bidders learn and adapt their strategies through social interaction over time. If land users interact with their acquaintances in their social network, seeking for information about their bidding strategies, over time they will have a better approximation of the bid cap. This will allow them to increase their information rents. In this context the thesis explores the role of the structure of the social network in the performance of auctions.

The second question is whether discriminatory and uniform auctions can induce a cost-effective provision of environmental services and pro-poor effects at the same time in a low-income country setting, where risk averse land users face uncertainty about their future opportunity costs, and when they learn through social interaction.

The third question is how can contracts in payment schemes be designed in order to overcome the problem of asset specificity, such that the scheme doesn't impose risk for the agency, and such that land users do not fear to lose their quasi rents.

The fourth question is whether auctions can provide environmental services cost-effectively when participation requires investments in specific assets, considering that social interaction frames learning effects and the reputation of the agency.

1.4 Outline

Each of the following four chapters is dedicated to answering the four research questions. In order to simulate the implementation of auctions, we used agent-based modeling. Our agent-based models are written in Java by means of Repast Simphony 2.5, an open source modeling toolkit developed by North et al. (2013) in the operating system Microsoft Windows and Java 8. Repast Simphony is an open source agent-based modeling and simulation platform that simplifies model creation and use. It supports the development of flexible models of interacting agents.

Chapter two addresses the question of the cost-effectiveness of repeated discriminatory auctions when bidders learn through social interaction. In order to answer this question, we extended the model of Hailu and Schilizzi (2004). The authors simulate a payment scheme for biodiversity conservation, where contracts are allocated by means of fixed payments and discriminatory auctions. Instead of adapting their bids according to a reinforcement learning algorithm, land users are embedded in a small world network that allows them to interact with their neighbors, and to learn from this social interaction. This chapter was submitted to the Journal *Biodiversity and Conservation* as a manuscript entitled "*Learning from social interaction in repeated conservation auctions*", written by Elsa Maria Cardona Santos, Sebastian Rasch and Hugo Storm.

Chapter three addresses the question of the potential of uniform and discriminatory auctions to induce pro-poor effects, while providing services cost-effectively. An agent-based model simulating conservation auctions in a low-income country is used to answer this question. Land users are assumed to be risk averse and to face uncertainty regarding future opportunity costs. This chapter was submitted to the Journal *Biodiversity and Conservation* as a manuscript entitled "*The use of repeated conservation auctions in low-income countries: An agent-based computational model of uniform and discriminatory auctions*", written by Elsa Maria Cardona Santos, Sebastian Rasch and Hugo Storm.

The contractual possibilities to deal with the problem of asset specificity are reviewed in chapter four. Different propositions about the design of contracts are developed for different implementation contexts. These are compared to the contract design of already implemented schemes, through which land users were paid for tree planting and conservation. Chapter five addresses the use of auctions to allocate contracts that require specific investments. An agent-based model with empirical data from a tree planting trial in Malawi is used for this purpose. This trial was implemented by Kelsey Jack, and is explained in detail in Jack (2010). The scheme simulated requires land users to retire cropland, and to invest in tree planting. The use of uniform and discriminatory auctions is analyzed for the allocation of short and long-term contracts. This chapter will be submitted as a manuscript entitled "The use of auctions in payment schemes that require specific investments: : An agent-based computational model", written by Elsa Maria Cardona Santos, Sebastian Rasch and Hugo Storm. The last chapter summarizes the most important findings of this research and provides an overall conclusion.

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2

Learning from social interaction in repeated conservation auctions

2.1 Introduction

Incentive-based mechanisms, such as Payments for Environmental Services (PES), have been increasingly used to give land users financial incentives to provide environmental services. The provision of environmental services might be lower than socially optimal because the potential providers of environmental services receive less private benefits from this provision than from alternative land uses. Compensating service providers allows internalizing what would otherwise be environmental external effects. Thus, payment schemes put into practice the Coasean theorem (Engel *et al.* 2008, pp.664-665). Although these payments are often made for forest conservation, they can be offered for the restoration or for the establishment of any land use that generates external benefits, including agricultural activities (Engel *et al.* 2008, pp.664).

Most of these schemes offer fixed payments. Some examples are the payments for hydrological environmental services in Mexico (Muñoz-Piña *et al.* 2008), the payments for environmental services in Costa Rica (Pagiola 2008) and the payments for re- and afforestation in Ecuador (Wunder & Albán 2008). In order to induce the desired land use or activity, payments have to exceed the opportunity costs of land users. Therefore, in some schemes payments are established based on estimations of the opportunity costs (Muñoz-Piña *et al.* 2008, p.5).

However, establishing the level of the payments can be challenging for an environmental agency. Whenever land users are better informed about their opportunity costs, they can claim to incur higher costs in order to secure higher payments. The difference between the payment a land user receives and her opportunity costs can therefore be regarded as an information rent. The provision of environmental services per unit spent decreases with the amount of information rents paid. Thus, the presence of information asymmetry leads to a less cost-effective provision compared to a situation in which opportunity costs are observable (Ferraro 2008, p.813). If the environmental agency is budget constrained, cost-effectiveness refers to the scope of environmental services that can be provided per unit of budget available. In the case of a target-constrained scheme, cost-effectiveness refers to the amount of budget necessary to provide a unit of environmental services.

Procurement auctions are claimed to improve the budgetary cost-effectiveness of payment schemes. The environmental agency invites bids from potential providers of environmental services for a specific contract. After receiving the offers, the agency contracts those with the best offers until the budget is exhausted, or until the target is met. By means of market competition and bidding rules, land users' incentives to inflate their contract prices are lowered, such that auctions allow reducing the information rents. The induced bidding behavior depends on the design of the auction (Ferraro 2008, p.813).

The Conservation Reserve Program in the United States is the biggest program where contracts are allocated by means of discriminatory auctions. In discriminatory auctions, land users are contracted according to lowest bids until the budget is exhausted, or until the target is achieved, and are paid an amount equal to the bid they made. Thus, bids determine not only the payments but also the probability of being contracted. Latacz-Lohmann and Van der Hamsvoort (1997) show that in order to maximize their pay-offs, bidders make offers that exceed their opportunity costs. Overbidding is higher for the land users with the lowest costs (p.411).

The potential of auctions to increase the cost-effectiveness of payment schemes is claimed to decrease over time in repeated settings. Auctions are often repeated over time because there are constraints to contracting all land users simultaneously or because renewable short-term contracts are offered. Land users can gather information about the outcomes of previous auctions and use it in order to increase their information rents. In this context, land users are interested in knowing what was the maximum accepted offer, and in receiving information that allows them to understand the distribution of the bids submitted. Every land user with opportunity costs lower than the maximum accepted payment (bid cap) will have an incentive to inflate the bid in order to secure a higher rent (Ferraro 2008, p.817).

There are studies providing evidence for the effect of these learning effects on the performance of auctions. According to Reichelderfer and Boggess (1988), in the United States Conservation Reserve Program, the average bid was very close to the maximum acceptable payment level after some bidding rounds (p.10). Because auction theory is less well developed for repeated procurement auctions because of the level of complexity involved in learning effects (Schilizzi & Latacz-Lohmann 2007, p.499), studies use approaches such as laboratory experiments and agent-based modeling. Cason and Gangadharan (Cason & Gangadharan 2004) and Schilizzi and Latacz-Lohmann (2007) show by means of laboratory experiments that in later rounds repetition erodes the relative advantage of auctions because of learning effects (p.83). The same is shown in studies using agent based modeling (Hailu & Schilizzi 2004; Hailu & Thoyer 2006, 2010; Hailu *et al.* 2010; Lundberg *et al.* 2018), where the performance of auctions is analyzed under different assumptions and for different settings.

Agent-based models allow simulating interactions between heterogeneous individuals, such that the macro-scale effects that emerge from these dynamics can be analyzed (Axelrod & Tesfatsion 2006). This allows understanding how learning effects, bidding strategies and interaction affect the outcome of payment schemes over time in the presence of bounded rationality (Hailu & Schilizzi 2004, pp.153-154). In most of these studies bidders are assumed to learn only from their own past experiences. However, in reality land users are also likely to gather information from the experiences of their acquaintances in order to understand their possibilities to increase their own rents (Hailu & Schilizzi 2004, p.165).

It is important to take into account that bidders can learn from social interaction, especially if they lack confidence in their own strategies or if they are not certain about their own opportunity costs (Chernev 2003, p.61). In the context of governance of many kinds of natural resources[1] it is observed that learning communities emerge because managers have common concerns and pursue knowledge through interaction. Knowledge can be shared through connected individuals, but also through bridging organizations acting as long-range links in a network (Berkes 2009). Social interaction can play an important role in the management of natural resources (Gunderson *et al.* 1999; Olsson *et al.* 2004), and its effect can depend on the topology of the network (Bodin & Norberg 2005).

Hailu and Schilizzi argue that communication is likely to increase the speed of learning, having implications for the cost-effectiveness of auctions (p.165). So far, Lundberg et al (2018) is the only study that assumes learning through social interaction. They introduce learning through neighbor interaction. In the first round bidders make an offer equal to their opportunity costs. They are assumed to know the bids of their eight neighbors, and whether they were successful or not. This information is assumed to have an accuracy of 10 percent. If bidders have information about a higher successful bid, they copy it in the next round. In case of not receiving a contract they offer again a bid equal to their opportunity costs. The authors show that the loss in cost-effectiveness over time will depend on the distribution of the opportunity costs and on the budget availability. If costs are subject to spatial correlation, agents will have

[1] Such as fisheries, forests, grazing lands, watersheds, wildlife and protected areas

costs similar to their neighbors' costs, such that it will take longer until the information about the cut-off price is spread in the population compared to a random distribution of costs(p.355). The higher the budget the longer it will take before the benefits from discriminatory auctions are lost(p.356).

The purpose of our study is to investigate the effect of social interaction on the cost-effectiveness of discriminatory auctions. We analyze the differences between the performance of discriminatory auctions in a setting where land users learn in isolation from their own experience, and a setting where land users are likely to exchange information with their peers and learn from their experiences as well. We compare these results with a fixed payment scheme in order to have a benchmark. Moreover, we analyze the effect of different levels of competition and of different patterns of the social network, because the latter is likely to affect the diffusion of information among land users.

We address this by means of agent-based modeling. Our model is based on the study of Hailu and Schilizzi(2004), who compare the performance of discriminatory auctions and fixed payments in a scheme that makes payment for biodiversity conservation on private land. The authors assume that land users start bidding their true opportunity costs, but that they learn in repeated auctions through a reinforcement learning algorithm. We extend their model by allowing land users to interact through a small-world network and to learn from social interaction. This study contributes to the literature by focusing on the relevance of information networks for the implementation of conservation auctions.

The structure of the paper is as follows. In the next section the model is described, as well as the assumptions made. In the third section we show the results and discuss them. The fourth and last section provides our conclusion.

2.2 Model

The purpose of our agent-based model is to analyze the effect of social interaction on the cost-effectiveness of discriminatory conservation auctions. Our model builds up on the model of Hailu and Schilizzi (2004). The authors simulate a scheme where land users are offered conservation contracts in order to protect biodiversity. Conservation contracts are allocated by an environmental agency through fixed payments or through discriminatory auctions. In exchange for the payments, contracted land users are expected to adopt certain practices that will favor the conservation of biodiversity on their private land. Land users are assumed to learn in isolation through a reinforcement learning algorithm.

We extend their model with a small-world network, that allows land users to learn through social interaction. We introduce a learning algorithm through which land users adapt their bidding strategies, according to the information they receive from their peers. We compare these results, and analyze their sensitivity to alternative levels of competition and to different levels of connectivity among bidders.

2.2.1 Individual decision making

There are two different agent types in the model. The first is an **environmental agency** that seeks to maximize the provision of environmental services by offering repeatedly the same conservation contracts, constrained by a fixed budget in every period. Conservation contracts have a duration of 1 period.

The second agent type is comprised of **land users** whose goal is to maximize their profits by enrolling their land in the payment scheme. The benefits from conservation are assumed to be homogeneous. Land users have different opportunity costs of participation, the profit of the next most profitable land use. This information is assumed to be private, so that there is an information asymmetry between land users and the agency.

2.2.2 Allocation mechanisms

The environmental agency can allocate the contracts through discriminatory auctions or fixed payments. These mechanisms are explained in the following.

Fixed payments are uniform, which means that all contracted land users receive the same payment. The level of the fixed payments is announced by the agency, and land users whose opportunity costs of participation are below this payment state their willingness to accept for participation. The agency successively selects random land users and observes their willingness to participate in the scheme for the offered payment. If those land users are willing to participate, and the budget is not yet exhausted, the agency contracts them.

Auctions are sealed and discriminatory, which means that land users cannot observe the bids of their peers, and that all contracted land users receive a payment equal to their bids. When contracts are allocated by means of auctions, land users announce their bids and then the agency contracts the land users offering the lowest bid, until the fixed budget is exhausted.

2.2.3 Learning algorithms

If land users are assumed to learn in isolation only through their own experiences, they learn through the reinforcement learning algorithm proposed by Hailu and Schilizzi (2004). If land users are connected in a social network to other participants, they learn according to the learning algorithm we introduce. The latter is based on the approach of Lundberg et al. (2018). Land users decide on their bidding strategies, according to the information they gather. In both scenarios land users start bidding their true opportunity costs, and adapt their strategies over time based on the respective learning algorithm. These are described in detail in the following.

The reinforcement learning algorithm implies that land users learn from their own past experiences. Land users change their current bidding strategy with a probability of 50 percent according to whether their last bid was successful or not. If it was successful, and the land user was contacted in the last round, they increase their bid by 10 percent. If it wasn't, they decrease it by 10 percent.

Learning through social interaction implies that bidders learn from the information they gather through social interaction and adapt their bidding strategy accordingly. In every round land users gain experience, and gather information about the payoffs of their peers in their network. This information allows them to update their expectations about the bid cap. The bidding strategies are adapted over time based on the highest payment they have information about. If a contracted land user has information about an accepted bid that was higher than her own (or than her own opportunity costs in case of not being contracted), she will have an incentive to increase her bid in the following period in order to increase her rent. If, however, the highest accepted bid she has information about is lower than her own, she could be a marginal winner, therefore she will have an incentive to lower her bid in the following round in order to secure participation. No bids are offered below the opportunity costs of participation.

This learning algorithm is described by equations 2.1 and 2.2. The term $b_{i,t-1}$ describes the last bid made by a land user i if contracted, or the opportunity costs of participation in case of not being contracted. The term $b_{j,t-1}$ describes the highest accepted bid land user i has information about. The difference between these values is described by the gap in equation 2.1. If the latter is positive, land user i will increase her bid in the next period according to equation 2.2. If the gap is negative, she will lower it according to the same equation (Latacz-Lohmann & Van der Hamsvoort, Carel 1997).

$$\triangle_{i,j} = b_{j,t-1} - b_{i,t-1} \tag{2.1}$$

$$b_{i,t} = b_{i,t-1} + \frac{\triangle_{i,j}}{2} \tag{2.2}$$

2.2.4 Social network

Land users are assumed to be connected through a social network through which they can share information with their acquaintances. We model a small-world network where each land user has a certain amount of neighbors k, and where each land user is likely to know someone from another neighborhood with probability β. This type of network can present a high connectivity among land users with a small number of connections, allowing information to spread rapidly to other areas of the network (Centola 2010).

We implement the Watts-Beta-Small-World Generator by Jung Project and Nick Collier. It is a graph generator that produces a small world network using the beta-model, as proposed by Duncan Watts (1998). It starts with a one-dimensional ring lattice in which each land user has k-neighbors. Then, it randomly rewires the acquaintances with probability β. This small world network can be created for different values of β and k, and exhibit low characteristic path lengths and a high clustering coefficient. Land users in the same neighborhood are likely to have similar opportunity costs. We investigate the role of connectivity among land users by assuming different values for these two variables. Land users with similar opportunity costs have a higher probability of being neighbors.

2.2.5 Performance indicators

We evaluate the extent to which an environmental agency can provide environmental services cost-effectively by means of auctions. In the literature, the environmental goal is measured by means of budgetary cost-effectiveness, meaning the extent to which environmental services can be provided with the given budget.

We consider the returns to budget, measured by the **number of contracts** in every period, and **information rents**, measured as the sum of the individual differences between payments (p_i) and opportunity costs (π_i)(see equation 2.3).

$$\text{information rents}_t = \sum_{1}^{N_t} (p_i - \pi_i) \tag{2.3}$$

The higher the number of contracts and the lower the information rents, the higher the cost-effectiveness of the scheme. We observe these two indicators in each period in order to address the dynamics of the model over time.

2.2.6 Initialization

Our parameters are based on the ones assumed in Hailu and Schilizzi (2004). The population consists of 100 land users, of which each is endowed with one unit of land, whose environmental value under conservation is homogeneous for all units. Each land user is assigned to a random level of opportunity costs in a range from 0 to 1, distributed uniformly. The fixed budget equals 15. Fixed payments equal 0.5, the average opportunity costs.

We assume that land users have two neighbors , and that they can be rewired with a probability of 20 percent. Afterwards we vary these parameters in order to investigate the effects of different connectivity patterns.

2.2.7 Sensitivity analysis

In order to investigate how the results of our model are influenced by the assumptions in the baseline setting, we vary the population and the budget restriction. Exploring the changes in the outcomes under these alternative assumptions, allows us to determine the impact of these variables on the performance of auctions, and thus to test the robustness of the results of the model.

We vary the budget and the number of land users to investigate whether there are interaction effects. We vary the budget from 5 to 25 units in steps of 1 unit. Ceteris paribus, we expect the level of budget to have an influence on the amount of contracts. The lower the budget level, the lower the number of land users contracted under a fixed payment scheme relative to conservation auctions. The number of land users is varied through a range between 50 and 150 in steps of 10, without varying the distribution of the opportunity costs.

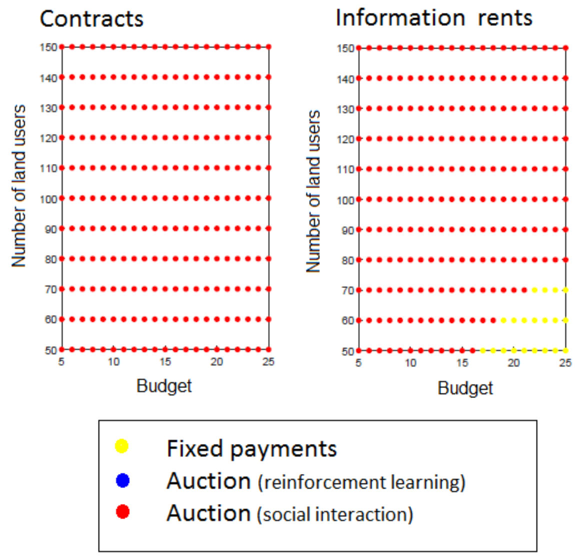

Figure 2.1: Best allocation mechanisms for different budget and population

Figure 2.1 shows the results of the sensitivity analysis, which explores how the indicators react to fluctuations of budget and population in the last implementation period. This graph shows the best allocation mechanism given a certain combination of budget and number of land users. The best allocation mechanism is the one that delivers the highest number of contracts, as well as the lowest value of information rents. The number of land users can be found on the vertical axis and the budget on the horizontal axis.

Conservation auctions perform better in terms of the number of contracts for any given level of budget and number of land users when they learn from social interaction. The payments on average are smaller under the fixed payment scheme for relatively higher ratios of budget to number of land users, which leads to smaller information rents on average under a fixed payment scheme.

From this analysis, we derive two extreme scenarios in order to analyze the relative performance of discriminatory auctions, describing a high and a low level of competition among participants.

Low competition scenario refers to an implementation of the scheme in the presence of 50 land users, given a budget equal to 25.

High competition scenario refers to an implementation of the scheme in the presence of 150 land users, given a budget equal to 5.

We run every scenario 1000 times for 100 periods. Assuming that each period in our model is equivalent to 1 year, our model would take into account 100 implementation years, which would exceed the expected lifetime of a single land user. This time frame allows us to evaluate the long-run effects of repeated auctions.

2.3 Results and Discussion

We analyze the effect of social interaction on the cost-effectiveness of repeated discriminatory auctions for different social network structures. Figure 2.2 shows the number of contracts allocated assuming different values for the parameters determining the structure of the social network. Variable k describes the amount of neighbors that each land user has, and the variable β describes the probability that two land users in different neighborhoods know each other. These time series are the averaged results of 1000 simulations.

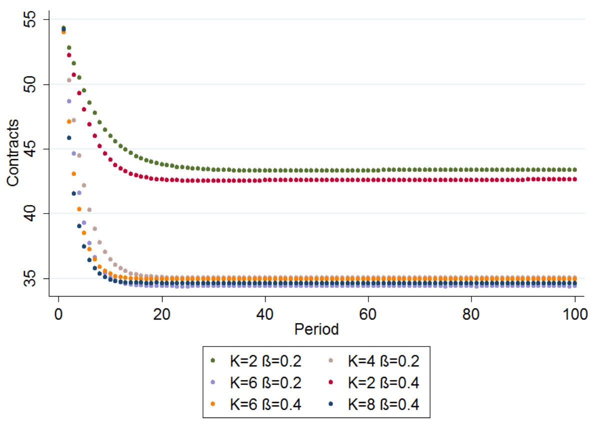

Figure 2.2: Performance of auctions in different network structures

As shown in figure 2.2, the potential of auctions to allocate contracts deteriorates with an increase in the number of neighbors and with an increase in the probability of having acquaintances in other neighborhoods. However, an increase in the number of neighbors has a smaller effect than an increase in the probability. The higher the number of acquaintances, the higher the amount of information available, and thus the better the estimation of land users about the bid cap. Land users in the same neighborhood are likely to have similar opportunity costs. This means that an increase in the number of neighbors will allow land users to gather more information, but their potential to increase their rents won't be as high as it would be if this information would come from another neighborhood. Land users in other neighborhood might face higher opportunity costs, and might thus receive higher compensation payments. Getting access to this information would allow low-cost land users to increase their rents even more.

An aspect worth noting in figure 2.2 is the fact that at some point a further increase in the amount of neighbors or in the probability of being rewired does not deteriorate the performance of auctions any further. This is the point where all land users are already fully informed. We take this setting into account and refer to it as **highly crossed-linked social interaction** ($k = 6$ and $\beta = 0.4$).

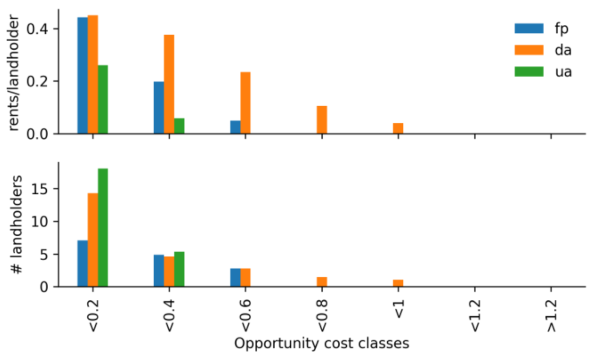

Figure 2.3: Baseline scenario

Now, we compare the results of repeated auctions in a setting where land users learn from social interaction with a setting where they learn only from their own experiences, and with the allocation of contracts by means of fixed payments. Figure 3.5 shows these results. The setting **social interaction** refers to the baseline assumptions about the structure of the network ($k = 2$ and $\beta = 0.2$) and the setting **reinforcement learning algorithm** refers to the assumption that land users learn only from their own experiences through reinforcement learning. We show the results for the two indicators of cost-effectiveness, the number of contracts allocated and the total information rents paid.

The fixed payment scheme leads to a constant number of contracts allocated over time and to constant information rents on average. As shown in figure 3.5, during the first implementation periods, discriminatory auctions lead to a clearly higher number of contracts and lower information rents, compared to the fixed payment scheme. Over time, the cost-effectiveness of discriminatory auctions decreases under all scenarios. The extent to which it decreases depends on how land users learn over time.

If land users do not know any other participant, they only adapt their bids according to trial and error (reinforcement learning). Successful bids provide them an incentive to increase their bids in the next period, and unsuccessful bids give them an incentive to lower the latter. As shown in figure 3.5, this learning pattern leads to a number of contracts over time that converges to the amount of contracts allocated by means of fixed payments. We confirm the result of Hailu and Schilizzi (2004). All low-cost land users keep increasing their bids in many rounds because of a lack of negative feedback. This leads to increasing information rents over time.

The number of contracts and the total information rents oscillate in the long run around a steady state. The marginal losers are those land users who did not win a contract but whose bids are close to the bid cap. Marginal winners are those who won a contract with a bid close to the bid cap. At some point the payments increase to an extent that allows the marginal losers to decrease their bids because the bid cap is above their opportunity costs. They enter again the winning pool instead of the marginal winners of the last period, forcing them to decrease their bids in order to enter the winners' pool again in the following contracting round. This effect is what Hailu and Schilizzi (2004) refer to as the "basket of crabs" effect.

Although discriminatory auctions also lose cost-effectiveness over time when bidders learn through social interaction, the effect is different. The cost-effectiveness decreases at a higher pace during the first periods, but it reaches a steady state already in the mid-term. The loss of cost-effectiveness depends on the potential of land users to gather information. The better connected they are in the network, the higher the amount of information obtained, and thus, the better the estimation about the bid cap. In a setting where land users are only connected to two neighbors, and where the probability that they know other participants that are not in their neighborhood is 20 percent (This scenario is referred to as " Auction (social interaction)" in the graphs), discriminatory auctions lead to a steady state number of contracts that is higher than the number of contracts allocated through fixed payments. In a setting where every land user has access to all the information available in the network (every land user has 6 neighbors and each one knows someone from the other neighborhoods with a probability of 40 percent), auctions allow contracting a lower amount of contracts (highly crossed-linked social interaction).

Nevertheless, in the setting where land users have access to all the information available in the network, discriminatory auctions perform better than in a setting where land users do not know anyone and learn through reinforcement. The reason for this result is that if land users adjust their bids over time according to the bidding strategies of others, the learning effects remain conditioned to winning bids. Learning effects in isolation imply that low-cost land users increase their bids in every period as long as they keep winning contracts. This leads to increasing payments over time. On the contrary, in the presence of social interaction, land users approximate the bid cap faster but the bid cap reaches a steady state that remains below the average payment made in a setting with reinforcement learning. Marginal winners don't keep on increasing their bids because they know that their bids could exceed the bid cap in the following period. Information diffusion implies that learning can lead to a faster deterioration of the cost-effectiveness in the short-run compared to isolated learning if participants know each other very well, but in the long run the effect on cost-effectiveness is smaller.

An interesting result is the effect on information rents. Although discriminatory auctions in settings with high crossed-linked social interaction lead to information rents higher than the ones implied in fixed payments, the number of contracts allocated is higher. This suggests, that the payments made under discriminatory auctions on average are lower, but that those participating have lower opportunity costs. If wealth is correlated with opportunity costs, this would be an interesting result for payment schemes with the secondary objective to induce pro-poor effects.

Figure 2.4 and figure 2.5 show the performance of the two different allocation mechanisms under the different learning settings, assuming a high and a low level of competition, respectively. Under a high level of competition, auctions outperform fixed payments independently of how land users learn. The high level of competition does not allow land users to increase the payments above the level of the fixed payment, even if land users learn through reinforcement learning. Increased competition leads to more aggressive bidding, as bidders try to maintain their chances of winning against more rivals. This is what Hong and Shum (2002) call the *competitive effect*. In the absence of a *winners' curse*, where bidders might make non-rational offers, and assuming that no landholder would offer a payment smaller than their own opportunity costs, the average bid level is expected to decrease as the number of bidders increases (Hong & Shum 2002, p.871).

Interestingly, the information rents of discriminatory auctions, assuming highly crossed-linked social learning, are higher than the ones under fixed payments. This suggests, that the higher connected land users are in the network, the higher the potential for low-cost land users to increase their rents. While under reinforcement learning all land users increase their rents by the same percentage, under social learning those with the lowest-opportunity costs increase their bids relatively more. Low-cost land users who have a good approximation of the bid cap, and thus understand their possibilities to gain information rents, have a higher comparative advantage.

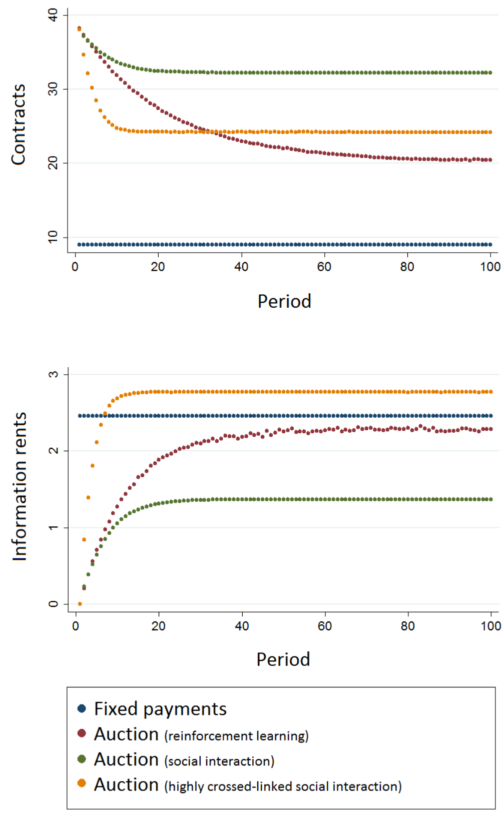

Figure 2.4: Effect of high competition

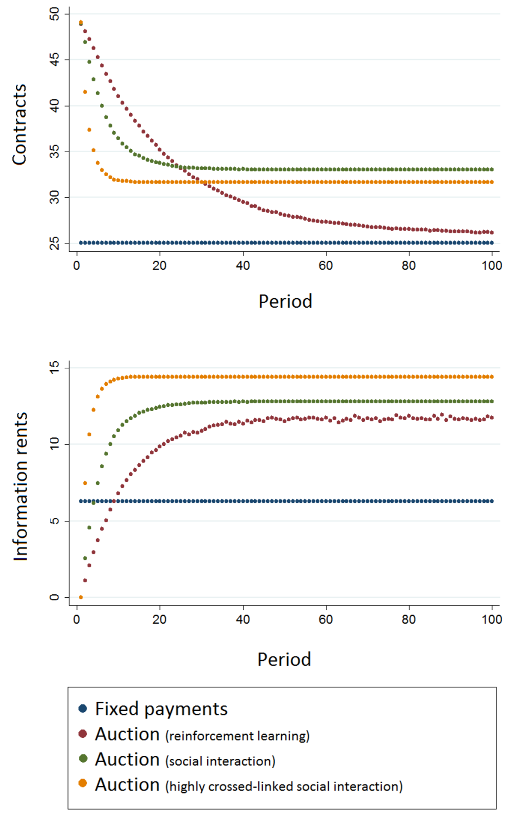

Figure 2.5: Effect of low competition

Although the cost-effectiveness of auctions deteriorates the less competitive the environment is, more contracts are allocated by means of auctions if land users learn through social interaction, compared to fixed payments. The number of contracts under reinforcement learning converges to the one under fixed payments. Nevertheless, the information rents are higher than the rents paid under fixed payments. The reason for this is that auctions target rather land users with lower opportunity costs, while fixed payment schemes contract land users randomly.

As our results suggest, the performance of repeated discriminatory auctions strongly depends on the learning algorithm assumed. If marginal bidders are not willing to take the risk of not receiving a contract, they won't increase their bids over their approximation of the bid cap. However, if they would do so, the results could be similar to the results of reinforcement learning. Nevertheless, the deterioration of the performance of auctions might take some time, especially if the scheme is implemented in a competitive environment. In settings where land users are rather risk averse, the cost-effectiveness of auctions would not deteriorate as fast. Risk averse land users could be willing to accept lower payments compared to risk-neutral land users with the same opportunity costs, in order to decrease uncertainty (Ferraro 2008, p.815). In low-income rural environments, land users are often confronted with uncertainty regarding their income, and in the presence of risk aversion they are lacking possibilities of insurance (Rosenzweig 1988, p.1148). Thus, it would be interesting to assess the potential of repeated auctions under such circumstances.

2.4 Conclusion

The objective of this paper was to investigate the effect of social interaction on the performance of discriminatory auctions. We introduce a small-world network in which land users are connected and can exchange information with their acquaintances. They learn from their own experiences and from the experiences of their peers, and adapt their bidding strategies based on this information.

Our results confirm the deterioration of the performance of discriminatory auctions over time in terms of cost-effectiveness. However, we show that this deterioration is dependent on how bidders learn over time. Contrary to the expectation that social interaction would deteriorate the cost-effectiveness of repeated auctions more than reinforcement learning (Hailu & Schilizzi 2004), our results suggest that social interaction can dampen the learning effects of bidders over time. When land users learn through social interaction, their bidding strategies remain conditioned to winning bids. Land users would not increase their bids over a level higher than the highest accepted bid they have information about, because they would risk participation. On the contrary, when land users have only information derived from their own experiences, they might increase their bids as long as they remain in the winners' pool.

The better informed bidders are, the higher the information rents they can secure, and thus the lower the cost-effectiveness in the long run. Nevertheless, higher connectivity also implies that other land users have access to the same information, which creates more competition among land users. Low-cost land users have thus a comparative advantage. Over time, the bids align, and so does the level of the payment. This means that the loss of cost-effectiveness occurs mainly during the first years of implementation and remains constant in the long-run. In such a setting, auctions can still be more cost-effective than fixed payment schemes. This is not the case when land users adapt their bids according to reinforcement learning. Because those land users with the lowest costs can keep on increasing their bids without getting any negative feedback, the cost-effectiveness of auctions keeps on deteriorating. In this setting, auctions might not be more cost-effective than fixed payments in the long-run.

The outcome of auctions when bidders can interact among each other could be similar to the results of reinforcement learning if low-cost land users would be risk loving. If low-cost land users would be willing to increase their bids despite the risk of not receiving contracts, the cost-effectiveness of auctions would deteriorate even more. The results would thus be conditioned to the share of risk-loving land users in the bidders pool.

An interesting result is the high amount of information rents paid under repeated discriminatory auctions compared to fixed payment schemes, even when a higher number of contracts are allocated by means of auctions. This implies that land users with relatively lower opportunity costs receive the rents. This would be an interesting result for schemes aiming to reduce poverty through the payments.

We conclude, that even in the presence of learning effects, discriminatory auctions can remain more cost-effective than fixed payments in the short-run, provided that offers do not exceed the fixed payments on average in the first round. Depending on the bidding strategies of land users and on their access to information, auctions can still be more cost-effective than fixed payments in the long-run. Moreover, even if fixed payments outperform auctions over time, there might be interesting pro-poor effects worth considering. The latter would be relevant for the implementation of payment schemes in low-income countries.

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3

The use of repeated conservation auctions in low-income countries

3.1 Introduction

Incentive-based mechanisms, such as Payments for Environmental Services (PES), are used to give landholders financial incentives to adapt their land use, in order to provide environmental services. In some schemes, payments have the additional goal of reducing poverty through the provision of these direct income transfers. This is claimed to come at the cost of the environmental objectives because of potential trade-offs between both goals (Pagiola *et al.* 2005, 2008; Wunder 2008a). Nevertheless, payment schemes are an interesting instrument for poverty reduction because of the high incidence of poverty in rural areas and the high reliance of this sector on natural resources (Bulte *et al.* 2008, p.247).

Some schemes target poor landholders specifically, such as the Western Altiplano Natural Resources Management Project in Guatemala or the National Environmental Management Project in El Salvador (Pagiola *et al.* 2005). Another example is Costa Rica. Although the PSA scheme is not designed to be a poverty reduction program, FONAFIFO, the agency implementing the scheme, added disadvantaged districts to priority areas in order to target poor landholders (Pagiola 2008). This scheme established fixed payments according to earlier forest subsidy programs based on estimations about the opportunity costs (Pagiola *et al.* 2005). The Mexican PSA-H scheme offers payments for conservation to landholders with primary forest cover, as a strategy to avoid deforestation. In order to target the very highly marginalized landholders, the Mexican government introduced a weight for poverty in the application grading system (Muñoz-Piña *et al.* 2008).

There is concern that the goal to maintain biodiversity can be in conflict with the goal of poverty alleviation. Creating protected areas to enhance biodiversity can have a negative impact on the poor, because it implies reducing their land use options. This has been a relevant element of the debate about conservation policies (Adams *et al.* 2004). Some countries face the dilemma of reducing deforestation rates, and at the same time preventing poor forest owners from generating income. There are attempts to integrate the needs of the local people into conservation goals. The latter has been referred to as "pro-poor conservation" (Adams *et al.* 2004). Payments for Environmental Services can be used as a means to protect the natural capital through the financial compensation of poor landholders (Muñoz-Piña *et al.* 2008). However such attempts to integrate both goals are claimed to be overambitious and underachieving because of the trade-offs they imply (Adams *et al.* 2004).

There is a broad discussion in the literature about the potential of payment schemes to reduce poverty. It is argued that although it might be attractive to try to achieve both, environmental and social goals, through payment schemes, it can be counterproductive. Focusing on targeting poor landholders might lead to a lack of provision of environmental services, which is the ultimate goal of payment schemes (Pagiola *et al.* 2005). After reviewing the ways in which payment schemes might affect poverty, Pagiola et al. (2005) conclude that schemes could be designed in a way that it allows the poor to participate. However, they suggest that schemes should not target highly marginalized areas if these are not likely to generate the desired services.

Budget constrained schemes face the trade-off between reducing the rents of landholders in order to increase environmental cost-effectiveness, and increasing them in order to induce poverty alleviation effects. Environmental cost-effectiveness refers to the potential of a scheme to maximize the provision of environmental services subject to the fixed budget. The lower the rents paid to landholders, where rents are the difference between the payments and their opportunity costs of conservation, the higher the number of conservation contracts that can be allocated. While the goal to achieve cost-effectiveness implies lowering these rents, the goal of poverty reduction requires overcompensating landholders.

Auctions can allow environmental agencies to improve the cost-effectiveness of payment schemes by reducing overcompensation through the revelation of landholders' true opportunity costs (Ferraro 2008). They can have a discriminatory payment format, such that contracted landholders receive a payment equal to their bid. Under an uniform payment format, all contracted landholders receive the same payment. Uniform payments can be determined by the lowest rejected bid, or by the highest accepted one. In discriminatory auctions landholders are confronted with a trade-off. The higher their bids, the higher their rents, but the lower the likelihood to receive a contract. Bidding strategies depend thus not only on their opportunity costs of participation, but also on their best guess about the highest acceptable bid. The dominant strategy is overbidding, especially for those with the lowest costs, because they can secure higher rents. In uniform auctions by contrast, the bids determine only the chance of winning but not the payment. Therefore, their dominant strategy is to offer a bid equal to their opportunity costs (Latacz-Lohmann & Schilizzi 2005, p.22).

Auctions could be particularly interesting in low-income countries, where markets do not function well, because the latter increases the asymmetric information between landholders and agency. In the presence of non-properly functioning land, labor and credit markets, it is difficult for the agency to estimate the opportunity costs of landholders (Ajayi *et al.* 2012). Moreover, in low-income countries landholders are likely to be heterogeneous in terms of opportunity costs because of inequality in respect to technology and assets. For agencies in such settings, auctions are particularly interesting for reducing rents paid to landholders (Wünscher & Wunder 2017, p.673).

However, there is concern that auctions could undermine pro-poor effects through the reduction of the payments made to poor landholders (Ajayi *et al.* 2012). While this might be true, it should be also taken into account that auctions have the potential to target the poorest landholders, as long as opportunity costs are positively correlated with wealth (Ajayi *et al.* 2012). Auctions could thus increase cost-effectiveness while ensuring that the rents are paid to poor landholders. In budget constrained schemes, a reduction of the compensation can imply offering payments to other poor landholders. The latter would thus be compatible with the goal of poverty alleviation (Khalumba *et al.* 2014). According to Wunder (2008b) poor landholders are likely to face low opportunity costs of participation if they possess marginal lands, are strongly capital and technology-constrained, and labor remuneration is low. However, if they work their smaller plots more intensively this might not be the case. The correlation of the level of opportunity costs and the level of wealth is thus likely to be context-specific. Nevertheless, Wunder claims that, in general, the poor are more likely to have lower opportunity costs (pp.284-285).

In theory, participation makes landholders better off as long as it is voluntary, because they would only accept payments that exceed their opportunity costs (Engel *et al.* 2008). In uniform auctions all participating landholders ensure an overcompensation if the payment is set at the lowest rejected bid. In discriminatory auctions landholders also ensure an overcompensation as long as they do not offer bids below their opportunity costs. Latacz-Lohmann and Van der Haamsvort (1997) show that the optimal bidding strategy in discriminatory auctions depends not only on the opportunity costs, but also on the expected bid cap, such that low-cost landholders can secure higher information rents, the closer their approximation to the true bid cap (p.411). The level of overcompensation could thus increase in repeated settings because bidders can learn and adapt their bidding strategies over time. The latter compromises the cost-effectiveness of payment schemes (Schilizzi & Latacz-Lohmann 2007), but it could provide pro-poor effects.

So far, repeated auctions have not been implemented in low-income countries. The experiences with auctions in low-income countries are limited to a couple of trials. These comprise a uniform auction to allocate tree planting contracts in Malawi (Jack 2010) and in Tanzania (Jindal *et al.* 2013), a uniform auction to allocate payments for soil erosion control in Indonesia (Jack *et al.* 2009), a uniform and a discriminatory auction in Peru and Bolivia to allocate payments for the conservation of traditional crop varieties (Narloch *et al.* 2013), a discriminatory auction to allocate tree planting contracts in Kenya (Andeltová *et al.* 2014), and an open discriminatory auction with multiple rounds in Kenya, where bidders could only revise their offers downwards after each round (Khalumba *et al.* 2014).

Some of these trials provide evidence for pro-poor effects. The trial in Malawi provided evidence for the potential of auctions to help achieve poverty alleviation goals (Ajayi *et al.* 2012). The auction allowed for positive livelihood effects. Landholders contracted through the auction experienced a marginally significant increase in food security, and they engaged in less casual labor. Moreover, the auction mitigated land use spillovers (Jack & Cardona Santos 2017). In Tanzania, the auctions allowed the agency to reveal the opportunity costs of bidders, and thus to estimate the costs of tree planting in that area. There were poor landholders participating under cost-effective targeting, although not all poor landholders could be contracted (Jindal *et al.* 2013). In Peru and Bolivia, wealthier landholders, with higher land availability and agricultural assets, had higher opportunity costs of conservation, and thus asked for higher payments in order to participate in the scheme (Narloch *et al.* 2013). In Kenya, bidders had no difficulties in understanding the auction mechanism, discriminatory payments were not perceived as unfair, and the poor were over-represented among the contracted landholders (Khalumba *et al.* 2014).

A concern posed by Ajayi et al. (2012) regarding the implementation of auctions in low-income countries, is the fact that landholders might not be better informed about their own opportunity costs compared to the agency, because they might not be familiar with the conservation technology, or because the determinants of their opportunity costs might be highly uncertain (p.3). Khalumba et al. (2014) also argue that if landholders are not able to precisely estimate their true costs, competition might lead to bids that are not profitable (p.865). This was also recognized as an issue in Indonesia, where low bids resulted in low compliance. In low-income rural environments, landholders are confronted with uncertainty regarding their income, and in the presence of risk aversion they are lacking possibilities of insurance (Rosenzweig 1988, p.1148). In Indonesia landholders perceived the contracts as an option, and thus offered relatively low bids. After uncertainty was resolved, they complied only if their opportunity costs were lower than the payments (Ajayi *et al.* 2012). Ajayi et al. (2012) call for more experimental designs in order to assess the benefits of repeated auctions in low-income countries.

To date there is no study focusing on the potential of repeated auctions to meet both goals. The purpose of our study is to fill this gap by means of agent-based modeling. We assess the compatibility or trade-offs between pro-poor targeting and an effective provision of environmental services under repeated uniform and discriminatory auctions. Agent-based models work as a computational laboratory. They allow analyzing the dynamics that emerge from individual decision making. They are suitable for the simulation of repeated auctions in different environments. One can model bounded-rational agents with a certain access to information and capacity to process it, their bidding strategies, and learning effects over time. These aspects are important determinants of the outcomes of auctions, because outcomes are very sensitive to the underlying informational structure (Hailu & Schilizzi 2005, pp.6-7). Agent-based modeling allows studying the effect of social interaction depending on certain behavioral patterns, underlying institutions and environmental components (Hailu & Schilizzi 2005, p.10).

There are many studies addressing the performance of conservation auctions to provide environmental services cost-effectively by means of agent-based models (Hailu & Schilizzi 2004, 2005; Hailu & Thoyer 2006, 2010; Hailu *et al.* 2010; Lundberg *et al.* 2018). However none of these studies has assessed the distributional implications of auctions, nor their potential to induce pro-poor effects. Our study contributes to the literature by evaluating the benefits of repeated auctions to allocate conservation contracts in low-income countries where pro-poor effects are part of the target of the scheme. Because the choice of the payment rule in auctions has a high influence on the distribution of rents (Wünscher & Wunder 2017, p.674), we investigate the outcomes of both uniform and discriminatory auctions in a low-income setting.

We assume that the opportunity costs of conservation are correlated with wealth (Wunder 2008b, p.284), and that landholders are risk averse and face uncertainty about their future opportunity costs (Ajayi *et al.* 2012). They are assumed to be willing to accept contracts with low payments as an insurance to even lower future opportunity costs. However, high-cost landholders are less likely to maintain compliance because their ex-post opportunity costs are more likely to exceed the payment agreed on ex ante (Kawasaki *et al.* 2012; Ajayi *et al.* 2012). The bidding strategies are based on the theoretical and empirical literature on conservation auctions (McKee & Berrens 2001; Cummings *et al.* 2004; Cason & Gangadharan 2004; Kawasaki *et al.* 2012; Deng & Xu 2015). In uniform auctions bidders make offers close to their costs (Cason & Gangadharan 2004, p.1215). In discriminatory auctions bidders make offers that exceed their costs, and repetition leads to higher offers over time (Cummings *et al.* 2004, p.352). This is especially true for low-cost bidders who increase their offers relatively more (Kawasaki *et al.* 2012, p.167).

Most of the studies using agent-based modeling assume that bidders learn over time only from their own experiences. However, learning is also a social process, and it is important to take this into account, especially whenever landholders lack confidence in their own strategies (Chernev 2003, p.61), or if they are not certain about their own opportunity costs, as pointed out by Ajayi et al. (2012). Following Lundberg et al. (2018), we assume that bidders learn and adapt their bids based on the information they gather through social interaction. The relative extent to which landholders overbid is assumed to depend on their position in the distribution of the costs (Schilizzi & Latacz-Lohmann 2007).

The structure of the paper is as follows. In the next section we describe our model, and in the third section we show the results of the simulations, which are further discussed in the fourth and last section.

3.2 Model

The purpose of our agent-based model is to analyze the extent to which repeated conservation auctions can induce pro-poor effects in a low-income setting. Our model builds up on the models proposed by Hailu and Schilizzi (2004) and Lundberg et al. (2018). Hailu and Schilizzi (2004) simulate a scheme where conservation payments are paid to landholders in order to protect biodiversity. The authors compare the performance of repeated discriminatory auctions with fixed payments, assuming that bidders learn over time through reinforcement learning.

We extend the model of Hailu and Schilizzi (2004) by a small-world network through which landholders can interact and learn over time. We implement a learning algorithm based on social interaction, following Lundberg et al. (2018). We assume that wealth is correlated with the opportunity costs of conservation, that landholders are risk averse, and that they face uncertainty in regard to their future opportunity costs. We compare the potential of uniform and discriminatory auctions to achieve the goals of biodiversity and poverty alleviation with a fixed payment scheme.

3.2.1 Agents

There are two different agent types in the model. The first is an **environmental agency** with the goal of protecting biodiversity and alleviating poverty. The second agent type is comprised of **landholders** whose goal is to maximize the profits derived from their land use. The agency is assumed to offer payments to landholders willing to apply a conservation technology, and to be constrained by a fixed budget in every period. Landholders are assumed to face different opportunity costs of participation in the payment scheme. Moreover, they are assumed to face uncertainty in regard to these costs. $\pi_{i,t}$ describes the opportunity costs of a landholder i in period t. The expected opportunity costs in every period equal the initial opportunity costs. In each period these costs change according to a normal distribution with a mean value equal to the expected opportunity costs, and a certain standard deviation (σ). σ determines the degree of uncertainty faced by all landholders, such that if it equals zero, landholders do not face uncertainty.

Landholders are assumed to use the conservation contracts as an option contract in order to counteract this uncertainty. Therefore, they are assumed to be willing to accept contracts with payments that are below their expected opportunity costs. Their minimum willingness to accept for participation in the scheme can be thus interpreted as a certainty equivalent. The certainty equivalent is the monetary value that guarantees them the same expected utility as their expected income from the conventional land use, and is described in equation 3.1.

$$wta_{i,t+1} = E[\pi_{i,t+1}] - x \tag{3.1}$$

The amount x is the risk premium, the amount they are willing to give up in order to insure themselves against uncertainty. This is uniformly distributed within the range $[0;\sigma]$. It accounts for differences in the risk preferences of landholders. If, after uncertainty is resolved, their opportunity costs exceed the payments, they are assumed not to comply with the contract. Non complying landholders do not receive the payment. Nevertheless, the agency incurs the opportunity costs of not having contracted another landholder, because it is assumed not to be able to save the unspent budget for further periods.

3.2.2 Allocation mechanisms and strategies

We consider three allocation mechanisms: fixed payments, discriminatory auctions and uniform auctions.

Fixed payments are uniform, which means that all contracted landholders receive the same payment. When contracts are allocated by means of fixed payments, the level of the fixed payments is announced by the agency. landholders state their willingness to participate if they are willing to accept less than the fixed payment. The agency successively selects random landholders and observes their willingness to participate in the scheme for the offered payment. If those landholders are willing to participate, and the budget is not yet exhausted, the agency contracts them.

Discriminatory auctions are sealed. All contracted landholders are offered a payment equal to their bids. Landholders announce their bids to the agency and the agency contracts those offering the lowest bid, until the fixed budget is exhausted. In the very first round landholders offer a bid that equals their minimum willingness to accept (equation 3.1). In further rounds, they adapt their bidding strategy according to their learning effects. The algorithm used to simulate the learning processes is described in the following section.

Uniform auctions are sealed. All contracted landholders are offered a payment equal to the lowest rejected bid. Landholders offer a bid equal to their willingness to accept in every period.

3.2.3 Learning algorithm

Landholders learn through their own experience and through social interaction. In every period they interact with their acquaintances and exchange information about their pay-offs. This diffusion of information allows them to adapt their expectations about the bid cap over time in discriminatory auctions. Landholders are assumed to adapt their bidding strategy over time based on the highest payment they have information about.

If a landholder has information about an accepted bid that was higher than her own (or higher than her minimum willingness to accept if not contracted), she will have an incentive to increase her bid in the following period in order to increase her rent. If, however, the highest accepted bid she has information about is lower than her own, she could be a marginal winner, therefore she will have an incentive to lower her bid in the following round in order to secure participation.

This learning algorithm is described by equations 3.2 and 3.3. The term $b_{i,t-1}$ describes the last bid made by a landholder i. The term $b_{j,t-1}$ describes the highest accepted bid landholder i has information about. The difference between these values is described by the gap in equation 3.2. If the latter is positive, landholder i will increase her bid in the next period according to equation 3.3. If the gap is negative, she will lower it according to the same equation (Latacz-Lohmann & Van der Hamsvoort 1997).

$$\triangle_{i,j} = b_{j,t-1} - b_{i,t-1} \tag{3.2}$$

$$b_{i,t} = b_{i,t-1} + \frac{\triangle_{i,j}}{2} \tag{3.3}$$

3.2.4 Social network

We assume that landholders are embedded in a social network. We implement a small-world network, a commonly found network structure, which was identified by Watts and Strogatz (1998). This type of network is characterized by a high connectivity with a small number of connections. This means that most landholders can be reached through a small number of links. These social networks are found in settings where landholders are connected to their neighbors, and where most connections do not involve separation by great distances (Wang & Chen 2003). In such networks, the presence of a few long-range links, meaning connections between landholders from different neighborhoods, allows a rapid spread of information throughout the population (Watts & Strogatz 1998; Centola 2010). Assuming this network structure is appropriate because residents in rural areas are shown to make more use of informal supportive neighborly relationships (Nation *et al.* 2010).

We implement the Watts-Beta-Small-World Generator by Jung Project and Nick Collier. The latter is a graph generator that produces a small world network using the beta-model, as proposed by Duncan Watts (1998). It starts with one-dimensional ring lattices in which each landholder has k neighbors. Then, landholders are rewired. landholders from different neighborhoods know each other with probability β. We create a small world network in which every landholder has 2 neighbors and a 20 percent probability of knowing other landholders in other neighborhoods. Landholders in the same neighborhood have similar opportunity costs.

3.2.5 Evaluation indicators

The extent to which auctions can provide biodiversity protection is measured by the number of contracted landholders that comply with the contracts. In order to assess the extent to which auctions can induce pro-poor effects, we observe the information rents paid, and the opportunity costs of the landholders receiving the payments. The information rents are defined by the sum of the individual differences between payments (p_i) and opportunity costs (π_i):

$$\text{information rents}_t = \sum_{1}^{N_t} (p_{i,t} - \pi_{i,t}) \tag{3.4}$$

The higher the information rents and the lower the opportunity costs of the landholders receiving them, the higher the pro-poor effects of the payments.

3.2.6 Initialization

The baseline setting (setting A).consists of the same values assumed in Hailu and Schilizzi (2004) for each parameter. There is a population of 100 landholders, each of which is endowed with one unit of land. The fixed budget equals 15 and the fixed payment equals 0.5. The uncertainty parameter σ equals 0.3. We explore three different scenarios, one for each allocation mechanism, respectively.

3.2.7 Sensitivity and scenario analysis

Additionally to the three different allocation mechanisms, we model different settings underlying the implementation of the payment schemes, in order to investigate how the results of our model are influenced by the assumptions made in the baseline setting A. We vary the population, the budget restriction, and the level of uncertainty for each allocation mechanism. We consider a **setting with low competition**, where the agency has a budget of 25 units and the population is comprised of 50 landholders, a **setting with high competition** with a budget of 5 units and a population of 150 landholders, a **setting without uncertainty** and a **setting with high uncertainty**, where the parameter σ equals 0.6. The combinations of these variations lead to a total of 8 additional settings (settings B-I) for each allocation mechanism, respectively, resulting in 24 additional scenarios (see Appendix).

Exploring the changes in the outcomes under these alternative assumptions allows us to determine the impact of these variables on the performance of auctions, and thus to test the robustness of the model's results. Moreover, it allows us to answer the question of how relevant are uncertainty and competition for achieving both goals simultaneously.

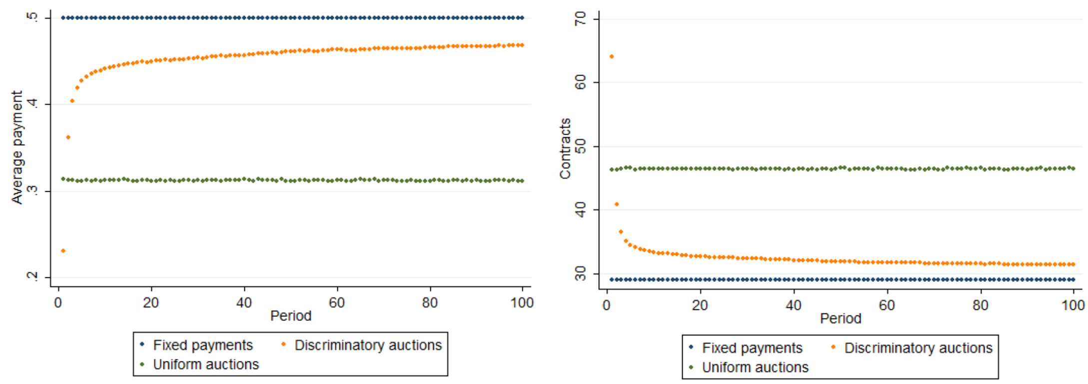
3.3 Results

We simulated each scenario 1000 times, considering 100 implementation periods. We start analyzing the scenarios with the baseline setting, for which we created time series representing the averaged outcomes per period for each mechanism. This is followed by the analysis of the additional scenarios.

Baseline setting

Figure 3.1a shows the averaged time series of the payments made under the different allocation mechanisms in the baseline setting. The lowest payments made on average are the ones resulting from the uniform auctions. While uniform payments oscillate around a steady state, average discriminatory payments increase over time. Social interaction and past experiences allow landholders to adapt their bidding strategies. The more information they gather, the better their approximation of the cut-off payment. Therefore, over time, they gain a better understanding about their possibilities to increase their rents. As it can be observed in figure 3.1a, bidders learn very fast during the first implementation rounds. The average payment made through discriminatory auctions exceeds in early periods the uniform payments, approximating the fixed level in the long run. Uniform payments remain low because they are only determined by landholders' willingness to accept, which, in the presence of uncertainty, is assumed to be lower than their current opportunity costs. On the contrary, discriminatory payments become also a function of the learning effects over time.

In figure 3.1b, we show the averaged time series of the number of contracts allocated. Auctions allow the agency to contract a higher number of landholders, compared to fixed payments because of the lower payments made on average. The number of contracts allocated under uniform auctions oscillates around a steady state, just like the uniform payments. Although the number of contracts allocated under discriminatory payments is the highest after the first bidding round, it decreases fast over time, approximating the number of contracts allocated by means of fixed payments.



(a) Average payment (b) Contracts allocated on average

Figure 3.1: Allocation and implementation of biodiversity conservation contracts

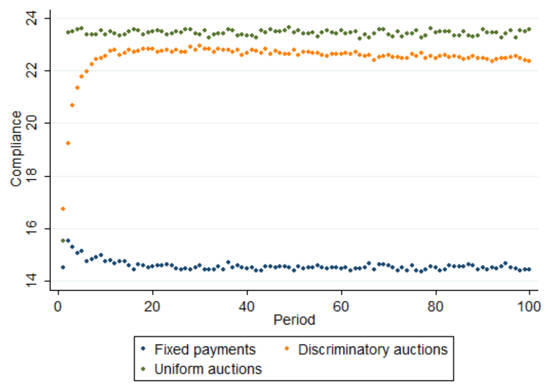


Figure 3.2: Compliance on average (ex post)

In order to determine which allocation mechanism provides the highest level of biodiversity conservation, we take a look at the number of landholders complying with the contract once uncertainty is resolved. Figure 3.2 shows the averaged time series of the number of landholders complying ex post with the contracts accepted. These are the landholders actually receiving the conservation payments agreed on. The agency is assumed not to be able to use the unspent budget in the next period. Thus, non-compliance implies opportunity costs for the agency. Even after uncertainty is resolved, uniform auctions remain the most cost-effective allocation mechanism. Nevertheless, the difference between the level of biodiversity conservation provided through discriminatory auctions and the one provided through uniform auctions is very small. This means that the incidence of non-compliance is higher under uniform auctions.

Compliance is a function of the payments agreed on and of the ex post opportunity costs of landholders. Landholders comply only as long as the rents derived from compliance are not negative, or put in other words, as long as the payments are at least as high as their ex post opportunity costs. While 73 percent of all landholders contracted through discriminatory auctions comply with the contract, only 50 percent comply with the contracts allocated through uniform auctions.

Figure 3.3 shows the budget expenditure under each allocation mechanism in the last implementation period. More than half of the budget remains unspent under uniform auctions and fixed payments. Under discriminatory auctions, the highest share of the budget is spent in form of rents to complying landholders.

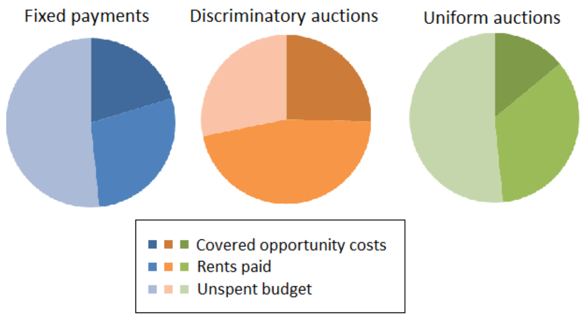
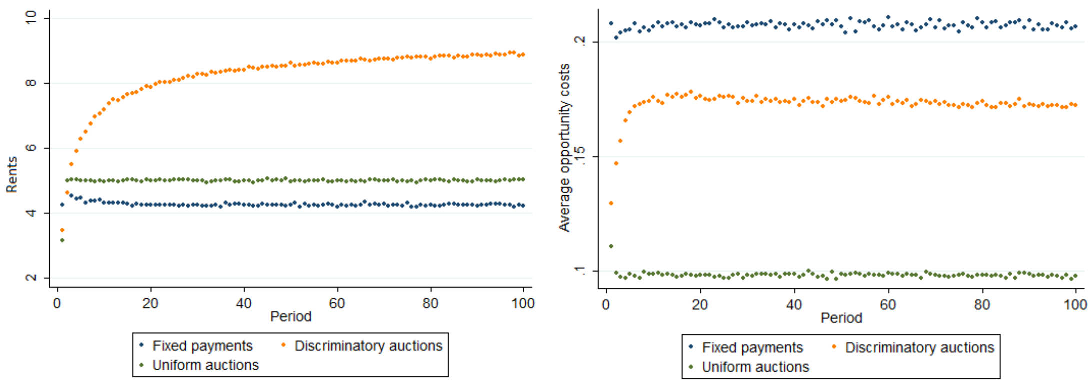


Figure 3.3: Budget expenditure

If the goal of the agency is not only to provide biodiversity conservation, but also to alleviate poverty, it is important to observe the size of the rents being paid and the type of landholders receiving them. Figure 3.4a shows the averaged time series of the total rents made to complying landholders. The learning effects under discriminatory auctions lead to increasing total information rents over time that exceed the rents paid through the other allocation mechanisms. The total rents paid through uniform and fixed payments oscillate around a steady state over time. Total rents under fixed payments are the lowest. Figure 3.4b shows the averaged time series of the average opportunity costs of the landholders receiving these rents.



(a) Rents (b) Average opportunity costs

Figure 3.4: Poverty alleviation effects

Complying landholders contracted through uniform auctions are clearly the poorest on average. In uniform auctions, those landholders with the lowest willingness to accept are the ones contracted. Thus, the lower the opportunity costs and the higher the risk aversion, the higher the likelihood of receiving a contract under uniform auctions. Although uniform payments always exceed the willingness to accept of all contracted landholders, they do not necessarily exceed their ex post opportunity costs. Landholders with low opportunity costs have therefore a higher likelihood to comply with the contract, resulting in a high share of low-cost landholders.

In discriminatory auctions we observe complying landholders that are wealthier on average. Learning effects lead to increasing payments over time, allowing also landholders with higher opportunity costs to receive a contract as long as their willingness to accept does not exceed the cut-off payment. Although the likelihood of compliance is higher for poorer landholders, some of the wealthier ones do also comply with the contract once uncertainty is resolved.

A similar effect is observed under fixed payments. The high payment allows wealthier landholders to participate. Because landholders are contracted randomly, they face the probability to be contracted, as long as their willingness to accept is lower than the fixed payment. However, wealthier landholders are less likely to comply ex post. Under fixed payments we observe the highest average opportunity costs, meaning that participating landholders are the wealthier on average.

Figure 3.5 shows the the distribution of the rents in each allocation mechanism during the last implementation period. We grouped all complying landholders into different classes of opportunity costs. This figure shows the average rents paid and the amount of landholders receiving them, for each of these classes. While only landholders in the two poorest categories receive rents under uniform auctions, also wealthier landholders receive rents under discriminatory auctions. However, under discriminatory auctions, the poorest landholders receive higher rents on average, compared to uniform auctions. Under discriminatory auctions, the majority of the participants belongs to the poorer sector, and the wealthier ones receive lower rents on average.

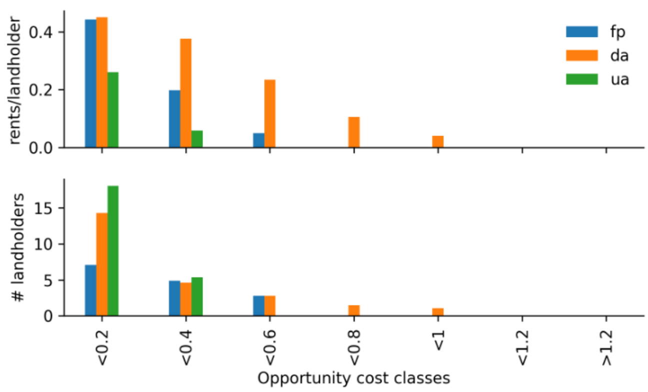


Figure 3.5: Rents distribution

These results suggest that, if landholders are risk averse and perceive the conservation contract as an option to insure themselves against too low opportunity costs in the future, uniform auctions are the most cost-effective allocation mechanism. The provision of biodiversity conservation under this mechanism is the highest despite of the high incidence of non-compliance. This mechanism targets the poorest sector, which is desirable in terms of the goal of poverty reduction. Nevertheless, the rents received by these landholders are low, and almost half of the budget gets lost as a result of non-compliance. Discriminatory auctions are the second-best allocation mechanism in terms of cost-effectiveness, providing only a slightly lower level of biodiversity conservation. Although not only poor landholders receive rents under this mechanism, the poorest sector receives rents that are higher than the rents received through uniform payments. About half of the amount lost under uniform auctions is actually spent in discriminatory auctions in form of rents.

Effects of competition and uncertainty

In this section we present the results of the simulation of the additional scenarios. As explaind in section 2.7, we varied the level of competition and the level of uncertainty. The results are summarized in table 3.1 in the Appendix of this chapter.

Figure 3.6 shows the number of complying landholders in the long run for different levels of uncertainty. According to these results, whenever risk averse landholders face uncertainty about their future opportunity costs, uniform auctions provide the highest level of biodiversity conservation. In the absence of uncertainty, the average discriminatory payment remains below the uniform one despite of the learning effects, allowing the agency to contract a higher number of landholders. All contracted landholders comply with the contract in the absence of uncertainty.

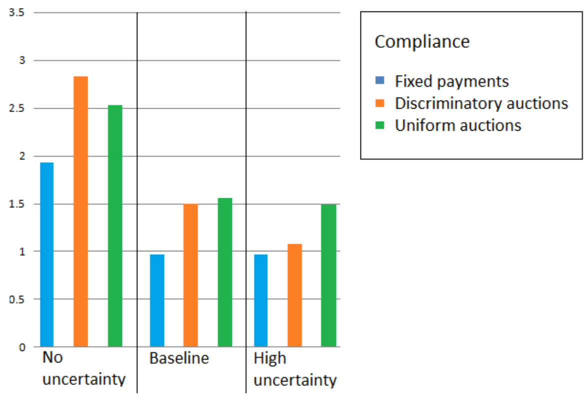


Figure 3.6: Compliance per unit of budget in the long-run

Figure 3.7 shows the average opportunity costs of complying landholders and their rents in the long run for different levels of uncertainty. In all allocation mechanisms, uniform auctions target poorer landholders, irrespective of the level of uncertainty. However, the total rents they receive are higher under discriminatory auctions, whenever landholders face uncertainty.

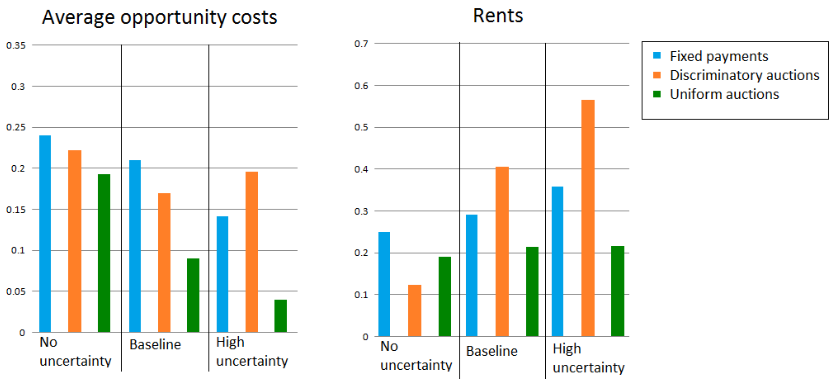
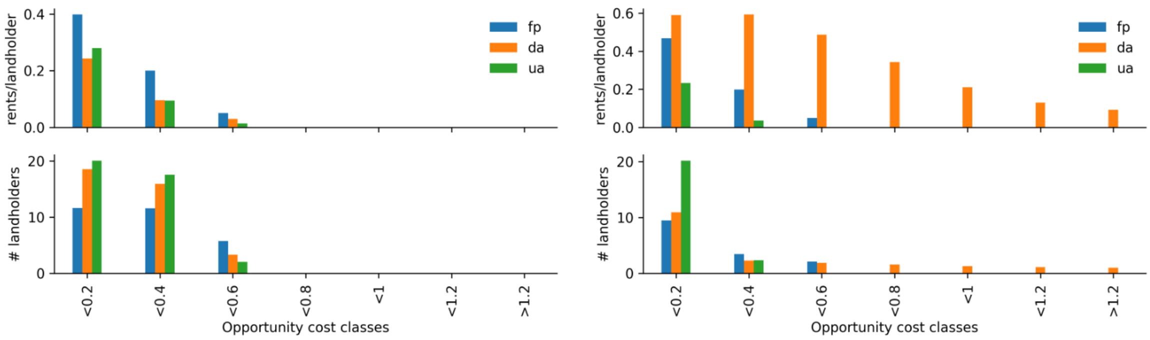


Figure 3.7: Poverty alleviation effects in the long run under different levels of uncertainty

Figures 3.8a and 3.8b show the distribution of the rents in the absence of uncertainty and under high uncertainty, respectively. In the absence of uncertainty, uniform auctions provide higher poverty alleviation effects, compared to discriminatory auctions. While the rents paid to poor landholders under uniform auctions decrease with the level of uncertainty, the rents paid under discriminatory auctions increase.



(a) No uncertainty (b) High uncertainty

Figure 3.8: Distribution of rents under different levels of uncertainty

Because landholders are assumed to be risk averse, uniform payments decrease with the level of uncertainty, and so do the rents. Discriminatory payments, on the contrary, increase on average with the level of uncertainty. The higher the uncertainty, the lower the willingness to accept of landholders, and the lower the first bids. The agency can thus contract many landholders in the first round, which means that a higher share of landholders in the network shares information. This accelerates the learning effects, leading to higher average payments. Figure 3.9 shows the averaged time series of the payments made on average under each allocation mechanism.

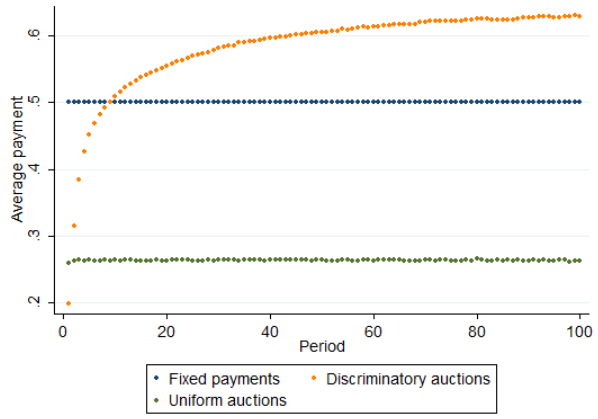


Figure 3.9: Payments made on average under high uncertainty

Figure 3.10 shows the budget expenditure in a scenario with high uncertainty. Compared to the baseline seeting (figure 3.3), a higher share of the budget remains unspent in uniform auctions, and a lower share is actually used to cover the opportunity costs of participants. Although the share of budget unspent in discriminatory auctions also increases with the level of uncertainty, the highest share of the budget is still spent in form of rents paid to complying landholders. Thus, high uncertainty does not only decrease the provision of biodiversity conservation, but also the poverty reduction potential of uniform auctions.

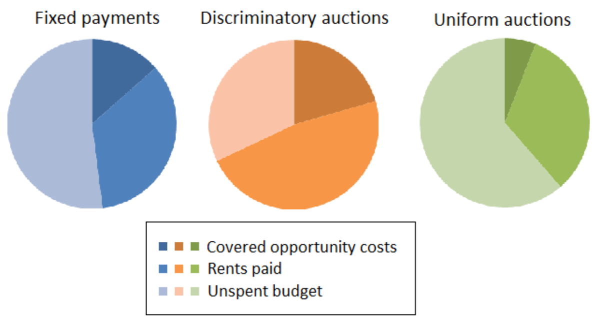


Figure 3.10: Budget expenditure under high uncertainty

Figure 3.11 shows the amount of landholders complying with the contract in the long run, for different levels of competition. The cost-effectiveness of auctions increases with the level of competition. Under all allocation mechanisms, we observe a higher provision of biodiversity conservation under uniform auctions. In the absence of uncertainty however, discriminatory auctions are the most cost-effective mechanism if landholders are confronted with a high level of competition. The cost-effectiveness of fixed payments does not vary much with changes in the level of competition because the level of the payments remains unchanged.

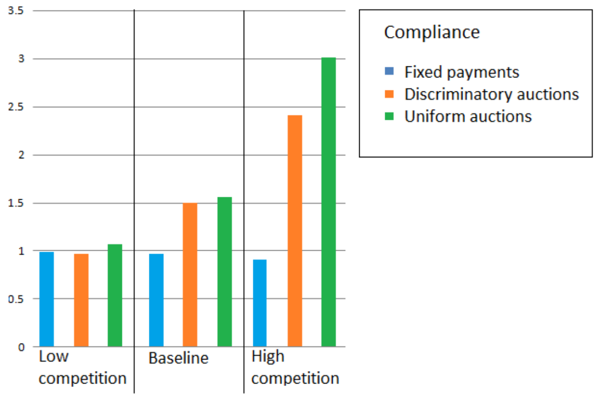


Figure 3.11: Compliance per unit of budget in the long-run under different levels of competition

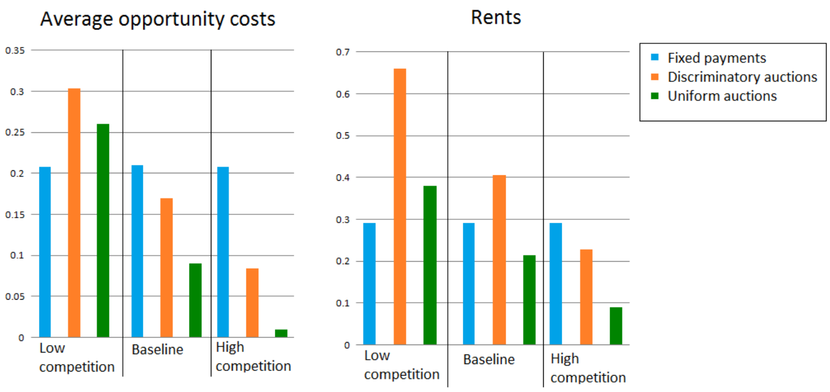


Figure 3.12: Poverty alleviation effects in the long run under different levels of competition

A high level of competition implies a lower budget and a higher population. The relative cost-effectiveness advantage of uniform auctions compared to discriminatory in the presence of high competition is a result of change in the population. A higher number of low-cost landholders keeps the uniform payments lower than the average discriminatory payment.

Figure 3.12 shows the poverty alleviation effects in the long run, for different levels of competition. Although, irrespective of the level of competition, the landholders receiving the rents are poorer on average under uniform auctions, the total rents paid under discriminatory auctions are almost double as high.

3.4 Discussion

The purpose of this study was to determine the potential of auctions to reduce poverty, while providing biodiversity conservation cost-effectively, and to understand the compatibility or trade-offs between these goals. By means of agent-based modeling, we simulate the implementation of a biodiversity conservation scheme in a low income country. Wealth is assumed to be positively correlated with opportunity costs. Landholders are assumed to face uncertainty about their future opportunity costs. Landholders are assumed to treat the conservation contracts as an option, in case of incurring very low opportunity costs. Therefore, they are willing to accept payments below their opportunity costs. If, after uncertainty is resolved, participation in the scheme would not be profitable for contracted landholders, they would not comply and the agency would incur opportunity costs.

According to our results, if risk averse landholders face uncertainty about their future opportunity costs, auctions are more cost-effective than fixed payments in the provision of biodiversity conservation. Moreover, auctions allow for higher poverty alleviation effects, compared to non-targeted fixed payment schemes. We observed a higher share of poor participants when contracts were allocated by means of auctions, and, under some conditions, in both auction designs these landholders received higher rents than the ones derived from the fixed payments. Our results show however that the level of competition among landholders has an effect on the potential of auctions to alleviate poverty. While the share of poor participants increases with the level of competition, their rents decrease.

If the goal of the environmental agency is to provide conservation cost-effectively, and poverty alleviation should only be a positive externality of the scheme, uniform auctions seem to be a more adequate allocation mechanism. The low uniform payments resulting from risk aversion allow the agency to allocate the highest number of contracts. Low-cost landholders have the highest likelihood of receiving a contract under this mechanism, and they are also more likely to comply with the contract once uncertainty is resolved. Thus, assuming that wealth is positively correlated with the opportunity costs of conservation, uniform auctions allow the agency to target the poorest landholders.

In the presence of uncertainty, discriminatory auctions provide biodiversity conservation less cost-effectively than uniform auctions, but they induce a higher poverty alleviation effect. The rents paid to the poorest landholders increase with the level of uncertainty. This is the result of learning effects. The higher the uncertainty, the lower the bids in the initial rounds, and the higher the share of participating landholders. More information spreads in the social network, allowing landholders to learn faster over time. This leads to higher discriminatory payments on average. Because low-cost landholders are more likely to comply ex post, they are the ones receiving these rents. Although the high cut-off payment allows also wealthier landholders to receive contracts, those actually complying do not secure high rents. Thus, if the main goal of the agency is the provision of so called "pro-poor" conservation, meaning that the conservation payments should help reducing poverty, discriminatory auctions seem to be the adequate allocation mechanism. Thus, learning effects, claimed to decrease the cost-effectiveness of discriminatory auctions, actually turn out to be an advantage for both goals in the presence of uncertainty and risk aversion. They increase the incidence of compliance and at the same time increase the rents paid to the poorest contracted landholders.

It is necessary to discuss the implications of the assumptions made in our model when interpreting the validity of our results. In our model we assume that the distribution of the opportunity costs is independent on the level of provision of environmental services, and we do not take into account that the quality of environmental services can be heterogeneous. Although this was not the focus of our study, this can have implications on our results. Lundberg et al. (2018) show that the cost-effectiveness of different allocation mechanisms can be determined by the relationship between provision costs and the provision of environmental services. If the correlation between both variables is positive, auctions might provide low additionality. The authors claim that this is the reason why in the tropical forest conservation schemes in Mexico and Costa Rica auctions would induce little gain (p.356).

In the Mexican scheme, for example, the risk of deforestation is a proxy for opportunity cost, such that these are lower, the lower the risk is (Muñoz-Piña *et al.* 2008, p.7). According to the results of Lundberg et al. (2018) in those cases, targeted fixed payment schemes are a more effective mechanism in enrolling those landholders that provide the highest additionality. This implies however a high cost, and a consequence would be that only a few landholders could be enrolled. The authors argue that if the program has the additional objective of decreasing poverty, which is the case in Mexico, this would be an important trade-off to consider (pp.354-355). While this argumentation is valid for uniform auctions, our results show that discriminatory auctions could still be an interesting allocation mechanism. Discriminatory auctions allow high-cost landholders to participate in the scheme for relatively lower rents. This means that the highest rents would still be paid to the poorest landholders, but also landholders offering a higher additionality would provide biodiversity conservation.

An additional aspect that has to be taken into account when evaluating the possibilities of payment schemes to induce pro-poor effects are potential barriers to participation of the poor. Some aspects that might prevent the poor from participating in payment schemes can be correlated with poverty, such as insecure land tenure, small land holdings, or lack of access to credits (Pagiola *et al.* 2005, p.248).

This study shows that, even in the presence of uncertainty and when landholders are risk averse, repeated auctions can be an interesting tool for the cost-effective provision of so called "pro-poor conservation". We show that, even though rents do imply a trade-off between both goals, trying to reduce poverty while enhancing biodiversity conservation is not necessarily counterproductive if auctions are used to allocate contracts. Uniform auctions can implicitly induce poverty alleviation effects, and learning effects in discriminatory auctions might act as a key element for synergies between these two goals in the presence of uncertainty and risk aversion.

Appendix

Table 3.1 shows a matrix with the values of the indicators at the last implementation period (period 100) for each scenario, in order to evaluate the indicators in the long-term. The abbreviations in the table *fp*, *da* and *ua* refer to fixed payments, discriminatory auctions and uniform auctions, respectively. Setting A describes the baseline setting. Settings B and C describe the variations in the level of competition from the baseline setting. Settings D and G describe the variations in the level of uncertainty from the baseline setting. Settings F, G, H and I describe combinations of low and high levels of competition with high and no uncertainty.

	Baseline			High competition			Low competition			
Indicator	fp	da	ua	fp	da	ua	fp	da	ua	
Setting	**A**			**B**			**C**			
Contracts	29	30.47	46.36	9	18.79	43.63	49	27.61	37.18	
Payment	0.5	0.48	0.31	0.5	0.25	0.10	0.5	0.88	0.64	
Rents	4.22	9.09	5	1.33	2.74	1.34	7.19	15.94	10.16	Baseline
Opportunity costs	0.21	0.17	0.09	0.20	0.08	0.01	0.20	0.30	0.26	
Compliance	14.52	22.45	23.42	4.57	12.04	15.04	24.65	24.15	26.70	
Setting	**D**			**E**			**F**			
Contracts	29	22.92	53.56	9	12.68	63.66	49	22.08	36.70	
Payment	0.5	0.63	0.26	0.5	0.36	0.66	0.5	1.10	0.63	
Rents	5.21	9.15	4.80	1.60	2.70	1.25	7.05	16.51	9.92	High uncertainty
Opportunity costs	0.14	0.19	0.04	0.54	0.09	0.03	0.2	0.32	0.19	
Compliance	14.53	16.20	22.29	4.48	7.79	19.98	22.15	18.26	22.39	
Setting	**G**			**H**			**I**			
Contracts	29	42.55	38.03	9	32.07	26.73	25.01	32.95	34.73	
Payment	0.5	0.35	0.38	0.5	0.15	0.18	0.5	0.74	0.69	
Rents	7.25	5.28	7.24	2.24	1.38	2.39	6.27	12.68	12.05	No uncertainty
Opportunity costs	0.24	0.22	0.19	0.25	0.10	0.08	0.24	0.36	0.34	
Compliance	29	42.55	38.03	9	32.07	26.73	25.01	32.95	34.73	

Table 3.1: Steady states under different levels of competition and uncertainty

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4

Design of payment schemes in the presence of asset specificity

4.1 Introduction

Offering land users payments for the adoption of environmentally friendly land uses has become a popular means to secure the provision of environmental services. These incentives, commonly called payments for environmental services (PES), have been implemented already all over the world (Wunder *et al.* 2008, p.836).

The requirements for participation in payment schemes vary considerably, depending on the environmental service considered. In some schemes land users are paid for restricting the land use in order to provide conservation or natural regeneration, and sometimes for actively providing protection. In other schemes, payments are offered for the restoration of ecosystems. This includes practices such as reforestation (Wunder 2005, p.7). In order to participate, land users are often asked to undertake investments that are necessary for the provision of environmental service. This can be in form of infrastructure, training and negotiation (Wunder 2008, p.293), reforestation or in the form of a land use change, such as afforestation or the retirement of land from agriculture (Wunder *et al.* 2008, p.836).

The requirement to make initial investments that are specific to the provision of environmental services can be a deterrent for participation in the scheme (Ducos & Dupraz 2007, p.23). Investments that are specific to the land use promoted are not redeployable beyond the contract, which means that they lose value in any alternative use. Investing in specific investments can therefore imply being locked in the transaction with the agency offering the payments. In case of contract cancellation, or if contracts are not renewed and land users are not fully compensated, they would lose their quasi-rents (Klein *et al.* 1978, p.301).

Making payments to land users can also be seen as a specific investment for the environmental agency. After contract expiration, the agency has no influence on the use of the land that was invested in. Therefore, as long as the provision of environmental services is desirable, it is in the interest of the agency to ensure that the land remains allocated to the promoted land use. Investing in new land would be more costly for the agency.

According to Williamson (1985), transactions that are uncertain in outcome, recur frequently, and require transaction-specific investments, are more likely to take place within a hierarchical organization instead of taking place between actors in the market. Hierarchical organization in the context of the provision of environmental services would imply buying the land instead of offering incentive based payments to land users. Wunder (2006) argues that payment schemes might be cheaper and more adaptive than making changes in land tenure. Land acquisition would only be an option whenever offering payments would imply prohibitively high transaction costs over time, or in the presence of a high likelihood of contract violation or cancellation. Moreover it would prevent a posterior integrated conservation-development dimension. In cases where land acquisition is not considered, the design of payment schemes has to remain incentive compatible in order to ensure the participation of land users and their compliance (Wunder 2006, p.5).

The presence of asset specificity gives room for opportunistic behavior. Opportunism refers to individual gain seeking behavior through the strategic use of asymmetrical information, or through the lack of self-enforced promises during the contract implementation and contract renewal (Williamson 1973, p.317). Thus, in the presence of asset specificity, promises alone are not credible. This and the presence of bounded rationality [1] call for a governance under which specific investments can be undertaken. Nevertheless, these contracts will always be incomplete because of the impossibility to take into account every single potential contingency (Williamson 1985, pp.66-67).

The purpose of our study is to analyze how payment schemes can be designed in order to give land users the incentive to make specific investments on their land. We consider contracts where land users are paid to plant trees on their land. We review the theoretical propositions to address the problem of asset specificity, derive hypotheses on the appropriate design of contracts under different scenarios, and compare the latter with the empirical results of already implemented reforestation contracts. Our study provides recommendations for the further implementation

[1] Bounded rationality is understood as a limited access to information and a limited ability to process it (Williamson 1973, p.317).

of such payment schemes.

4.2 Asset specificity in payment schemes

Examples of land uses promoted by payment schemes are the conservation of forests, reforestation or afforestation, and silvopastoral practices, among others (Engel *et al.* 2008, p.668). There are two main actors in payment schemes, the providers and the buyers of environmental services. Potential providers are land users who would be willing to adapt their land use in exchange for the payments. Potential buyers are those who benefit from the environmental service provision, which in some cases are represented by a governmental entity (Engel *et al.* 2008). These contracts are established on a voluntary basis. Land users will only be willing to participate in the program if their participation makes them better off. This means that the expected benefits from participation have to exceed their expected opportunity costs, or in other words, their expected benefits from the second-best land use (Pagiola *et al.* 2005; Wunder 2005; Engel *et al.* 2008).

Some contracts require land users to invest in different forms of capital. Asset specificity refers to the extent to which these investments have a higher value in the use established in the contracts, compared to an alternative use. The level of specificity varies with the degree to which the investment can be redeployed. Williamson (1983) identifies several forms of asset specificity. Site specificity refers to a dependence of the exchange relationship on the location of the assets, which become immobile or costly to relocate, for example fences, windbreaks, shelterbealts, or corridors of trees. Physical asset specificity refers to physical assets designed for a specific transaction or use, such as certain tools or machinery. Human asset specificity refers to all skills, knowledge or know-how specific to a certain transaction, activity or land use, including the knowledge related to the enrollment process in the payment scheme.

The provision of environmental services is additional as long as the returns to investment do not overcome the investment costs in the absence of financial incentives. This means that if the provision is not profitable outside the scheme, it will only be undertaken under a contract with the environmental agency. Payment schemes are evaluated according to their effectiveness (Engel *et al.* 2008, p.670). The overall objective of a scheme is to generate profits to land users, while generating additional positive environmental externalities without leakage effects. As long as the permanence of these environmental benefits is desirable, and as long as this is not profitable for land users, their participation has to be ensured through further compensation payments. Permanence cannot be expected in the absence of further financial incentives (Engel *et al.* 2008, p.671).

Asset specificity creates ex post advantages for land users that already enrolled land in the scheme against those who have not (Vogt & Bizer 2013). This asymmetry can result in what Williamson (1985) calls a *fundamental transformation*. Even if there are many potential providers of the environmental services at the outset, a bilateral trading relationship would evolve over time (Williamson 1983, p.211), ensuring the permanence of the environmental benefits. The agency would contract the same pool of providers over and over again, whenever the level of asset specificity is nontrivial.

Asset specificity can, however, be a deterrent to participation when land users fear not to be compensated for their investments (Ducos & Dupraz 2007). Asset specificity implies the creation of quasi rents. The quasi rent is the difference between the value of the investment in the transaction to which it is specific and its value in the second best use. This is the loss that occurs whenever the investment cannot be used in the intended way. The higher the specificity of the investment, the higher the quasi rent. Klein et al. (1978) refer to them as "appropriable quasi-rents".

Quasi rents could be appropriated by taking advantage of the position of the partner who made the transaction-specific investment. If land users have invested in the scheme, and the investment loses value outside the contract, land users become dependent on the willingness of the environmental agency to compensate them. If ex post the agency is able to reduce the compensation payment without endangering the provision of environmental benefits, land users' quasi rents would be appropriated. This would be especially the case for irreversible land use changes, meaning that reconverting the land is not profitable. On the other hand, if the agency makes a site specific investment on privately owned land by fully compensating land users for their investments ex ante, it would face the possibility to lose its quasi rents ex post. This would be the case if land users would decide to cancel their contracts, or if they would not comply with the contractual requirements.

The higher the possibility to be harmed through an appropriation of the quasi rent, the higher the contractual gaps (Williamson 1985, p.60). It is important to distinguish between two forms of uncertainty, parametric and strategic. Parametric uncertainty refers to the unpredictability of external events, such as environmental changes, or price changes. Strategic uncertainty refers to uncertainty related to the behavior of the transaction partner. Asset specificity gives room to this type of uncertainty, because opportunism is a source of behavioral uncertainty (Williamson 1985, p.49).

Williamson (1983) identifies three circumstances that could potentially occur after the specific investment is made, and that would prevent land users from investing in the scheme. The first one derives from demand uncertainty, or in other words, the uncertainty about contract renewal in case of not being fully compensated ex ante. The second one is uncertain valuation, referring to a situation where land users do not recognize whether the value of the investment is the one the agency claims to be, for example long-term environmental benefits, such as better soil quality, less erosion, and better water quality. And the third one is incomplete contracting, referring to situations where complexity does not allow contracts to adapt to unforeseen circumstances, such as natural disasters.

Granovetter (1985) supports the theory that behavior and institutions are influenced by social relations, and claims that Williamson fails to recognize the extent to which transactions are embedded in social systems. The author suggests that complex market transactions do not necessarily have to be internalized within a hierarchical structure. Economic actors are connected by networks of personal relations. The latter generate trust and discourage opportunistic behavior, allowing these transactions to take place in the market (p.490). Trust refers to the perception that one can rely on the partner's benevolent intentions. In other words, trust refers to the perception that the partner won't behave opportunistically. Trust eliminates the need for formal contracts that are costly to formulate and enforce, and reduces thus transaction costs (Dyer & Chu 2003, pp.58-59). The presence of trust is, however, not a sufficient condition if outcomes are highly uncertain, if reputation is difficult to establish, and if the payoffs from opportunism overcome the discounted future value of cooperation (Hill 1990).

Ducos and Dupraz (2007) identified trust as a a crucial condition under which land users would be willing to adopt more specific practices. The authors showed empirically that the more land users trust the environmental agency, the lower the magnitude of transaction costs, and the higher the probability of choosing more specific assets. Gong et al. (2010) also provide evidence that if land users do not trust the agency, they might perceive that the agency could behave opportunistically and reduce the benefits to the land users after signing the contracts. Transparency and trust are important elements for collective practices in payment schemes (Muradian *et al.* 2010, p.1207).

Hwang (2006) suggests that the concern of quasi-rent losses can be expected to decrease with the degree of trust and a relationship characterized by a longer time horizon. This implies that engaging in repeated transactions with a trusted agency has a multiplicative impact on land users' willingness to make specific investments.

4.3 Contract Design

In this section, we analyze the extent to which the presence of asset specificity in payment schemes hinders their successful implementation under different scenarios, and discuss how this can be prevented through the design of contracts. We discuss the aspects that we consider to be crucial determinants of the problem of asset specificity. Then, we introduce different contractual possibilities that the agency has to counteract this problem. We conclude this section by deriving propositions about how contracts should be designed in order to overcome the problem of asset specificity in payment schemes.

As a reference for our analysis, we consider a scheme where participating land users are paid to plant trees on their land. We chose this example because reforestation implies a specific investment for land users. The level of specificity depends on the net benefits land users derive from reforestation outside the scheme (the opportunity costs). Thus, it depends on the net value of the use of the trees once harvested, and on the time it takes for them to be ready for harvest. During this period, land users incur opportunity costs in terms of forgone profits from an alternative land use, and might not get any benefits. The level of specificity of such an investment is determined by the difference between the net benefits that land users derive from participation in the scheme, and the net benefits of the trees in an alternative land use.

4.3.1 The problem of asset specificity given different scenarios

Assuming that the goal of each land user is to maximize the profits derived from the land they are endowed with, they would only be willing to enter a reforestation contract under the condition that the expected net present value of the investment is positive[2]. Both the benefits and the costs of reforestation vary according to the payment scheme. If land users are required to invest in commercial plantations, they can profit from future returns from payments, but also from timber sales. In schemes where the goal is to promote forest conservation, land users can benefit from conservation payments and from byproducts. Reforestation can also imply benefits such as the improvement of the soil quality, the prevention of erosion, and the production of raw material, among others. The costs associated with participation in a reforestation scheme are the opportunity costs of participation, investment costs, and in some cases also maintenance

[2]If the decision to invest can be postponed, option values have to be taken into account. When investments are specific and their returns uncertain, and when the decision to invest can be postponed in order to gain more information about future returns, an option value arises (Dixit & Pindyck 1994). When an irreversible investment is undertaken, the option to invest is lost, and the option of waiting for new information that might influence the desirability or timing of the expenditure is given up. This option value increases the opportunity costs, which can considerably change the decision to invest in the provision of environmental services (Schatzki 2003; Isik & Yang 2004; Yemshanov *et al.* 2015).

costs. Land users would thus only be willing to participate in a reforestation scheme as long as the total payment offered by the agency exceeds the costs incurred, diminished by the discounted future expected returns to investment.

Investing in reforestation implies for a land user i the creation of quasi rents under two conditions. The first condition is the presence of asset specificity. By definition, as long as investments are specific, their value in the current use is higher than their value in any alternative one. The quasi rent of land user i equals the difference between the value of the forest under a conservation contract with the agency and the value of the forest in any alternative land use. As long as conservation payments are higher than the opportunity costs of the land user, a quasi rent arises. The second condition is that this land user is not fully compensated ex ante for the investment costs.

On the other hand, paying a land user i ex ante for the investment implies for the environmental agency the creation of a quasi rent under two conditions. The first condition is that the provision of biodiversity is not safeguarded, meaning that this land user can decide ex post to allocate the land to an alternative land use. The second condition is that the difference between the net value of conserving the unit of land of user i is higher than the net benefit of contracting a new land user j.

The existence of quasi rents creates room for opportunism. As long as the quasi rents are positive and observable, there is potential for the parties to increase their own rents. Land user i can demand higher conservation payments ex post, as long as they don't exceed the difference between the agency's benefit of conserving her land, and the net benefit of contracting another land user j. The agency's net benefits would still exceed its opportunity costs, but its quasi rent would be appropriated by the land user. The same would be true if the land user does not comply ex post with the level of environmental service provision they agreed on. This is a typical problem of *moral hazard*, a situation where land users lose the incentive to comply with the contractual responsibilities, after ensuring a compensation through the contract (Ferraro 2008, p.811). Land users would only put effort in conservation to the extent to which this has an effect on their benefits. Therefore, the agency has no incentive to fully compensate land user i ex ante. However, by not doing so, land user i would be the party facing the possibility to be harmed by opportunism. This would be the case if ex post the agency would not compensate the land user with the payment they agreed on ex ante.

The extent to which the agency and land users face quasi rents, and thus the risk of quasi rent appropriation, depends on the scenario under which the payment scheme is implemented. In the following, we describe the aspects that act as key determinants for the problem of asset specificity.

Land use change irreversibility

Asset specificity implies sunk costs, which can lead to land use rigidity (Roberts & Lubowski 2007, p.535). After reforesting the land, if the net present value of allocating the land back to the alternative use is equal or lower than the present value of not doing so, the land will remain reforested even in the absence of further financial incentives for conservation. The lower the opportunity costs ex post, the higher the degree of irreversibility, and the higher the dependency of land users on the agency's willingness to compensate them for their investment. This means that land users face the possibility of a quasi rent appropriation if participation in the scheme implies a high degree of land use change irreversibility.

In order to illustrate this, we consider a scheme where reforestation is promoted as a strategy to increase biodiversity. Plantations are most likely to contribute to biodiversity when native tree species are established on degraded lands (Bremer & Farley 2010). If native trees have a long rotation age and little commercial value, participation in the scheme implies a high level of specificity. The longer the permanence of the trees, the higher the level of irreversibility. The more trees get established, the more difficult and costly will be their removal. Land users might not be keen to reverse this process (Van Kooten, G Cornelis *et al.* 2002, p.570). If plantations are made on idle land, where the opportunity costs are close to zero, the degree of reversibility will be rather low.

Liquidity constraints

Land users might not be able to incur the costs for the required initial investment. The reason might be liquidity constraints and no access to credits. Whenever payment schemes are implemented in such a context, ex ante payments can be offered in order to help land users finance the implementation.

Such payments should however not substitute a long-term payment stream because they could reduce the incentives of land users to comply (Pagiola *et al.* 2005, p.245). Conditionality is an essential element of the design of payment schemes. Payments must be conditional on the provision of environmental services in order to ensure it (Engel *et al.* 2008, p.668). A lack of compliance with the contract requirements would imply losses in the quasi-rent of the environmental agency, if the former leads to a lower provision of environmental services.

If, however, participation in the scheme implies irreversible land use changes, up front payments would not compromise the quasi-rent of the environmental agency. An irreversible land use change would ensure the permanence of the provision of environmental services, such that the requirement of conditionality would be automatically met once land users invest in reforestation.

Trust in the environmental agency

Even if no party is actually willing to behave opportunistically, the sole perception that the partner might do so leads to strategic uncertainty. Trust in the intentions of the partner is thus a key element in the contracting process in the presence of quasi rents. We refer to trust as the land users' perceived probability of being harmed by opportunism in the future. Trust reflects the extent to which land users expect not to lose their quasi rents if they invest in the scheme (Ducos & Dupraz 2007).

As long as land users fully trust the intentions of the agency to compensate them over time, the agency can offer them payments ex post. The lower the trust, the higher the initial willingness to accept of land users for reforestation. For any level of distrust, land users would expect an insurance payment ex ante. Thus, the higher the level of distrust, the higher the agency's exposure to a quasi rent appropriation.

Uncertainty about the relative profitability of participation

In reforestation schemes, land users are confronted with the decision between participating and receiving payments, or not participating and deriving returns from alternative land use practices. There might be uncertainty about the profitability of the payments made by the agency in case of participation, relative to the profitability of alternative practices. In this case, land users would also experience uncertainty about their quasi rents.

Some land users might prefer to participate in the scheme in order to have a stable income if this sort of uncertainty is the result of fluctuating crop prices or yields (Isik & Yang 2004, p.243), this could be especially the case for poor land users (Pagiola *et al.* 2005, p.247). Risk averse land users might even be willing to accept lower payments compared to risk-neutral land users with the same opportunity costs, in order to decrease parametric uncertainty (Ferraro 2008, p.815).

On the other hand, if land users expect alternative crops to become more profitable over time, or if there is uncertainty about the agency's future budget availability, or policy changes, about tree planting costs, yields, or about the long-term returns to investment, future crop prices or governmental agricultural programs, land users might not be willing to accept a contract for reforestation (Van Kooten, G Cornelis *et al.* 2002, p.561), or might do so for payments that compensate them for this uncertainty. The latter would expose however the agency's quasi rent.

Observable external indicators

Changes in external conditions could be addressed by making payments dependent on the market prices of alternative products (Benítez *et al.* 2006). According to Williamson (1985), there are two preconditions that have to be met for contract specifications to be adjustable to parametric uncertainty: they must relate to exogenous, relevant and easily verifiable events, and the resulting costs must be quantifiable (Williamson 1985, p.77). By making payments dependent on an external indicator, quasi rents become also dependent on this information.

The extent and nature of the problem of asset specificity, and therefore the solution possibilities, depend on the scenario in which the payment scheme is implemented. In figure 4.1 we show how the interplay of the aspects listed above have an influence on the contracting process. Following Williamson (1985), depending on the different attributes, we differentiate between three contracting processes: **competition**, **promise** and **governance (private ordering)**.

If participation does not imply asset specificity, no other contracting process is needed, other than discrete market contracting. The transaction partners are not interested in the identity of one another. Williamson refers to this as a world of competition (Williamson 1985, p.31).

Whenever the specific investment implies land use irreversibility, the land will remain allocated to the use promoted by the agency. Compensating land users ex ante for their investment does therefore not compromise the quasi rent of the agency, nor the quasi rent of land users. The transaction can thus take place in a world of competition as well.

Whenever participation implies land use reversibility to some extent, the quasi rent of the agency is exposed for any ex ante compensation made to participating land users. This becomes more evident in a situation where land users face liquidity constraints and can thus not finance the investment without ex ante monetary transfers. Such a contracting process has to take place in the world of governance, where contract execution falls on the institutions of private ordering (Williamson 1985, p.32). Transactions have to be organized so as to economize on bounded rationality, in a way that the environmental service provision is ensured, simultaneously safeguarding the transaction partners against opportunism.

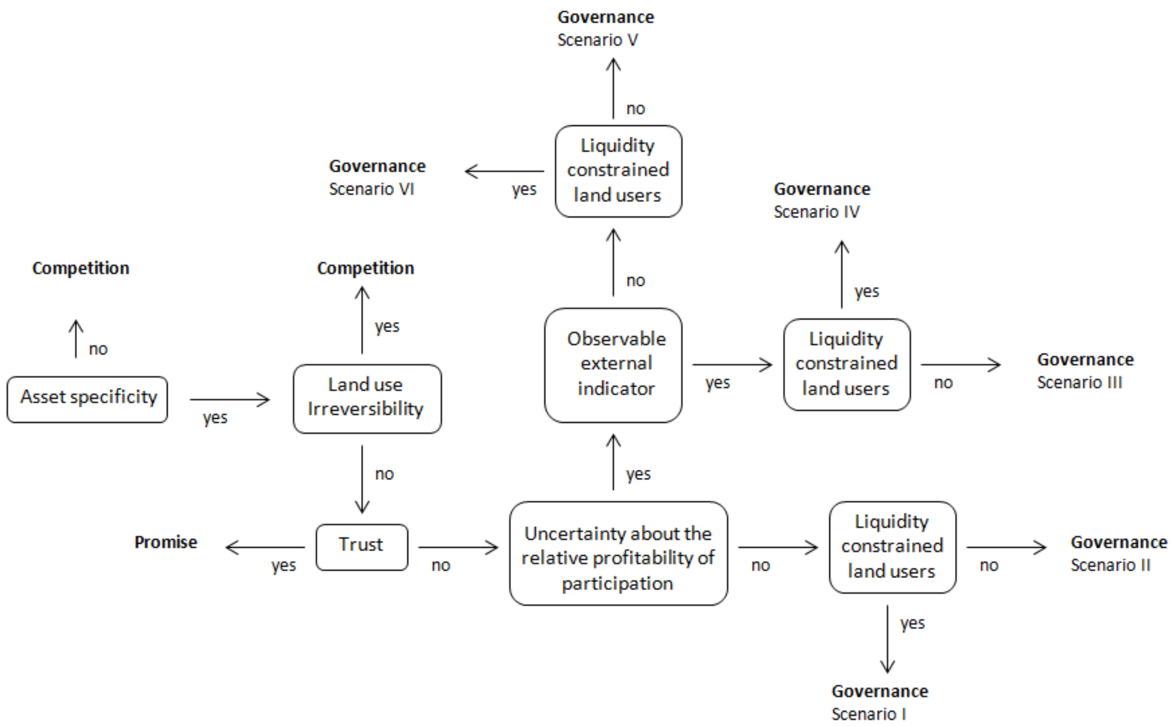

Figure 4.1: Aspects of the contracting process

The presence of land use reversibility does not require governance, as long as liquidity constraints are absent and the land users trust the agency. In this case, promises are credible. Land users can provide environmental services without fearing being harmed by opportunism, and the agency can compensate land users ex post, not exposing itself to quasi rent appropriation. If there is uncertainty about the relative profitability of participation, land users might demand higher payments.

Whenever land users do not trust the intentions of the agency, they would expect an ex ante compensation, and the agency would face a quasi rent. This would call for an alternative governance structure, one of private ordering. Environmental services would thus be provided by means of contracts safeguarding both transaction partners from opportunism. The design of these contracts will depend on the presence of liquidity constraints, on the presence of uncertainty about the relative profitability of participation, and on the existence of observable external factors to account for the latter.

In total we identify six different scenarios in which contractual governance is needed to address the problem of asset specificity (figure 4.1). Each of these scenarios calls for a different contract design. In the following section we review the contractual possibilities and derive propositions for the design of contracts.

4.3.2 Contractual possibilities

In the last section we showed that, when the contracting process cannot take place in a world of competition or promises, governance is needed to address the problem of asset specificity. The contract design necessary to address this problem depends on the attributes present in the scenario in which the scheme is implemented. Contracts should ensure the provision of environmental services without endangering the quasi rents of the transaction partners. In the following, we review the contractual possibilities of the agency.

Contract length

Short-term contracting implies the risk of one party having advantages that can be exploited in bilateral negotiations over renewal terms, and thus discourage specific investments (Pollak 1985, p.582).

According to Klein (1978), the primary alternative to vertical integration, as a solution to the risk of quasi rent appropriation, is offering economically enforceable long-term contracts. This would imply integrating reforestation and conservation payments under the same contract.

Long-term contracts act as an enforced contractual guarantee and allow the specification of possible contingencies. However, the longer and more detailed contracts are, the more negotiation time and potential legal fees may be required (Greiber 2009, p.47). This often implies high costs of policing and litigation, detection of violations and contract enforcement (Klein *et al.* 1978, p.303).

Long-term contracts can also employ market instead of legal enforcement mechanisms, such as the imposition of a capital loss through the withdrawal of expected future transactions (Klein *et al.* 1978, p.303).

Payment design

The payment structure can be adapted according to the specific situation. For example, higher initial payments can be made in the presence of liquidity constraints, in order to ensure that investments can be made (Pagiola *et al.* 2005, 245).

In order to give land users an incentive to meet the environmental goal, the contract can include *result-oriented payments*. These payments are directly linked to the desired environmental goal, for example, land users may receive payments per surviving tree. By increasing land users' intrinsic motivation, result-oriented payments can create incentives for land users to be innovative, and to choose the best practices according to their own know-how. Making at least part of the compensation dependent on the performance, can prevent non compliance (Matzdorf & Lorenz 2010, p.536), and thus reduce the risk of quasi rent appropriation. Result-oriented payments can only be implemented when the environmental goal is quantifiable and observable, such that the development of appropriate indicators is possible (Matzdorf & Lorenz 2010, p.537).

Payments can be thought of as an insurance for the agency to prevent non-compliance (Klein *et al.* 1978, p.305). Land users can be offered future payments whose present discounted value exceeds the gain from opportunism, creating quasi rents that would make opportunism unprofitable. Payments increase with the monitoring and enforcement costs (Klein *et al.* 1978, p.304).

Result-oriented payments might negatively influence the willingness to participate of land users if meeting the environmental goal does not only depend on their efforts, but also on exogenous factors, such as the weather condition (Wätzold & Schwerdtner 2005).

Flexible terms

Long-term contracts increase the rigidity of land conversion (Parks 1995, p.35). If land users expect crop prices to rise over time, they would require very high payments in order to commit to a long-term contract for reforestation and conservation, or might not even be willing to enter into a contractual relationship with the agency. Although both parties have an incentive to sustain the contractual relationship ex post, they cannot be expected to accede to proposals for contract adaptation. Adjustments of conservation payments have a zero sum quality, meaning that the benefit of one party would be the loss of the other one. There is therefore a need for flexibility under terms which both trust (Williamson 1985, p.76). Long-term contracts can adapt to changing external conditions, as long as an exogenous, relevant and easily verifiable indicator exists (Williamson 1985, p.77).

If the trees have a commercial value, their opportunity costs of conservation will increase over time with the growth of the trees. In order to ensure participation, conservation payments have to increase with the opportunity costs of conservation. The same is true for increasing crop prices. The agency has an incentive to increase conservation payments over time, provided that this is more cost-effective than reforesting other land units.

Sanctions

An alternative to the costly specification of every possible contingency, is imposing costs on the opportunistic party (Klein *et al.* 1978, p.303). The reduction of the likelihood of non-compliance requires an adequate deterrent. A sanction to avoid contract termination or non compliance should be high enough to make the expected value of this options unprofitable.

One possibility is to terminate future payments. If the payments have been made ex ante, then an alternative form of sanctioning would be necessary (Greiber 2009, p.54). Sanctions could take the form of monetary penalties, however, this could be counterproductive to develop trust among the parties, and to promote participation. Within particular social contexts, seemingly weaker penalties can prove effective, such as the the exclusion of the payment scheme for a certain period (Greiber 2009, pp.54-56).

The transaction costs incurred through the specification of contracts have to be taken into account. The costs implied should not exceed the potential benefits of sanctioning or of the procedures for non-compliance (Greiber 2009, p.56).

Bonding

Another alternative to detailed long-term contracts is bonding (Klein *et al.* 1978, p.303). A fully bonded contract implies that each party is fully insured against opportunism. Both transaction partners would pay for the investment. Part of these payments would be used to finance it, and the other part would serve as a bond to enforce the contract. An impartial umpire, assigns responsibility for any action deceiving the initial agreement between the transaction partners. This prevents both sides from being harmed by opportunism, and allows enforcing the agreement without difficulty (Kennan 1979, p.62).

Bonding contracts are however only feasible as long as land users do not face liquidity constraints. In the presence of liquidity constraints, the agency would have to offer ex ante payments to the land users for them to be able to undertake the investment. Premiums as an incentive to meet the agency's environmental goal would therefore be necessary to ensure the provision.

4.3.3 Contractual governance

After reviewing the contractual possibilities that an agency has to counteract the problem of asset specificity, we derive propositions about the design of contracts, depending on the scenario in which payment schemes are implemented. We refer to the six scenarios identified in section 4.3.1, for which contractual governance was identified as an alternative to competition and promises.

Contract type 1 *In the presence of asset specificity, and as long as land users do not face liquidity constraints, bonded contracts or long-term contracts with result-oriented payments will ensure the provision of environmental services.*

In the presence of asset specificity and in the absence of credible promises, land users will require a contract that safeguards them from quasi rent losses. They would be willing to invest in specific assets if compensated ex ante. However, ex ante payments are not conditional on the successful provision of environmental services, and thus the provision of environmental services would not be safeguarded with such payments. In order to ensure that no transaction partner suffers losses from opportunism, long-term contracts can be offered with payments dependent on the provision of the services. Contracts could also include sanctions for non-compliance. The duration of the contracts should be as long as the desired horizon of the provision. An alternative to long-term contracting is bonding. The latter implies an insurance for both parties against opportunism through a co-financiation of the investment. In bonded contracts, a third impartial party has the task to ensure the enforcement of the agreement (Kennan 1979, p.62).

Contract type 2 *If potential participants face liquidity constraints, the provision of environmental services will be ensured through ex ante and result-oriented payments.*

If land users face liquidity constraints and lack access to credits, the agency cannot offer bonding contracts. The agency has to finance the investment through unconditional initial payments. This can endanger the provision of environmental services. Once ensured the compensation, land users' incentives to comply with the contract requirement are lower (Ferraro

2008, p.811). If land users do not comply, the agency cannot impose monetary sanctions and land users won't be able to pay the investment costs back. This calls for incentives for compliance. In order to ensure the provision of environmental services, ex ante payments should not compensate land users for their opportunity costs. Conditionality can be ensured through result-oriented payments. They compensate land users for their opportunity costs, and provide them with the necessary incentives for compliance.

Contract type 3 *If land users face uncertainty about the relative profitability of participation in the scheme, and as long as an external observable indicator exists, flexible long-term contracts will be offered to land users, in which payments are adapted to changes in the profitability of alternative land uses. In the absence of an external indicator, land users will require a premium to account for this uncertainty.*

Uncertainty implies that land users do not know whether investing in the scheme will result in a relative profitable land use or not, and they might not be willing to make a specific investment unless they are sure about its profitability. To account for this, contracts could be flexible. This means that payments could vary according to the opportunity costs of participation, as long as an external observable indicator exists. This insures land users when committing to a long-term contract that might imply payments that do not cover future opportunity costs in case they are increasing. On the other hand, it prevents the agency from committing to long-term contracts that imply payments that overcompensate land users for their provision in case the opportunity costs decrease over time. In the absence of an observable indicator, land users will require a premium to account for the possibility of a future increase of their opportunity costs in order to enter a long-term contractual relationship. The level of the premium necessary to induce participation in the scheme will depend on the level of uncertainty, but also on the expected future opportunity costs of land users. Land users would be willing to accept lower payments if they are risk averse compared to risk neutral land users, because this would reduce parametric uncertainty (Ferraro 2008, p.815).

According to the latter propositions, we show in table 4.1 the attributes that contract design could include in each of the scenarios identified in figure 4.1. Scenario I implies land use reversibility, uncertainty and liquidity constrained land users in a setting where no credible promises can be made. This scenario would require long-term contracts with an initial payment to help land users finance the investment and result-oriented payments to ensure compliance. Scenario II would allow for the use of bonding contracts because land users are not liquidity constrained. An alternative to bonded contracts would be long-term contracts with result-oriented payments. In this scenario contracts could also include sanctions for non-compliance.

Scenario	Ex ante payment	Bonding	Result-oriented payments	Flexible payments	Premium	Sanctions	Long-term
I	+		+				+
II		+	+			+	+
III		+	+	+		+	+
IV	+		+	+			+
V		+	+		+	+	+
VI	+		+		+		+

Table 4.1: Contract attributes for each scenario

In Scenario III flexible contracts could be offered to land users in order to account for uncertainty. In the absence of such an indicator, such as in scenario V, the agency could offer premiums instead, which would account for the potential increase in future opportunity costs. Additionally, contracts would have to include initial payments as long as land users face liquidity constraints, such as in Scenario IV and VI. Scenario VI represents the highest risk for the agency, as well as the highest costs. If initial payments and premiums are paid, the agency runs the risk of reduced compliance incentives, and thus of quasi rent losses. Moreover, in the absence of increasing opportunity costs, the agency would have unnecessarily committed to payments that overcompensate land users for the provision of environmental services.

4.4 Case studies

In this section we review payment schemes where land users were required to plant trees on their land, and compare their design with our theoretical predictions. Although these reforestation schemes imply a specific investment for land users, they do not necessarily imply that the land use is irreversible once the trees are planted.

4.4.1 Commercial plantations in Costa Rica

Since the year 2000, the PSA(Pagos por Servicios Ambientales) program in Costa Rica, managed by FONAFIFO, offers land users payments for the establishment of commercial plantations on their land. The goal of this scheme is to help land users finance the initial costs of establishing plantations. By converting an unprofitable investment into a profitable one, the scheme enhances the provision of forest resources for timber production (Pagiola 2008, p.13).

This scheme implies a high degree of reversibility, because trees could be removed right after being planted. Because land users face liquidity constraints, the payments would have to be made ex ante in order to allow them finance the planting costs. This setting leads to contracts of type I. The permanence of the trees depends on the perception of land users about the profitability of the plantations. The higher the time preferences of land users, the lower the expected net present value of the plantations. Put in other words, the more they discount future consumption, the higher their incentives to remove the trees and plant other crops instead. Moreover, in this setting land users lack liquidity, which means that waiting for the investment to be profitable might compromise fulfilling their primary needs. They might thus prefer to remove the trees and plant other crops instead, which would provide them returns in the short run. The agency would have to ensure the conservation of the trees between reforestation and harvesting period.

FONAFIFO ensures the permanence of the trees through long-term contracts. Contracts have a length of 20 years. This is written into the land title, so that it transfers to the new buyer in case that the land is sold. Land users pay for the initial management plan, and in case of being contracted they are required to comply with the provisions stated in their plans until the contract terminates. Payments are made per hectare enrolled, and are conditioned to at least 85 percent of trees survival. At the beginning, payments were made during the first five years (about 550 USD): half of the payment was made in the first year, 20 percent in the second year, 15 percent in the third, 10 percent in the fourth, and 5 percent in the fifth. However, because most land users found it difficult to maintain plantations because of the lack of revenue in the interval between the end of the plantation contract and the harvest of the timber, both the amount and the duration of payments had to be increased in 2006 (816 USD/ha over 10 years)(Pagiola 2008, p.7-8).

The scenario in which this payment scheme is implemented is compatible with scenario I in table 4.1. Land users are expected to make a specific investment on their land, but they face liquidity constraints that do not allow them to finance the investment costs. The land use is reversible, so that the agency has to ensure the permanence of the land use. As we proposed for this scenario, the agency offers long-term contracts to ensure that the trees are not harvested during 20 years. The initial payments implied in these contracts are the highest in order to finance the plantation costs. At the beginning, result-oriented payments were offered only during the first 5 years, because the intention of the scheme was only to allow them finance the investment. The idea was that land users would have had an incentive to conserve the trees because they will profit from the harvesting the trees after 20 years. Facing a positive net value of conservation, land users would not require payments that compensate them for their opportunity costs of conservation. Nevertheless, this was not the case in reality. Land users' opportunity costs of conservation seemed to exceed the net present value of the trees. The reason for this could be high time preferences. If land users discount future benefits at high rates, the value of the trees will be rather low during the period prior to harvest. Moreover, land users faced liquidity constraints, such that they might still have needed income to fulfill their needs.

4.4.2 Agroforestry systems in Costa Rica

The SAF (Systemas Agroforestales) program is implemented in southern Costa Rica since 2004 by FONAFIFO in order to promote agroforestry. Agroforestry on small-scale farms is claimed to provide important ecological services (e.g. carbon sequestration and biodiversity), while providing on-farm products for domestic use and marketing. The scheme's goal is thus to promote sustainable farming practices through the adoption of this farming technology (Cole 2010, p.208). Participants are required to have active areas of agriculture or cattle grazing on their land. Tree planting is funded for the following categories: hardwoods in perennial crops, multiple-use trees, windbreaks, forestry planting in fence lines, forestry plantations in blocks, inter-planting trees with agricultural crops and fallow systems on indigenous reserves. These systems are expected to provide land users with subsistence and market products such as food, fodder for animals, and wood for construction and future sale. Tree planting is therefore expected to make marginal farm areas more productive. Furthermore, the scheme is expected to contribute to the reduction of poverty by targeting small-scale farmers in regions with low socioeconomic status (Cole 2010, p.209).

The scenario in which this scheme is implemented resembles scenario I in table 4.1. The scheme targets small-scale farmers with low income, thus, they are likely to face liquidity constraints. This would require higher initial payments in order to finance the investment. In principle all tree plantations are highly reversible because they can all be removed after plantation. However, the degree of irreversibility changes over time depending on the type of plantation. The shorter the rotation age, and the higher their value, the higher the degree of reversibility. Land users will choose the planting category according to the expected value of the investment, and according their opportunity costs. Land users might for example prefer to make inter-cropping plantations instead of large forestry plantations, unless they have idle land, because otherwise they would compromise productive land for the production of other crops (and thus uncertainty would play a role). The permanence of the trees would be ensured only to the extent to which they provide land users with benefits in the short term, otherwise they would require conservation payments at least during the first implementation years.

The SAF program offers five-year contracts, during which land users have to maintain the planted trees. Land users are responsible for establishing a management plan for tree planting, and for certifying the project for payments. Payments are made per tree planted (1.30 USD), under the condition that at least 350 trees per contract are planted. Participants receive payments during the first three years: 65 percent in the first year, 20 percent in the second, and 15 percent in the third year. Payments are contingent on tree survivorship of at least 85 percent. Farmers planning to plant more than 1000 trees can apply for an advance on the first payment(Cole 2010, p.209).

The payments helped to overcome potential barriers to reforestation, such as the high initial costs, perceived risk in investing in activities with long-term returns, and a lack of technical knowledge. However, according to Cole (2010) land users planted more often trees in forestry blocks than in inter-cropping systems, because they were not willing to engage in practices that compromise crop production. They depend on agriculture for their subsistence and cash incomes. Most of the forestry blocks were located on marginal land without agriculture, and where opportunity costs were low. Moreover, land users preferred to plant timber trees over trees that supplied fuelwood, fruit, or mulch for perennial crops. The payments often exceeded planting expenses (p.213). According to Cole (2010), there was a concern that participants would minimize tree maintenance activities in order to save payment money for other uses. Because most of the planted trees were timber species, farmers viewed them as a 'savings account' for future generations, so that they did not get short-term benefits (p.215).

Cole's conclusions suggest that the scheme did not give land users the proper incentives to adopt inter-cropping systems in their land. In order to promote this land use and its permanence, the scheme should have included premiums as to give land users the incentive to plant in inter-cropping systems instead of planting large blocks of trees on land with little additionality. The design of the scheme was compatible with our predictions, however payments should have been offered over a longer period of time in order to ensure the permanence of the trees, and to allow land users fulfilling their basic needs.

4.4.3 Reforestation and afforestation in Ecuador

The PROFAFOR program is implemented since 1993 in Ecuador in order to offset the carbon emissions of Dutch electricity companies through reforestation and afforestation. Initially, the program considered only exotic species with short rotation age (15 to 20 years), mostly pines and some eucalyptus, but since 1999 also native species are planted through this program. The scheme's goal is to promote reforestation and the permanence of the tree cover through the re-establishment of the trees after harvest (Wunder & Albán 2008, pp.691-692).

The land use promoted by this program can be reversed to some extent. The permanence of the trees is conditioned to their relative profitability. As long as the production of alternative crops is more interesting than the production of timber, land users will have an incentive to reverse the land use, unless they have idle land, or unless payments account for this. In the Ecuadorian scheme, land users are offered long-term contracts that give them the incentive to plant new trees after harvest. Participating land users are likely to face liquidity constraints, mostly communal and individual land users are the beneficiaries of the program (Wunder *et al.* 2008, p.836). Thus, the scenario would be comparable to scenario I, or to scenarios IV or VI in the presence of uncertainty.

The process of plantation site selection in this scheme was based on biophysical conditions, such as slopes, soils and altitude, but also on economic criteria, such as the locally marketability of timber. At the beginning of the implementation, land users were offered contracts to reestablish and maintain tree cover for single cropping cycles of fast growing trees (15 years for eucalyptus and 20 for pines). In the year 2000, contracts were extended to 99 years, covering several cropping cycles. Land users receive an initial per-hectare payment for the production of seedlings and planting (100 to 150 USD/ha). This covers about 80 percent of the costs (labor, tools, transportation, etc.). The remaining 20 percent are paid after three years conditioned to at least 75 percent of tree survival. Land users benefit from all by-products such as thinning and pruning, but also from timber sales after harvest. They receive only 70 percent of the revenues from harvest after the end of the cycle if they do not re-establish the plantation. In case of not fulfilling the terms, land users would have to reimburse the payments (Wunder & Albán 2008, p.692).

In practice it is difficult to ensure contract compliance for the extended contract length. Participants do not seem to take the extension seriously. In some cases land users had the incentive to repeat planting, but in other cases the contracted area was reduced ex post. It is not always feasible to make land users reimburse payments in case of non-compliance, or to keep 30 percent of timber sales in case of non re-establishment of forests. The scheme faces the dilemma of making initial payments that are attractive for land users, and reducing leverage for contract compliance. Between the first three years and the harvest, land users' revenue is limited. In order to deal with non-compliance contracts had to be modified. 20 percent of the payment was withhold and made contingent on plantation conditions(Wunder & Albán 2008, pp.692-693).

Although initially the design of the contracts did not include result-oriented payments as we predict for this type of scenario, these were introduced later. As Wunder and Albán (2008) confirm, the extension on contract length was not enough to ensure compliance. Sanctions in this case were not an effective deterrent because their application is not feasible. Contracts have to provide the correct incentives for land users to maintain the forest cover. The result-oriented payments were a first step in this direction. However, the incentives should be provided along the whole contract period. Permanence over time depends on the relative profitability of forest conservation, and depends therefore on the development of prices for timber and agricultural products. A scheme planned to be implemented for several cropping cycles has to take the development of prices into account to the extent that observable indicators exist. If feasible, the Ecuadorian scheme should include on-going payments that ensure the relative profitability of timber production, and thus of carbon sequestration.

4.4.4 Silvopastoral practices in Nicaragua

The Regional Integrated Silvopastoral Ecosystem Management Project, implemented in 2003 in Nicaragua, promoted silvopastoral systems. These imply combining fodder plants with trees and shrubs. Such systems provide on-site benefits such as fruits, fuelwood, fodder and timber, but also biodiversity benefits, hydrological beenfits and carbon sequestration (Pagiola *et al.* 2007, p.2). These systems imply however a very costly investment. Establishment costs are high for sowing improved pasture, planting trees, establishing fodder banks and live fences, and increasing herds to take advantage of increased fodder production. The investment becomes profitable only in the long term. The goal of this payment scheme is to generate biodiversity conservation and carbon sequestration by encouraging the adoption of silvopastoral practices in degraded pastures (Pagiola *et al.* 2007, p.3).

This scenario is compatible with scenario I because it is thought to help land users to overcome liquidity constraints in order to promote silvopastoral systems, and because land use reversibility is possible. Uncertainty might not play a role because land users can still maintain the current land use. The permanence of the systems depends however on their returns. Because land users in this setting face liquidity constraints, in order to ensure permanence, the scheme should include incentive payments for conservation until the investment becomes profitable.

Land users were offered four-year contracts with annual payments, based on their Environmental Services Index (ESI). Contracted land users receive a one time payment(10 USD/per baseline point) and further annual payments over a four-year period after the land use change is undertaken (75 USD/ESI point/year). This scheme design assumes that a payment provided ex ante will increase the net present value of investments in silvopastoral practices enough to ensure permanence (Pagiola *et al.* 2007, p.5). To determine the permanence of the land use changes, a randomly selected group was paid the same amount over two years, instead of four. Some of this land users cut some of the trees they had planted soon after they had received the final payment. This suggests that in the absence of further financial incentives, the land use change might not necessarily be permanent (Pagiola *et al.* 2007, p.9).

Although initial payments were offered as we predicted, result-oriented payments were not included in the contracts. Our predictions are confirmed by Pagiola et al. (2007), who claims that the scheme requires long-term payments in order to induce permanent land use changes. These would prevent land users from burning their fields, or cutting trees in other parts of the farm (p.9).

4.4.5 Cropland retirement in the US

The goal of the Conservation Reserve Program (CRP) in the USA since 1990 is to establish forests on agricultural land. Highly erodible and environmentally sensitive land is retired from production, and resource conserving practices are promoted instead. This should contribute to the provision of environmental benefits, such as reduced soil erosion, improved water quality through wetlands and field buffers, reduced fertilizer use, and increased wildlife habitat (Stubbs 2014). The program addresses a full range of objectives through the Environmental Benefits Index (EBI). The EBI includes following factors: (1) wildlife habitat benefits, (2) water quality benefits from reduced water erosion, runoff, and leaching, (3) on-farm benefits of reduced wind or water erosion, (4) long-term benefits of certain practices, (5) air quality benefits from reduced wind erosion, and (6) benefits from enrollment in conservation priority areas . Land is eligible for enrollment if it has a history of crop production and is highly erodible, if it is located in a national or state Conservation Priority Area, or if it will be devoted to wetland restoration, streamside buffers, or conservation buffers (Claassen *et al.* 2008, p.741).

Assuming that land users are not constrained by liquidity problems and that they face uncertainty about the future profitability of participation, the scenario in which this scheme is implemented would be compatible with scenario III or V in case flexible contracts are not feasible. Long term contracts would ensure permanence, and on-going result-oriented payments would ensure compliance. A premium could account for uncertainty if flexible contracts are not feasible.

In the CRP program, participants are offered contracts with duration of 10 to 15 years and annual payments. The program covers moreover 50 percent of the planting costs. Land users wishing to cancel a contract face a penalty of full repayment with interest (Stubbs 2014, p.10). Contracts are allocated by means of auctions. When a land user submits a bid, objective data is provided in order to estimate the EBI, which is divided by the bid, the cost of contracting that land user. A bid cap ensures that bids do not exceed a certain value. Land uses that can induce long-term benefits beyond the 10–15 years of the contract, receive higher points in the EBI. The EBI is flexible, and changes over time as the goals of the program change (Ribaudo *et al.* 2001, pp.12-15). Because land was cropped prior to enrollment, it is likely that land users allocate it back to crop production after contract termination, depending on its relative profitability. Because of the uncertainty about the permanence of the land use change, and due to the fact that many contracts would have expired by 2007, contracts were extended for one to three years, and the Department of Agriculture committed to fully replace or renew expiring contracts (Roberts & Lubowski 2007). Land is eligible for re-enrollment, but the latter is not automatic. Land users have to apply for it (Claassen *et al.* 2008, p.741).

Although these payments seem to be an attractive and profitable option for land users, they might prefer to dedicate to agriculture as a consequence of risk-aversion and expected capital gains. When not only the returns of crop production, but also those of forests are uncertain, and the correlation between them is non positive, risk-averse land users will diversify the land among both land uses. If however, only agricultural returns are known with certainty, land users might not be willing to convert their land to forests (Parks 1995, pp.44-45).

Roberts and Lubowski (2007) examine the permanence of cropland retirements. Their findings suggest that temporary enrollment of land often reduces cropping activities beyond the contract period. The likelihood of land re-conversion is not only associated with the profitability of cropping activities, but also on land attributes and location. Land units with trees were about half as likely to return to crops as lands covered with grasses or legumes. Land that did not return to crop production, despite the increase in crop net returns since 1986, suggested land-use irreversibility. This is a very interesting claim. If the contract length was long enough as to cause a high degree of irreversibility, no further payments would be necessary to ensure the permanence of the land use. However, as the authors point out, this could also be the result of a lack of additionality because land users could have exited cropping even in the absence of the program. Moreover, for some land users it may not be optimal to re-convert land immediately after contract termination due to option values associated with uncertain future returns from crops. Land users who did not re-convert right after exiting CRP may, nevertheless, plan to do so eventually. Therefore, incentive payments should still be provided for land management practices in addition to land retirement.

Although long-term contracts are offered, as we proposed for this scenario, uncertainty could still be addressed through flexible contracts that take into account the development of the relative profitability of alternative land uses over time. Because participants do not face liquidity constraints, both contractual partners can co-finance the tree-planting investment, sharing thus the risk of quasi rent appropriation, as proposed in bonded contracts. Compliance was ensured by means of sanctions.

4.4.6 Reforestation in China

The Guangxi CDM project has multiple objectives comprising carbon sequestration, enhancing biodiversity, reducing soil erosion, and improving local livelihoods through contracts for reforestation in China's Southern Province of Guangxi from 2006 to 2035 (Gong *et al.* 2010, p.1295). The private sector has no incentive to reforest because of low rates of return. The goal of this project is to remove financial and institutional barriers to reforestation, assuming that land users would profit from the sales of carbon credits, timber and pine resin. The project considers 3000 ha to be planted with five tree species (mainly native species) with different growth rates and rotation periods, and 1000 ha with eucalyptus. Participation should take place in abandoned and degraded land (Gong *et al.* 2010, p.1296).

Because reforestation is undertaken in idle non-productive land, the likelihood that the land use change will be reversed is rather low. This implies that participants could be offered ex ante payments without endangering the quasi rent of the agency, at least as long trees are not ready to be harvested. The incentive to maintain the trees is mainly the sale of carbon credits, although participants would also profit from resin and environmental benefits in the long term. As long as the net present value of the maintenance of the trees over time exceeds the opportunity costs, land users will have an incentive to maintain the tree cover. Otherwise, the scenario would resemble scenario I and thus contracts would have to include long-term result-oriented payments.

The Guangxi CDM Project offered land users a contract with local forest companies for a period between 2006 and 2035. These contracts, whose framework was called "share-holding system", stipulate that the local forest companies are fully responsible for financing the project. This includes monitoring costs, costs associated with reforestation and forest management, harvest and product sales, as well as technical support and training to the local land users regarding the carbon project. Local land users only need to contribute their lands. The forest companies are allowed to establish plantations by leasing lands from local land users at the local land rent prevailing in 2005 (60 yuan/ha/year). Local land users receive 40 percent of the income from the future sales of timber and pine resin and 60 percent of the income from sales of carbon credits. The companies claim all revenues from the sales of products from eucalyptus (Gong *et al.* 2010, pp.1296-1297).

Although the net present value of the project was estimated to be positive for all parties, and although the share-holding contracts were an attempt to make the project accessible to small land users, a large area remained unforested. Gong et al. argue that this is the result of restrictive contractual rules, property rights disputes, and weak social capital. The authors suggest that high social capital can overcome the lack of clearly defined property rights. Land users did, however, not trust the intentions of the local forest companies to fully compensate them (Gong *et al.* 2010, p.1299). The implementation of this project shows the importance of trust in the agencies offering the payments, and the importance of providing the proper governance in order to deal with distrust.

The contracts would have to include initial payments, in order to give land users an incentive to participate according to Gong et al. If land users did not participate because they face high time preferences, such payments would have compensated them for the commitment of their land. Other lands might have remained unforested because of increasing opportunity costs in the production of other species (orange trees)(Gong *et al.* 2010, p.1301). This would imply scenario IV or VI, depending in the availability of an external indicator to approximate changes in the opportunity costs of participation. In order to account for uncertainty about the relative profitability of participation,contracts could be flexible or include a premium.

4.5 Discussion

In the last section we reviewed the implementation of payment schemes under different scenarios. Although each scheme had a different goal and setting, they all have in common that land users are contracted to plant trees on their land. Table 4.2 gives an overview of the requirements of the contracts and their design. In this section, we discuss the advantages and drawbacks of the contract design of these schemes.

Bonded contracts were not used in any of the schemes described. This has partly to do with the fact that in most of the schemes land users faced liquidity constraints. Moreover, policy makers assumed that the investments would be profitable enough in the long-run to ensure conservation until harvest. The crop retirement scheme is the only one that offers contracts where land users have to co-finance the investment. These contracts have a duration of 10 to 15 years with ongoing result-oriented payments and the possibility of renewal. However, no resources are served as a bond to enforce contracts.

The duration of the contracts proved to be an important aspect in the design of the schemes. The optimal duration of contracts depends on the net present value of the future returns to investment. Land users will only have an incentive to maintain the trees to the extent to which they value the returns to investment. This means that the optimal duration of the contract depends on the value of the future returns, on the time lag between investment and returns, but also on the time preferences of land users.

Case study (source)	**Specific investment**	**Returns to investment** (excluding payments)	**Contract length**	**Payment design**
Commercial plantations in Costa Rica (Pagiola 2008)	management plan and tree planting	Timber sales	20 years	Payment per ha conditional on tree survival: decreasing share over 10 years
Agroforestry systems in Costa Rica (Cole 2010)	Management plan and tree planting	Subsistence and market products, fodder, timber, land productivity	5 years	Payment per tree: decreasing share over 3 years
Reforestation in Ecuador (Wunder & Albán 2008)	Seedlings production and tree planting	By-products and returns from harvest (70 % without reforestation)	99 years	Payment per ha conditional on tree survival: decreasing share over 3 years
Silvopastoral practices in Nicaragua (Pagiola *et al.* 2007)	Tree planting, fodder banks and live fences	Fodder, fruits, fuelwood and timber	4 years	Initial payment + annual payment per index point
Cropland retirement in the US (Roberts & Lubowski 2007)	Field clearing and tree planting		10 years + renewal	Annual payments according to bids
Reforestation in China (Gong *et al.* 2010)	Tree planting	40 % from timber sales and 60 % from carbon credits	30 years	Annual land rent per ha

Table 4.2: Case studies

The shorter the rotation age and the higher the commercial value of the trees, the lower the optimal duration of the contract. We observe this in contracts for commercial plantations and agroforestry in Costa Rica, but also in contracts for silvopastoral practices in Nicaragua. Land users are only offered payments during the first years to finance the initial specific investments, under the assumption that the land use will provide enough future returns to make conservation profitable. In schemes that enhance biodiversity, and where plantations provide low or no returns, long term contracts are necessary to enhance conservation. This is the case in Ecuador, where contracts were extended to 99 years, but also in the US, where land users are able to renew their contracts.

The degree of land use irreversibility can increase with the duration of contracts. The more trees get established, the more costly it becomes to remove them. This means that long term contracts could ensure the permanence of the trees even after contract termination and in the absence of further payments. However, land users would have to be fully compensated during the contract length. This can explain why some land users in the US did not remove the tree cover after contract termination.

The length of the contract does, however, not ensure conservation per se. The purpose of the duration of the contracts is twofold: on the one hand it should provide land users with certainty about future compensation, on the other hand it should ensure the permanence of the trees during that period. However, the necessary financial incentives should be provided along the contract duration. As long as the benefits of non-compliance exceed the net present value of conserving the trees, forest cover will not be ensured.

Sanctions or financial incentives for compliance are shown to be an important aspect of contract design along with an optimal contract duration. In Costa Rica, conservation payments had to be increased and offered during a longer period of time because land users had difficulties in complying with the maintenance of the trees. In Ecuador, instead of being offered conservation payments, land users were confronted with sanctions in case of non-compliance. This however was not feasible because the agency was not able to reimburse the payments or to keep a share of the returns from timber sales. This suggests that offering land users conservation payments might be more effective than threatening them with sanctions, because the difficulty to implement the latter can lead to a loss of credibility of the scheme.

While offering long term contracts with the proper financial incentives can ensure additionality, offering short term contracts can give land users the incentive to plant trees in areas where the additionality is rather low. This was the case in the agroforestry scheme in Costa Rica. High short-term payments made participation attractive for land users, but they compromised the permanence of the trees and the additionality of the scheme. Land users preferred not compromise agricultural production because of a lack of ongoing benefits. Thus, the contract design allowed them to incur low opportunity costs. Furthermore, they reduced the expenses for the maintenance of trees to the minimum. If trees are harvested, land users have to be offered further incentives for reforestation. This can take the form of reforestation payments. Alternatively, the income from timber sales can be made conditional on reforestation, as done in Ecuador.

Flexible contracts were not offered in any scheme. In some cases they were not necessary because land users could partly maintain the land use. But in other cases, accounting for the increase in opportunity costs could have been beneficial to promote participation. This was the case in the Chinese scheme for example. Flexible contracts might not have been offered because of a lack of proper indicators to approximate opportunity costs, or because of the high transaction costs implied in the contract design. In the absence of flexible contracts, land users expecting increasing opportunity costs will require a premium in order to enroll their land to the scheme. Although no scheme offered premiums explicitly, the rents implied in fixed payments could have accounted for this uncertainty. In the US, land users might have included these premiums in their bids, such that the payments they required implied a full compensation during the contract duration.

Distrust can lead to inefficiencies even in the presence of seemingly attractive contract designs. Although participation seemed to be profitable in the Chinese scheme, land users were not willing to commit their land. This was partly explained by the lack of trust in the intentions of the companies to compensate them over time for their investment. Ex post payments only give an incentive to invest as long as they are credible. If there is no trust in the institutional setting, contracts won't be credible. For those cases initial payments and/or on-going payments are crucial to induce participation. Under such circumstances, the agency faces the dilemma of compensating land users ex ante to decrease their perceived risk, and risking thereby its own rent. A solution to this problem could be to offer land users higher on-going payments, instead of a share of the revenues from timber sales in the long run.

If several contracting rounds are intended, the agency can gain reputation over time through the compensation of already participating land users. However, until then, the allocation of payments might be inefficient in the presence of a certain degree of distrust. If fixed payments are offered, those offering little or no additionality, those with very low opportunity costs, would profit from large over-compensations. This could be however seen as an investment in the future reputation of the agency. In this respect, it remains important to focus on the role of information access and diffusion among land users, in order to understand to which extent this influences the opinions of land users about the environmental agency.

Initial payments were often needed in order to finance the investments. This alleviated land users' liquidity constraints, but also their potential for quasi rent losses. While in some cases the agencies financed the whole investment costs, in other cases, they only co-financing it. By doing so, agencies exposed themselves to the possibility of quasi rent losses.

Result-oriented payments were part of the contract design of all schemes. These were made per area, per tree planted, or per unit of environmental benefits delivered. Payments made for a certain area were conditional on survival rates. This means that, while payments are still conditional on the efforts of the land users, the agency takes responsibility for a smaller share of non-surviving trees. This design reduces the risk for land users, and gives them an incentive to take care of the trees.

In most schemes, fixed payments were offered to all potential participants. The level of these payments was established by taking into account estimates of the investment and opportunity costs that land users would incur, as well as the value of environmental services they would provide. These can be adapted over time in order to to changing conditions, or corrected if misestimated, as it was done in Costa Rica's commercial plantations program. This can however lead to inefficiencies. Determining appropriate payments is a challenge in the implementation of schemes.

Auctions can serve as a cost-revealing mechanism (Ferraro 2008). The crop retirement program in the US allocates contracts by means of discriminatory auctions. The bids determine not only the payment, but also the probability of receiving a contract. Therefore, land users are confronted with a trade-off between increasing the bid to receive higher rents, or keeping the bid low to increase the chance of winning. This might avoid overcompensation and increase the effectiveness of the scheme.

Allocating contracts by means of auctions could allow agencies to replace long-term contracts by short-term ones. Having already made the specific investment the agency requires, increases the chances of being re-contracted for conservation (Vogt & Bizer 2013). Thus asset specificity allows for advantages over other potential participants. This might ensure the permanence of the contractual relationship over time. This is what Williamson refers to as *fundamental transformation* (Williamson 1985, p.61). A repeated interaction allows for the creation of trust between contractors, which is crucial for the willingness to engage in conservation activities, but also for the willingness to accept. It might increase cooperation and reduce uncertainty in respect to the provision of environmental services (Vogt & Bizer 2013, pp.3-7). Moreover the bidding system allows the adaptation of the payments to changing conditions.

Whether auctions offer an increase in cost effectiveness for payment schemes requiring specific assets needs to be assessed. Allocating reforestation and further conservation contracts by means of repeated auctions could allow the agency to contract those land users with the lowest opportunity costs, reducing the contracting costs, and reducing the potential of leakage effects. Land users expecting increasing opportunity costs can include a premium in their willingness to accept for participation. The possibility to adapt the payments according to the development of the opportunity costs of land users is an interesting tool to avoid misestimation of payments. However, learning effects leading to strategic bidding over time could also undermine the effectiveness of the scheme (Schilizzi & Latacz-Lohmann 2007). The gains in cost-effectiveness might moreover be diminished by the administrative costs of auctions (Ferraro 2008, p.814).

4.6 Conclusion

In this paper, we analyze the design of contracts of payment schemes that require land users to make specific investments, focusing on payments for tree planting. We provide a theoretical framework to analyze the conditions under which the schemes are implemented in order to address them with a proper contract design. We review different case studies in order to compare our theoretical predictions with the implementation of such contracts in reality. The analysis of the implementation of several tree-planting schemes allowed us to confirm our propositions, and gave us insight about further contractual possibilities.

We observed that long term contracts have to be offered whenever the reversibility of investments endanger the quasi rent losses of the agencies. Long-term contracts, or the possibility for contract renewal, are key to ensure the permanence of the trees if desirable.

We confirmed that the adequate contract design depends on whether land users face liquidity constraints, on whether they trust the agency, and on whether the relative profitability of participation is uncertain. Long-term contracts have to go hand in hand with proper incentives for compliance, taking into account the opportunity costs of land users.

Trust is a key determinant for participation in payment schemes requiring specific assets. This becomes more evident in the presence of irreversibility, and in the presence of parametric uncertainty about future external shocks and future returns. We learned that the existence of long-term contracts offering high future payments might not enhance participation as long as these are not credible commitments. This means that distrust can still be a deterrent to participation even in the presence of contracts. In those cases the agency might have to expose itself to quasi rent appropriation through ex ante payments in order to increase the trust of land users, or might offer high on-going payments.

Compensating land users ex ante can decrease their incentives for maintenance ex post, leading to quasi rent losses for the agency. This issue can be addressed by sanctioning non-compliance, or by making financial incentives dependent on the outcome. The decision to choose sanctions instead of result-oriented payments depends on the costs implied, but also on the social context.

Furthermore, we learned that sanctions might not always be an appropriate solution to non-compliance. Especially in countries where participants face liquidity constraints, schemes have to promote compliance through on-going financial incentives. These should take into account the opportunity costs of conservation, but also the costs for maintenance. This could allow land users to fulfill their basic needs, while complying with the requirements of the contracts.

We do not observe flexible contracts in any scheme. Schemes offer mostly incentives for investment, assuming that the returns will be compensation enough for land users to conserve the trees. In contrast, the scheme in the US allows for re-negotiation through contract renewal.

Auctions can be used to disclose information about the opportunity costs of land users, and thus to increase the cost effectiveness of the scheme. In the long run this could lead to a fundamental transformation, where the same land users would be contracted over time, ensuring the permanence of the environmental benefits. The use of auctions in order to allocate schemes for environmental services open up possibilities to increase the effectiveness in the presence of asset specificity. If several contracting rounds are intended, the agency could gain reputation over time through the compensation of participating land users. Costs related to inefficient allocations until then could serve as an investment in the future reputation of the agency. In this respect, it remains important to investigate whether repeated auctions could potentially increase the cost effectiveness of schemes requiring specific assets. The role of information access and diffusion among land users would have to be taken into account in further research. This would allow understanding the extent to which social interaction can influence the reputation of the agency.

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5

The use of auctions in payment schemes that require specific investments

5.1 Introduction

Through the conservation, restoration or establishment of forest ecosystems, land users are potential providers of many environmental services. Some examples of these services are the regulation of hydrological flows, the conservation of biodiversity, and carbon sequestration. Forests are being lost at rapid rates because their conservation provide land users less private benefits compared to alternative land uses. Incentive-based mechanisms, such as Payments for Environmental Services, address this issue by financially compensating land users for their provision (Pagiola *et al.* 2005, p.238). Participation in payment schemes is voluntary, therefore, payments have to exceed the opportunity costs of land users in order to induce participation (Engel *et al.* 2008, p.667). These schemes are typically offered by governments, NGOs, or other organizations, on behalf of the users of these services (Engel *et al.* 2008, p.666).

Participation in payment schemes implies adapting the land use to the environmental goal of the scheme. In some cases, land users are required to make investments that are specific to the transaction with the environmental agency. This implies that the investment yields lower returns in the second best use (Williamson 1985, p.55). Some examples are fences, windbreaks, shelterbealts, or corridors of trees; these assets are site specific. Also tools and machinery can be specific assets if they cannot be used for alternative activities. Investments in human capital such as knowledge and acquired skills can also be specific to the transaction (Ducos & Dupraz

2007, p.6).

Through payment schemes, environmental agencies might also make specific investments. The extent of these investments is determined by the payments made to land users in advance for their provision. By making payments in advance for the adaptation of the land use, agencies would be making site specific investments that cannot be redeployed for alternative uses, or at least not without losses.

When a specific investment is made, a quasi-rent arises (Klein *et al.* 1978, p.298). The quasi rent is the difference between the returns to investment in the intended transaction and the returns to investment in the second best use. Therefore, the investor runs thus the risk of incurring the costs and not being compensated for the investment ex post. In the absence of an ex ante full compensation for the specific investment undertaken, the transaction partner has thus the potential to appropriate the quasi rent of the investor.

If payment schemes require land users to make specific investments on their land, the contracts have to be designed in a way that both transaction partners are safeguarded from opportunism. Offering ex ante payments might compromise the provision of environmental services ex post, and thus the quasi rent of the agency. On the other hand, land users might not accept ex post payments in order to avoid being harmed by an opportunistic agency.

The higher the level of asset specificity, the higher the contracting costs (Klein *et al.* 1978, p.298). Williamson (1985) identified vertical integration as a solution to the problem of asset specificity. Specific investments are more likely to take place within a hierarchical organization because of the high transaction costs implied in such an agreement. Applied to the provision of environmental services, a vertical integration would imply buying the land instead of offering incentive based payments to land users. However, payment schemes might be cheaper and more adaptive, compared to changes in land tenure. Moreover, land acquisition would prevent a posterior integrated conservation-development dimension. The acquisition of land would only be an option in the presence of prohibitively high transaction costs, or a high likelihood of contract violation or cancellation (Wunder 2006, p.5).

Klein (1978) argues that some form of economically enforceable long-term contract would be the primary alternative to vertical integration (p.302). Long-term contracts can ensure that quasi rents are not appropriated by the transaction partner (Klein *et al.* 1978, p.303). Short-term contracts can allow one party to have advantages that can be exploited in bilateral negotiations over renewal terms. This can discourage investments in specific assets (Pollak 1985, p.582). However, long-term contracting can imply high costs of policing, litigation, and enforcement (Klein *et al.* 1978, p.303).

Granovetter (1985) supports the theory that behavior and institutions are influenced by social relations. This is what he calls the "embeddedness" argument (pp. 481-482). The author suggests that trust is generated through personal relations and social networks, and that decision makers seek for the best information they can get about their potential transaction partners. He argues that trust discourages opportunistic behavior, allowing these transactions to take place in the market (p.490). Trust, referring to the perception that one can rely on the partner's benevolent intentions, eliminates the need for formal detailed contracts that are costly to formulate and enforce, and reduces transaction costs (Dyer & Chu 2003, pp.58-59,Gulati 1995, p.93). Ducos and Dupraz (2007) show that if land users trust the intentions of the agency, they are more likely to enroll their land for agri-environmental practices requiring specific investments. They refer to trust as the perception that the transaction partner shares the same goals and won't make unfair decisions. Trust is therefore "*expected to reduce the hold up pressure on the transacting parties*" (Ducos & Dupraz 2007, p.12). The more land users trust the intentions of the agency, the lower their need to protect themselves, and thus the lower the transaction costs implied in the contracting process.

In most payment schemes, contracts are allocated by means of posted offers. Payments should exceed the opportunity costs of land users in order to induce participation. However, estimating these costs imposes a challenge for the agency because land users are usually better informed about their own opportunity costs. This allows them to secure informational rents by claiming to incur higher costs (Ferraro 2008, p.811). Reverse auctions are claimed to allow agencies to reduce informational rents because bidders reveal their costs through their offers (Ferraro 2008, p.813).

Pricing in auctions can be discriminatory or uniform, both formats leading to different bidding strategies. In uniform auctions, every winner receives the same payment. It is determined by the highest accepted bid or by the lowest rejected one. Theoretically, the dominant strategy in this auction design is to offer a bid equal to the opportunity costs because bids only determine the chance of winning a contract, but not the payment (Latacz-Lohmann & Schilizzi 2005, pp. 21-22).

Under a discriminatory auction, land users receive a payment equal to their bid. They are confronted with the trade-off between increasing the bid to secure a higher rent, and decreasing it to increase the likelihood of winning a contract. Theoretically, the dominant strategy in this pricing format is to overbid. Latacz-Lohmann and Van der Haamsvort (Latacz-Lohmann & Van der Hamsvoort, Carel 1997) derive the optimal bidding strategy of land users. They show that the optimal bidding strategy of risk-neutral land users is a function that increases linearly with the opportunity costs of participation and their expectation about the cut off payment (bid cap). Moreover, they show that land users who have already participated in previous rounds, and have thus already incurred the implementation costs, will make use of this relative advantage in order to increase their rents. The authors highlight that this might lead to a free-rider problem whenever the agency is unable to counteract this behavior (p.411).

Many economists have turned to experiments and agent-based modeling in order to determine which auction design leads to a higher cost-effectiveness (Ferraro 2008, p.815). Experimental settings show that the bidders' behavior corresponds to the theoretical predictions (McKee & Berrens 2001; Cummings *et al.* 2004; Cason & Gangadharan 2004; Kawasaki *et al.* 2012; Deng & Xu 2015). The repetition of auctions over time allows bidders to learn and adapt their bidding strategies. This leads to overbidding over time, and thus to a lower cost-effectiveness of discriminatory auctions, especially if low-cost bidders have an accurate estimation of the bid cap (Cummings *et al.* 2004; Kawasaki *et al.* 2012). Kawasaki et al. (2012) provide evidence for seemingly irrational underbidding. The authors explain this behavior through a lack of comprehension of the auction dynamics or through the *joy of winning*, a phenomenon in which bidders bid more aggressively because they derive utility from winning or from spite (p.165). The authors analyze the incentives for compliance in auctions. Their results show that low-cost participants are more likely to comply with the contract requirements. Participants with costs higher than the bid cap would only be willing to underbid in the expectation of benefits from non-compliance. Thus, discriminatory auctions can lead non-compliance to the extent that these allow high-cost land users to enter the winners' pool (p.176).

Repeated auctions create an asymmetry among bidders through learning effects, reputation, and asset specificity (Vogt & Bizer 2013, pp.2-8). This asymmetry can lead to what Williamson (1985) calls *fundamental transformation*: even if at the outset there are many potential providers of the environmental services, the agency is likely to contract the same land users over time. This can lead not only to institutional but also to trust relations [p.62]. This in turn could imply a better reputation for the agency, given that trust building is a social process, as Granovetter proposes. A better reputation would lead to more trust in the agency, and thus to lower bids over time. On the other hand, auctions can imply uncertainty for land users in regard to future payments because their participation in the scheme is not only dependent on their own bids, but also on the bidding strategies of other bidders. Uncertainty could lead to an increase in land users' willingness to accept for participation.

The purpose of our study is to analyze whether auctions could increase the cost-effectiveness of the allocation of contracts in the presence of asset specificity. We consider one shot auctions to allocate long-term contracts and repeated auctions to allocate short-term contracts. We contribute to the literature by taking into account the role of asset specificity and the role of social networks in the implementation of payment schemes. In this context social networks allow for information diffusion, having an influence on the reputation of the agency and on land users' learning effects over time.

By means of agent-based modeling, we simulate the implementation of a scheme of payments for carbon sequestration. The scheme requires land users to invest in reforestation and for further conservation. Agent-based modeling allows simulating interactions between heterogeneous individuals, allowing for the analysis of macro-scale effects that emerge from these dynamics (Axelrod & Tesfatsion 2006, p.1649). It allows understanding how learning, strategizing, and interaction affect over time the outcome of payment schemes in the presence of bounded rationality (Hailu & Schilizzi 2004, pp.153-154).

We simulate two types of contract design, short-term and long-term contracts, as well as three different allocation mechanisms, fixed payments (posted offers), uniform auctions and discriminatory auctions. In our model bidders are connected through a small-world network that allows them to interact and exchange information about their bidding strategies and their level of trust. Social interaction allows land users to learn over time. This has an effect on the cost-effectiveness of the scheme through the influence on reputation and on the level of payments. The parameters used in the model are based on empirical data from a tree-planting field experiment in Malawi (Jack 2010).

The paper is structured as follows. In the next section we describe the agent based model and the data used. In the third section we present the results of our simulations, which are analyzed and discussed in the fourth and last section.

5.2 Model

By means of agent-based modeling, we create an hypothetical payment scheme in a low-income country. The scheme's goal is to provide carbon sequestration by offering land users payments for reforestation and for further conservation of the trees. Our model is based on a tree-planting trial in Malawi undertaken by Jack (2010), where land users were offered payments for planting a certain amount of M'bawa trees (African Mahogany) on their land.

The purpose of our model is to determine which contract length and allocation mechanism induces environmental services more cost-effectively, when participation requires investing in specific assets. We take into account the perceived trust in the agency, and the presence of learning effects over time, which both have an effect on land users' willingness to accept for participation.

5.2.1 Individual decision making

Our model consists of two agent types, an environmental agency and land users. We explain their objectives and decision making processes in the following.

The environmental agency has the goal of maximizing the provision of carbon sequestration through the conversion of marginal agricultural land to forests. It offers reforestation payments to land users willing to invest in planting 100 M'bawa trees in one acre of their land, which is allocated to crop production.

The agency values each unit of land according to the carbon storage it provides. Table 5.1 shows the estimation of the carbon storage potential (in tons) of a M'bawa tree in Malawi, based on biomass estimates by Kachamba (2008) (Jack, 2010, p. 51). According to this table, the carbon storage potential of a tree increases until year 40, and it starts to decrease afterwards. The value of a tree in terms of its carbon storage potential is thus higher for older trees than it is for younger ones, as long as they are not older than 40 years.

Year	Above ground biomass	Below ground biomass	Total tons/tree
5	0.01	0.003	0.013
10	0.01	0.003	0.013
15	0.06	0.016	0.076
20	0.16	0.041	0.201
25	0.51	0.127	0.637
30	0.64	0.160	0.800
35	0.65	0.161	0.811
40	0.47	0.117	0.587

Table 5.1: Carbon storage potential of M'bawa trees in Central Malawi

This implies that the agency is interested in contracting reforested land for conservation, as long as the net benefit of doing so exceeds the net benefit of reforesting other areas. The agency offers conservation payments that are expected to give land users an incentive to maintain the trees. Thus, these payments account for their opportunity costs after the land use change is undertaken.

The agency is endowed with a fixed budget in every period that can be spent for reforestation or for conservation of previously reforested land. In the contracting process, the agency takes the value of the land into account, as well as the price of contracting it. Therefore, the agency gives priority to conservation contracts, as long as the net benefit of re-contracting a land user for conservation is higher than the net benefit of contracting a new land user for reforestation.

Land users are assumed to maximize the profits derived from their land. They can keep their land allocated to the production of crops, or enroll it in the payment scheme. The annual profit from crop production is described by π_i, and is a proxy for the opportunity costs of participation in the payment scheme. Reforestation is not a profitable land use in the short run, however, in the long run, when the trees are high enough, land users can use them as firewood. These benefits (f_i) become thus part of the opportunity costs of conservation. Land users would only be willing to invest in the scheme if the discounted expected net benefits from reforestation exceed their discounted expected opportunity costs during a time horizon T (condition 5.1). The latter refers to the time horizon in which land users could potentially receive payments.

$$p_{i,0}[\sum_{0}^{T} \frac{p_{i,t}}{\beta^t}]\theta_{i,t} > \sum_{0}^{T} \frac{\pi_i}{\beta_i^t} + I + \sum_{\tau}^{T} \frac{f_i}{\beta_i^t} \tag{5.1}$$

The left hand side of condition 5.1 describes the expected benefits from participation in the scheme; the reforestation payment $p_{i,0}$, and the expected discounted future payment flow $[\sum_0^T \frac{E[p_{i,t}]}{\beta^t}]$. Land users discount their future benefits at a factor β_i. They create expectations about the level of future conservation payments $p_{i,t}$ and about the probability of receiving them. The latter is determined by their trust in the agency's willingness to re-contract them over time, and thus to compensate them for the specific investment. Trust is modeled as an individual factor $\theta_{i,t}$ that takes a value between 0 and 1, where 0 means that land users do not trust the agency's intentions to compensate them over time, and 1 that they fully do.

The right hand side of condition 5.1 describes the discounted costs implied in participation. While investment costs I are only incurred once for reforestation, opportunity costs are incurred in every contracting period. The forgone profit from crop production is incurred in every period, while the opportunity costs of not deforesting the land are incurred only from period τ on, when the trees are high enough to be harvested. Transforming condition 5.1, gives the condition for reforestation, as follows:

$$p_{i,0} > \sum_{0}^{T} \frac{\pi_i}{\beta_i^t} + I + \sum_{\tau}^{T} \frac{f_i}{\beta_i^t} - [\sum_{1}^{T} \frac{p_{i,t}}{\beta^t}]\theta_{i,t} \tag{5.2}$$

Land users will only be willing to invest in reforestation if the reforestation payment exceeds their minimum willingness to accept. The latter equals all costs incurred, diminished by the expected level of future compensation through conservation payments. The willingness to accept for reforestation decreases with the level of trust. The higher their level of trust, the higher their expectation about future benefits from conservation, and thus the lower their willingness to accept for reforestation. If land users do not trust the intentions of the agency to contract them for conservation after reforesting their land, they would only agree to invest in reforestation as long as the reforestation payment fully compensates them for all costs incurred.

The minimum willingness to accept for conservation (after having invested in reforestation) is given by the discounted sum of opportunity costs. After having reforested the land, the opportunity costs comprise the foregone benefits from firewood if the trees are old enough, and the foregone benefits from crop production if the land would be reconverted back. The latter would imply re-conversion costs c. The condition for conservation for any period $\Gamma > \tau$ is expressed in condition 5.3. Land users will only be willing to conserve the trees as long as the conservation payment fulfills this condition.

$$p_{i,\Gamma} \geq \sum_{0}^{T-\Gamma} \frac{\pi_i + f_i}{\beta^t} - c - [\sum_{1}^{T-\Gamma} \frac{p_{i,\Gamma}}{\beta^t}]\theta_{i,\Gamma} \tag{5.3}$$

5.2.2 Contract design

As explained in the last section, the agency offers land users reforestation and conservation payments in order to achieve its goal of carbon sequestration. These can be embedded in short-term or long-term contracts, as explained below.

Long-term contracts are offered for a time horizon equal to 40 years ($T+1$). This is the time during which trees provide increasing carbon storage. A long-term contract includes an initial reforestation payment and annual conservation payments that remain constant over time. Land users are required to conserve the trees during the whole contracting period. While reforestation payments are equal for all land users independently of the mechanism used to allocate the contracts, conservation payments are determined by the respective allocation mechanism.

Short-term contracts have a duration of one year. Reforestation contracts are offered to new participants, and conservation contracts are offered to re-enrollers. Because contracts for conservation can be renewed every year, the terms can be adapted. At the end of every contract period land users compete again for conservation contracts. In case of not being contracted, they can allocate their unit of land back to the previous land use, if profitable. However, once re-converted, the land looses eligibility for further participation in the payment scheme. Short-term conservation contracts are only renewed for a total of 40 years.

5.2.3 Allocation mechanisms

Contracts can be allocated by means of fixed payments (posted offers), uniform auctions, or discriminatory auctions. The contracting process, the strategies, and the implication for the payment scheme change depending on each mechanism. In fixed payment schemes, reforestation and conservation payments are established ex ante. These are equal for short and long term contracts. When long-term contracts are offered, the reforestation payments equal the fixed payments, and land users are contracted according to the bids they offer for annual conservation payments. When short-term contracts are offered, both reforestation and conservation contracts are determined through the auctions.

Fixed payments for reforestation and conservation are established ex ante by the environmental agency for both contract types. Land users with opportunity costs lower than these payments are assumed to be willing to accept a contract.

Uniform auctions imply that all bidders are offered the cut-off bid, the lowest rejected bid. Land users' dominant bidding strategy is assumed to be offering a bid equal to their opportunity costs.

Discriminatory auctions imply that bidders are offered a payment equal to their bid, as long as these are lower than the cut-off bid. Their dominant strategy is assumed to be overbidding.

5.2.4 Social network

Land users are embedded in a social network through which they share information with their acquaintances in every period. According to this information, they adapt their perceived likelihood to receive future payments (trust) and their expectations about the level of these payments. The latter allows them to estimate the bid cap, and to adapt their bidding strategy accordingly.

We model a small-world network where land users know their neighbors, and where they might also know land users from other neighborhoods. Such that, although most land users are not neighbors of one another, their neighbors are likely to know each other. This has implications on the diffusion of information. We implement the Watts-Beta-Small-World Generator by Jung Project and Nick Collier, a graph generator that produces a small world network using the beta-model, as proposed by Duncan Watts (1998). It is described by two factors; the number of neighbors that every land user has, and the probability to know someone from another neighborhood. In our model we assume every land user to have 2 neighbors, and a probability of 20 percent to know someone else. Land users in the same neighborhood have similar opportunity costs. This type of network can present a high connectivity among land users with a small number of connections, allowing information to spread rapidly to other areas (Centola 2010).

The information land users receive through social interaction has an influence on their willingness to accept for participation, and on their bidding strategies, as explained below.

Social interaction and reputation

As explained in section 2.1, trust refers to the perceived likelihood of receiving conservation payments in future periods. The average level of trust among the population can be interpreted as the reputation of the agency. This variable is a function of the dynamics of contract allocation and of social interaction.

If land users are fully compensated during the period in which the trees do not provide any benefits, their trust level is assumed to increase by 10 percent. If a land use re-conversion is not profitable, and they are not compensated for their investment, their trust level decreases by the same percent because they lose their quasi-rent.

The level of trust can also be influenced by social interaction. We model trust based on the opinions model of Sun and Mueller ((2012)). Each land user has an initial trust level that is uniformly distributed among the population in the range [0;1]. A trust level of 0 refers to full distrust and 1 to full trust. This level can be influenced by the trust level of other land users. In every period a land user i interacts with a random land user she j knows. They exchange information on their trust levels. Land users with extreme values are less open to external influences. This is captured by σ, which decreases for values close to 1 and close to 0 (see equation 5.4).

$$\sigma_i = 1 - 2(|\theta_{i,t} - 0.5|) \tag{5.4}$$

As long as the difference between both trust levels is smaller than σ, land user i adapts the perceived trust level according to equation 5.5. The convergence factor μ, which also ranges between 0 and 1, reflects the personality of land users. This is exogenously given. Land users with a value equal to 0 never change their initial trust level, whereas those with μ values close to 1 would always follow the trust perception of their peers.

$$\theta_{i,t} = \theta_{i,t-1} + \mu_i(\theta_{j,t-1} - \theta_{i,t-1}) \quad \text{if} \mid \theta_{j,t-1} - \theta_{i,t-1} \mid < \sigma_i \tag{5.5}$$

Social interaction and learning effects

Social interaction allows land users to learn and adapt their expectations about future conservation payments. In every period land users gain experience through the interaction with the agency, and gather information about the payoffs of their acquaintances. They use this information to update their expectations about future conservation payments, and thus to adapt their minimum willingness to accept in every period.

This is especially relevant when repeated auctions are implemented because, in contrast to fixed payment schemes, the level of conservation payments is not known. In uniform auctions, land users assume that future conservation payments are going be equal to the last value payed by the agency. In discriminatory auctions, the expectations about future conservation payments are adapted according to the highest payment they have information about. They do not take into account land users whose land's value is higher.

5.2.5 Bidding strategies

The bidding strategies differ according to the payment format and to the contract design, as explained in the following.

Long-term contracts

Long-term contracts imply one-shot auctions, such that learning effects become irrelevant. In long-term contracts all land users receive the same initial reforestation payment, which exceeds the investment costs. Bids determine only the level of the annual conservation payments.

Uniform auctions imply that land users offer a bid equal to their opportunity costs of conservation. They offer an annuity payment equivalent to their willingness to accept for conservation during the whole contracted period.

Discriminatory auctions imply that land users' dominant strategy is overbidding. They inflate their opportunity costs ($\hat{\pi}_i$), according to equation 5.6, following Latacz-Lohmann and

Van der Haamsvoort (1997). $\bar{\pi}$ describes the average opportunity costs of all potential participants, assumed to be common information. Thus, those with relatively lower opportunity costs offer relatively higher bids, and land users with a willingness to accept higher than $\bar{\pi}$ do not expect to receive a contract. Nevertheless, they are assumed to inflate their costs by 10 percent. After having inflated their costs, they offer the annuity payment equivalent to their willingness to accept for conservation during the whole contracted period.

$$\hat{\pi}_i = \frac{\pi_i + \bar{\pi}}{2} \tag{5.6}$$

Short-term contracts

Short-term contracts imply repeated auctions, such that learning effects become relevant for the optimization of bidding strategies.

Uniform auctions imply bids equal to the current opportunity costs of conservation (see condition 5.3), influenced by the current level of trust and the current expectation about future conservation payments.

Discriminatory auctions imply learning effects. If a land user i has information about an accepted bid ($b_{j,t-1}$) that was higher than her own (or than her current opportunity costs in case of not being contracted), she has an incentive to increase the current bid in order to increase her rent (Lundberg *et al.* 2018). The bid adaption is determined by the difference between both pay-offs. This difference is given by the gap $\triangle_{i,j}$) (see equation 5.7). If the gap is negative (positive), land users are assumed to decrease (increase) their bids according to equation 5.8. In the absence of information about higher accepted bids, land users do not change their bidding strategy (Lundberg *et al.* 2018).

$$\triangle_{i,j} = b_{j,t-1} - b_{i,t-1} \tag{5.7}$$

$$b_{i,t} = b_{i,t-1} + \frac{\triangle_{i,j}}{2} \tag{5.8}$$

5.2.6 Data description

We use empirical data from a tree-planting field trial in Malawi, explained in detail in Jack (2010). The field trial was undertaken in Ntchisi District, an area heavily dependent on rainfed agriculture, where land users grow primarily maize, soy, tobacco and potatoes. The tree planting contract required land users to set aside half an acre of land and plant 50 seedlings of M'bawa trees (African Mahogany) provided by an organization. They were paid a fixed payment for each surviving tree over three years. Contracts were allocated by means of fixed payments and uniform auctions. Information was shown to flow easily within villages and contract holders, such that within a village, land users may have learned from each other about how to keep the trees healthy after contract allocation. Moreover, land users might have exchanged information before participating in the auction.

In our model, we assume the agency to contract land users for a maximum of 40 years. Land users are expected to plant 100 seedlings in one acre. We use the foregone income from crop production as a proxy for opportunity costs, because this represented the largest cost associated with allocating land to the tree planting contract. We include in the opportunity costs the value of firewood, because most land users in the trial stated that they would use the trees for this purpose. We approximate this value by multiplying the times per year they have to gather wood by the price they would pay for it in the market.

African Mahogany trees have gained great interest because of its rapid growth and its supply of wood in the short term (Pinheiro *et al.* n.d., p.64). On average, participants expected to keep the trees on their land for 7 years before harvesting or replacing them. In Malawi these trees can reach a height of 8 m and a diameter of 9 cm after 7 years. However, removing them with a diameter less than 70 cm can result in a lack of natural regeneration (Pinheiro *et al.* n.d., p.68). In our model, we assume that trees can be harvested after 10 years for the purpose of using the timber as firewood. The individual discount rates were calculated based on the time preferences revealed through the questionnaire in the trial. The population equals 428 land users. Table 5.2 shows the descriptive statistics of the empirical data.

Variable	Mean	Std. Dev.	Min	Max
Crop income (MWK)	42526.14	50462.99	750	370000
Firewood value (MWK)	12625.58	11709.69	480	108000
Discount rate (%)	515	491	120	125

Table 5.2: Descriptive statistics

Investment and clearing costs are derived from the calculation of costs per acre provided by Ntchisi District Agriculture and Development Officers and by the 2007 Crop Estimate Report for Ntchisi District (Jack 2010). The numbers are given in units corresponding to Malawi Kwacha (MWK). Investment costs are assumed to be the same for all land users, and to equal 10400 MWK. These are comprised by land clearing costs (2400 MWK) and by field preparation and planting costs (8000 MWK). In case of reconverting the land to crop production after the contract expires, land users are assumed to face again the land clearing costs, and the costs for field preparation and planting. Re-conversion costs equal 6800 MWK, taking the numbers for the production of soya, the most profitable crop in that region. Because similar weeding and harvesting costs are implied in crop production and tree planting, these are not considered in the model.

The fixed budget available to the agency every period is determined by multiplying the amount of contracts allocated with the fixed payment. It equals 546000 MWK. The fixed initial reforestation payment equals 12000 MWK, following Jack (2010), and the fixed conservation payment is set at half the reforestation payment. The environmental value of the land is determined by the report on carbon storage potential of M'bawa trees in Central Malawi, shown in table 5.1. This is given in tons of carbon sequestrated. Sequestration benefits are reversed if trees are used for firewood.

5.2.7 Performance indicators

To measure cost-effectiveness we consider the returns to budget, measured as the number of conservation contracts allocated.

Although we do not consider the agency to behave opportunistically, we consider land users' perceived risk of being harmed by opportunism. Land users who invested in the scheme, and for whom re-conversion is not a profitable option, could lose their quasi rents if they would not receive conservation payments because of the allocation dynamics. We use the number of land users that are hold up in the transaction, and that do not receive conservation contracts, as a proxy for land users' quasi rent appropriation.

The environmental agency would lose its quasi rents any time a land user decides to re-convert her land back to crop production, or whenever land users do not comply with the contract requirements. The latter implies cutting down trees in order to obtain firewood. We measure the agency's quasi-rent losses by the number of land users that allocate their land back to crop production, and the share of land users that do not comply with the contract requirements. Furthermore, non-compliance is also an indicator for additionality, because in the absence of conservation payments these land users would not necessarily re-convert their land back to crop production.

5.2.8 Sensitivity analysis

We conduct an analysis in order to determine how sensitive our model reacts to changes in the parameters. The parameters we varied are the distribution of the opportunity costs, the initial range of trust, the range of personality of land users (μ), the amount of budget available for the agency and the number of land users. We run the model 1000 times for each combination of these parameters and for each contract type.

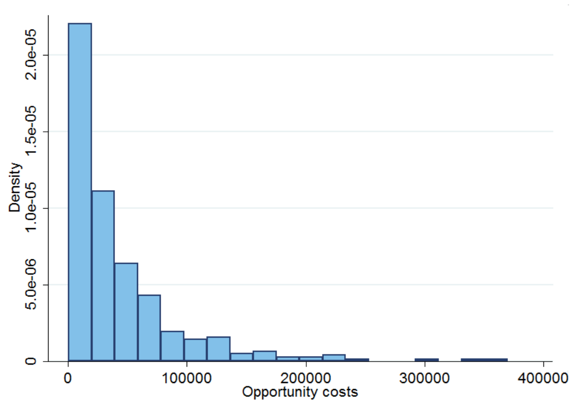

Figure 5.1: Empirical distribution of opportunity costs

Figure 5.1 shows the empirical distribution of opportunity costs. This is a right skewed distribution where the majority of the land users have rather low opportunity costs. In order to investigate the effect of an alternative distribution of opportunity costs, we model a normal distribution with a mean value equal to the empirical average.

In our model we assume that the level of trust is uniformly distributed among land users within a range of [0;1]. We model an initial reputation from within the ranges [0;0.5] and [0.5;1], in order to account for an initial bad and good reputation, respectively. We do the same with the factor describing the personality of land users, and thus their likelihood to be influenced by the opinions of their peers. By doing this, we account for a society that is highly influenced by social interaction, and a society who is not. This might influence the dynamics of the reputation, and thus the allocation of the contracts. We vary the budget available to the agency, as well as the number of land users through the random generation of numbers. We generate 10 different random numbers of farmers within the range [50;1000], and 10 different random budget levels within the range [100000;1000000].

We generate regression trees in order to illustrate our results, taking into account the amount of conservation contracts allocated in the last implementation period considered, which is our main performance indicator. Linear regression is a global model, that produces a single predictive formula for the entire data-space. Regression trees can be used when the data has variables that interact in complicated, nonlinear ways. Regression trees are a conceptually simple and powerful tool (Friedman *et al.* 2001, p.305). This method partitions the observations into a set of clusters, and then fits a simple model in each one. Each cluster is represented as a "leave" in the regression tree. The tree starts with a root node, and asks a sequence of questions about the features in every leave. Each question refers to only a single attribute, and has a yes or no answer, for example, “Is the number of land users > 50?” or “Do the opportunity costs follow a normal distribution?”. According to the attributes, the tree predicts which allocation mechanism is the one allowing the agency to allocate the highest number of contracts in the last implementation period. Thus, each "leave" of the tree represents a parameter that leads to a certain class variable, which in our analysis is the allocation mechanism. The gini index measures the level of impurity, the lower this index, the lower the misclassification rate (Friedman *et al.* 2001, p.309).

Figure 5.2 shows the result of long-term contracting. As it can be seen in this figure, the only relevant attribute is the distribution of the opportunity costs. It determines which allocation mechanism leads to the highest number of contracts. The tree shows that if the empirical right skewed distribution is considered, uniform auctions provide the highest number of contracts. However, if the opportunity costs follow a normal distribution, contracts should be allocated by means of discriminatory auctions. The empirical distribution implies that most of the land users have rather low opportunity costs. These land users secure high rents through fixed payments and through their bids in discriminatory auctions, such that more contracts can be allocated through uniform auctions.

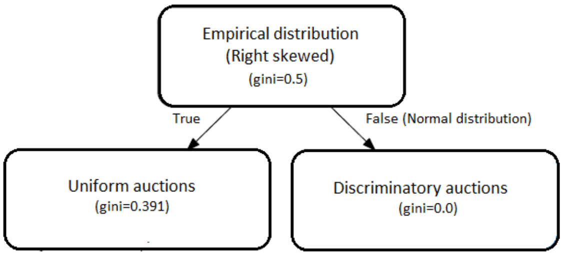

Figure 5.2: Regression tree for long-term contracting

Figure 5.3 shows the regression tree for short-term contracting. As it can be seen in this regression tree, the relevant attributes are the distribution of the opportunity costs, the level of budget available, and the number of land users competing for contracts. This means that the level of competition plays a role in the differences in cost-effectiveness between the allocation mechanisms only if short-term contracts are offered. The reason for this is that the level of competition determines the possibilities of land users to increase their rents over time under discriminatory auctions.

If the opportunity costs follow a normal distribution and the agency has a low budget, discriminatory auctions allow allocating a higher number of conservation contracts. Uniform auctions do not perform better than discriminatory auctions because low-cost land users receive uniform payments that overcompensate them more than discriminatory payments. Nevertheless, for higher levels of budget, uniform auctions promise a higher number of contracts. The reason for this is the level of competition. Discriminatory auctions allow bidders to learn and increase their rents according to this information. The higher the budget, the higher the informational rents that low-cost land users can secure, and thus the less cost-effective in comparison to uniform auctions, where their overcompensation is smaller.

Considering the empirical right skewed distribution, discriminatory auctions lead to a higher number of contracts if the budget is large. This indicates that overcompensation through discriminatory payments would still be lower under discriminatory auctions despite of learning effects, compared to uniform auctions. If the agency faces a low budget, the result will depend on the number of land users competing for a contract. If there is a small number of land users, the likelihood that they have low opportunity costs on average is high. According to the regression tree, discriminatory auctions allow the agency to allocate more contracts in such a setting. The repetition of auctions allow them to increase their rents over time, however not as much as in cases where land users are more heterogeneous. If the majority of the contracted land users faces low opportunity costs, increasing their bids implies risking participation in the next round. Securing rents through the increase of bids is therefore rather possible for bigger samples, where land users are more likely to be heterogeneous. Uniform auctions would allow the agency to contract the highest number of land users.

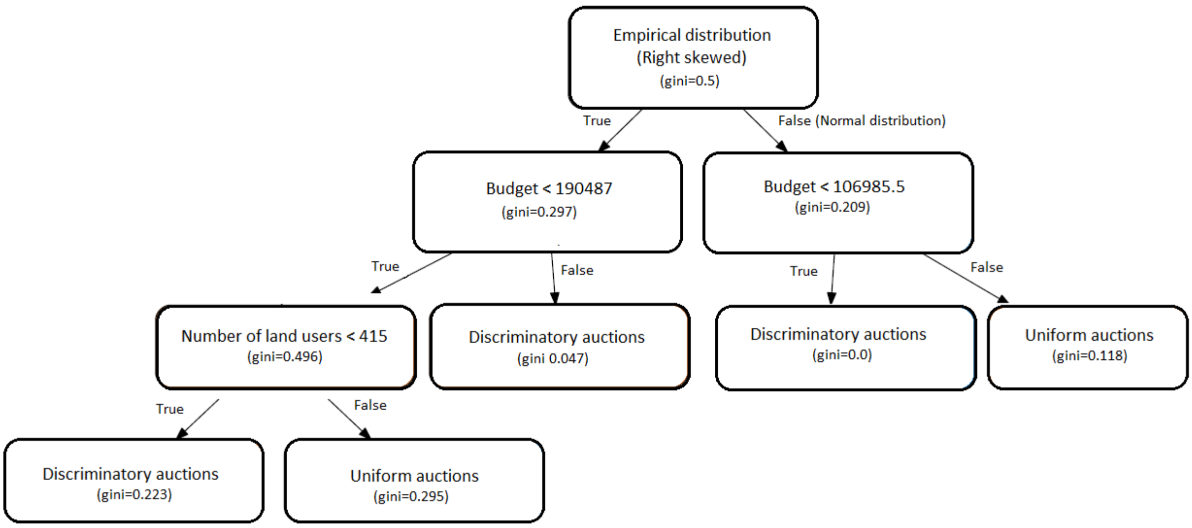

Figure 5.3: Regression tree for short-term contracting

This analysis shows that our results are not sensitive to variations in the initial trust range, nor in the range of the personality factor. The latter determines the likelihood that the trust level is influenced by social interaction. Although the level of trust has implications on the willingness to accept, it does not have an effect on the choice of the allocation mechanism.

5.3 Results

We simulate a payment scheme for carbon sequestration in order to investigate the performance of fixed payments, uniform auctions and discriminatory auctions to allocate short- and long-term contracts. We compare the results based on the performance indicators described in section 2.9. The results of 1000 simulations are averaged. Table 5.3 summarizes the results in the long term (the last implementation period in year 40.). The time series are shown below in order to illustrate the dynamics over time, whereas 50 random runs are shown in the graphs in order to show the variation of the results.

Long-term contracts

We start analyzing the results of long-term contracting, where land users receive contracts with a duration of 40 years. They are expected to reforest their land and to conserve the forest during this contracting period. Figure 5.4 shows the number of long-term contracts allocated over time under each allocation mechanism. Contracting occurs mainly during the first implementation periods, afterwards the budget constraint does not allow the agency to contract more land users, because contracted land users receive annual payments for conservation. Clearly, less contracts are allocated by means of fixed payments. The conservation payments resulting from auctions are lower on average than the fixed conservation payments. This can be seen in figure 5.5. Discriminatory payments are slightly higher than the uniform payments on average, which means that the environmental agency pays higher information rents under the former allocation mechanism. This is a result of the dominant strategy of overbidding, where those land users facing the lowest opportunity costs inflate their bids relatively more than the high-cost land users.

Allocation mechanism	Reforestation contracts	Conservation contracts	Conservation payments	Info. rents	Non-compliance	Avr. Trust	Re-conversion
Long-term contracts							
Fixed payments	0	54.72	6000	0.49	0.68	-	-
Uniform auctions	0	328.14	1621.33	0.50	0.95	-	-
Discriminatory auctions	0	259.76	2050.12	0.49	0.95	-	-
Short-term contracts							
Fixed payments	0	23.05	6000	0.62	0.33	0.62	25.69
Uniform auctions	5.32	40.32	6978.17	0.53	0.78	0.53	152.34
Discriminatory auctions	0.25	63.87	8261.41	0.55	0.33	0.55	87.45

Table 5.3: Long term results of short-term and long-term contracting

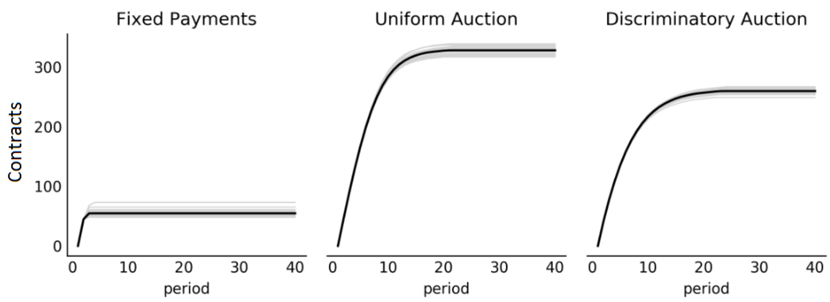

Figure 5.4: Number of long-term contracts

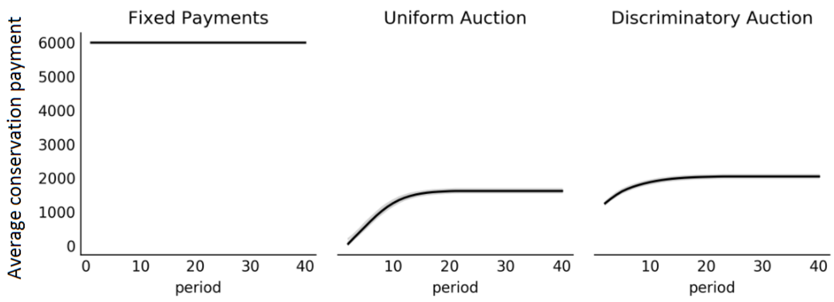

Figure 5.5: Average conservation payments in long-term contracts

The quasi rent losses of the environmental agency are the losses in environmental value resulting from non-compliance. Non-compliance means that, despite of being paid for conservation, land users cut-off the trees they need in order to satisfy their needs for firewood. Non-compliance implies therefore that the expected level of environmental benefits are not provided, which is equivalent to a loss in the quasi-rent of the agency. Once the trees are high enough to be harvested, contracted land users incur additional opportunity costs in the form of forgone benefits from firewood. We assume that land users would not have an incentive to comply with the contract requirement if their benefits from firewood in one period are higher than the conservation payment, because a loss of future payments would still imply positive net gains from non-compliance. We do not have information about the amount of trees land users would cut in case of non-compliance, so that we cannot quantify the losses of the agency.

The payments for conservation are not high enough to give land users an incentive to comply with the contract requirement, once trees can be harvested. This is especially the case in auctions, where we observe a share of non-compliance close to 100 percent.

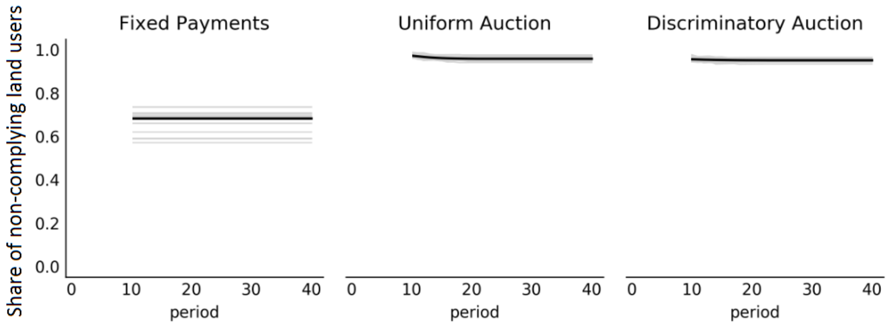

Figure 5.6: Share of contracted land users that do not comply under long-term contracting

As long as the trees are not high enough, there is no reason not to comply, because conservation payments exceed land users' opportunity costs. The latter are only comprised by the forgone benefits of allocating their land back to crop production. However, after period 10, land users' opportunity costs increase with the possibility to harvest of the trees. Conservation payments are not high enough to compensate land users for these additional opportunity costs. Non-complying land users receive more benefits from the use of firewood than from land use-reconversion. This means, that keeping such land users contracted does not imply additional conservation, because they would not re-convert their land in the absence of payments. Figure 5.6 shows the share of land users that would not have an incentive to comply.

The reason why land users accepted ex ante conservation payments that would not fully compensate them ex post for their opportunity costs can be explained by the high time preferences land users have (see table 5.2). Land users calculate the net present value of the costs they will incur if they participate in the scheme. The opportunity costs with the highest weight in this calculation are those incurred in the first period, where land users plant the trees and receive conservation payments. The periods given the lowest weight in the calculation are those in which conservation implies higher opportunity costs because of the foregone benefits from the use of the trees as firewood. This means that the higher the rent they receive through the reforestation payment, the lower their willingness to accept for conservation in the future. Land users secure the rents from reforestation at cost of future compensation. This leads to payments that are not high enough to provide the incentives to comply with the contract, once trees can be harvested. In the Appendix we provide figures showing the number of contracts allocated under each mechanism and the share of non-complying land users, for different assumptions on the level of discount rates.

Our results suggest, that fixed payment schemes result in more environmental benefits compared to auctions, if long-term contracts are offered to land users with high time preferences. Auctions provide more environmental services than fixed payment schemes only during those years where trees are not high enough to be harvested, whereas uniform auctions provide the highest number of contracts.

Short-term contracts

Short-term contracts have a duration of one year. They are offered for reforestation to new enrollers, and for conservation to re-enrollers. Re-enrollers are those who have already invested in reforestation. Figure 5.7 and figure 5.8 show the number of short-time contracts allocated over time for reforestation and for conservation, respectively.

While new enrollers are mostly contracted during the first implementation periods in fixed payment schemes and discriminatory auctions, contracts for reforestation are allocated under uniform auctions throughout the 40 years. Under all three mechanisms, the number of conservation contracts allocated decreases rapidly once the trees are high enough to be harvested (after period 10). The increase in opportunity costs leads to a higher willingness to accept for conservation, and thus to higher payments necessary to induce conservation. In fixed payment schemes and discriminatory auctions, the number of conservation contracts reaches a steady state over time. The latter being higher under discriminatory auctions. In uniform auctions, however, the number of conservation contracts is subject to variations. In order to understand the dynamics behind these results, we take a look at the average conservation payments in figure 5.9.

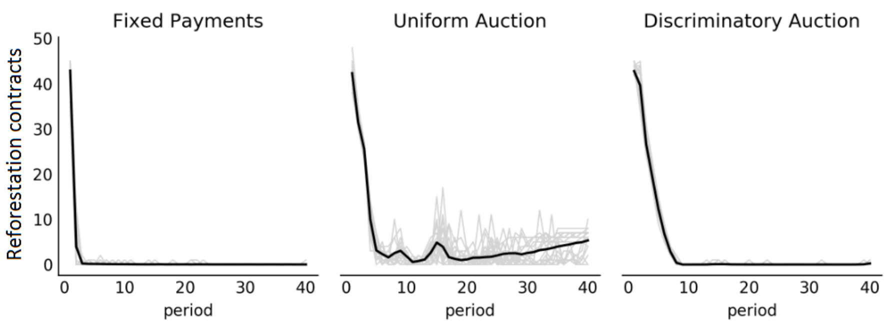

Figure 5.7: Number of short-term reforestation contracts allocated

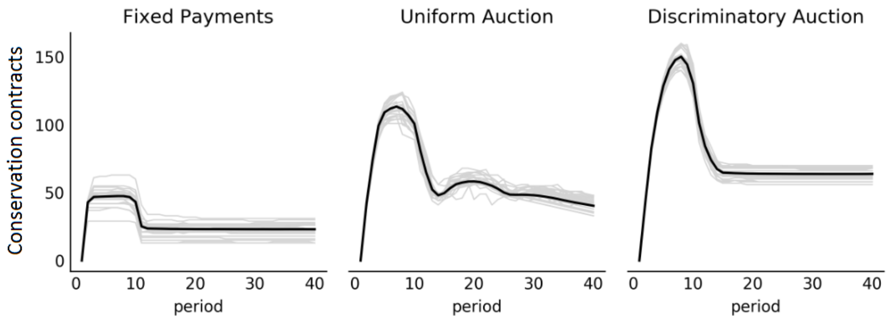

Figure 5.8: Number of short-term conservation contracts allocated

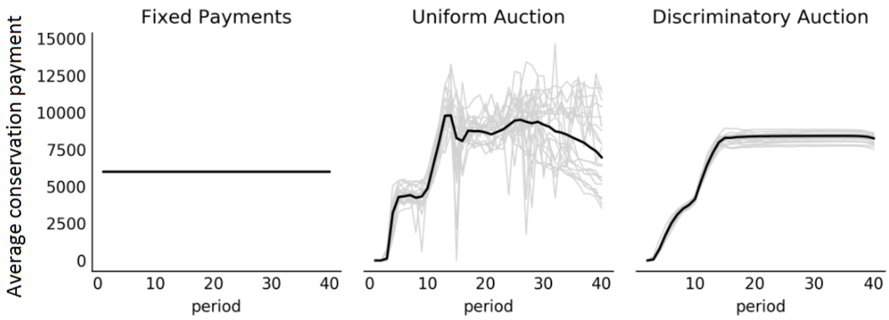

Figure 5.9: Average conservation payments in short-term contracts

Discriminatory payments increase over time, until the average payment level reaches a steady state at a level higher than the fixed conservation payments (figure 5.9). This increase occurs in two phases. The first one is the result of learning effects. In every period land users receive information about the bidding strategies of the participating land users they know. This allows them to have a better estimation about the bid cap. They adapt their bidding strategy accordingly, in order to secure higher information rents. The second phase corresponds partly to the increase in opportunity costs once the trees are high enough to be harvested. Land users adapt their bids to their increased opportunity costs.

The steady state reached over time describes what Williamson (1985) calls *the fundamental transformation*, predicted as well by Voigt and Bizer (2013) for repeated conservation auctions. Over time, the payments align and the agency re-contracts the same pool of land users. All contracted land users have bids close to their estimated bid cap, such that they believe that increasing their bids would compromise their participation in the conservation scheme. The budget constrained agency does not contract new-enrollers because re-enrollers have a comparative advantage. Because they already invested in the scheme, the value of their land is higher in terms of the provision of environmental services. Figure 5.10 shows the cumulative number of land users who reconverted their land in every period. In discriminatory auctions, re-conversion occurs only after trees can be harvested. Over time no additional units of land are re-converted, such that the same land users remain contracted in every period.

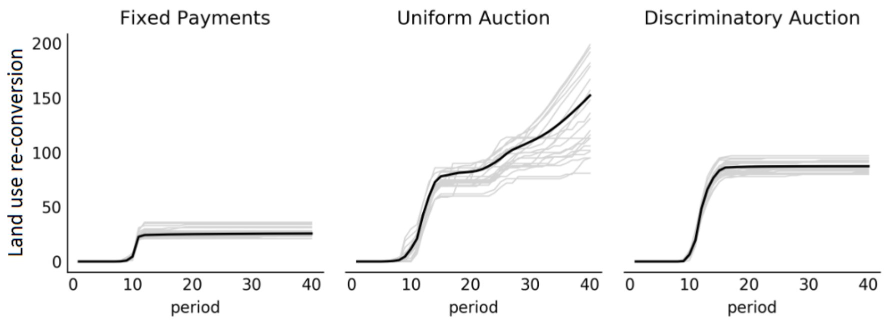

Figure 5.10: Cumulative re-conversion of land in short-term contracting

In uniform auctions conservation payments are very volatile. They remain constant during the first 10 years. Afterwards, they increase as a result of increased opportunity costs when trees become high enough to be harvested. This increase in conservation payments does not allow the agency to re-contract all land users again. Non-contracted land users re-convert their land if profitable. This is shown in figure 5.10.

As a result of the price increase in period 10, contracted land users expect higher future benefits from conservation. This in turn lowers their willingness to accept in the next period. Because all land users do so, the level of the conservation payments decreases, leading to a collective negative effect in terms of their information rents. This allows for budget availability, such that the agency agency can contract new enrollers for reforestation. This is reflected in the second increase in the number of conservation contracts in figure 5.8. We observe afterwards a slight increase in the level of conservation payments as a result of the lower expected future benefits from conservation. For some years, this leads to a rather stable number of conservation contracts on average (figure 5.8) and no re-conversion (figure 5.10).

Over time, the opportunity costs of those who reforested their land later increase as well as a result of the growth of the trees. We observe therefore the same effect again, however this time it is less strong because a smaller amount of land users is contracted in every period, compared to the first years of implementation. This rise in opportunity costs over time leads to an increased rate of re-conversion (figure 5.10). The dynamics are the same as before. We observe two effects. The first effect is a decrease in the level of uniform payments, resulting from the fact that reforestation contracts are allocated in almost every period. Those who reforested their land less than 10 years before face lower opportunity costs than those who are already incurring the opportunity costs of foregone firewood benefits. This decreases the conservation payments. The second effect is an increase in the uniform payment level as a result of lower expected benefits from conservation. However, the first one is higher because the share of early adopters is lower as a result of the high re-conversion rates. The contracting dynamics lead to a substitution effect, where old-enrollers are substituted by new ones.

While long-term contracts prevent land users from losing their quasi-rents, we observe some quasi-rent losses under short-term contracting. Land users only face quasi-rent losses under discriminatory auctions, as it is shown in figure 5.11. This occurs, however, only during the time where conservation implies higher opportunity costs, such that not all land users can be re-contracted with the fixed budget. High-cost non-contracted land-users re-convert their land, and low-cost non-contracted land-users face quasi-rent losses. The latter lower, however, their bids in the following round, such that they are re-contracted in further periods.

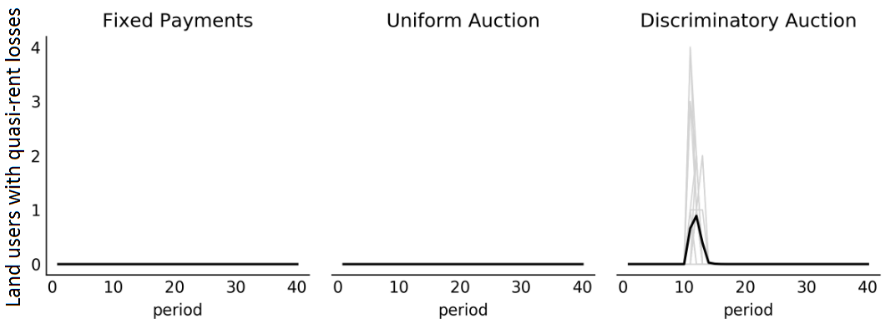

Figure 5.11: Quasi-rent appropriation in short-term contracting

These results explain why trust does not have a high effect on the cost-effectiveness of auctions (recall the sensitivity analysis for short-term contracting). In the absence of quasi rent appropriations, the reputation of the agency is not influenced negatively by the allocation dynamics (see figure 5.12). Although there are some quasi-rent appropriations after period 10 in discriminatory auctions (figure 5.11), the number of land users whose trust level increases is higher. This is the result of full compensation during the period where trees did not deliver any private benefits to the land users. Nevertheless, we observe a higher trust level in fixed payment schemes on average, compared to auctions (table 5.3). The reason for this are the higher re-conversion rates, that do not allow a full compensation of land users, which in turn does not allow those land users to experience a higher trust in the agency.

During the 40 years of implementation, the level of conservation payments that result from repeated auctions remains on average above the fixed level. Nevertheless, a higher number of conservation contracts is allocated through auctions. The reason for this is that no other land user is willing to invest in the scheme given the level of future conservation payments. All land users with opportunity costs lower than the fixed payment have invested already. This is why we see almost no reforestation in later periods (5.7). Conservation payments are higher in auctions. This increases the expected future benefits from reforestation. This is why more land users are willing to reforest their land. This implies that a share of the budget is not spent in fixed payment schemes.

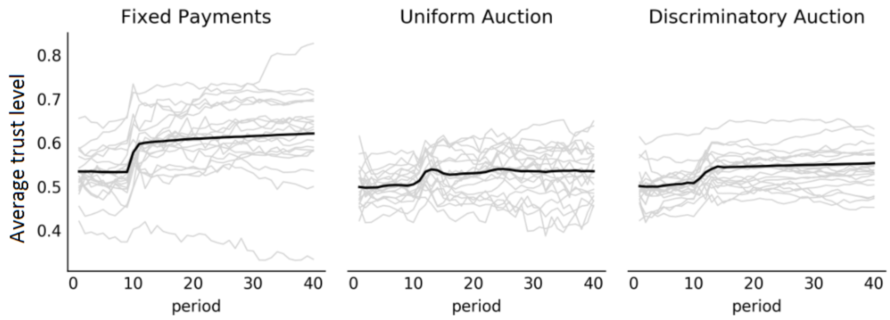

Figure 5.12: Reputation of the agency in short-term contracting

Compared to long-term contracting, short-term contracting results in higher conservation payments, and thus in a smaller number of contracts. However, higher payments result in higher incentives for compliance (figure 5.13). The share of land users not complying with the contract requirements is similar under discriminatory auctions and fixed payment schemes. Although uniform auctions result in conservation payments that are higher than the payments in the other allocation mechanisms (see figure 5.9), the share of non-complying land users is the highest. The reason for this is the fact that land users contracted in uniform auctions have higher opportunity costs on average. Although auctions target the land users with the lowest opportunity costs from crop production, after reforesting their land, these land users are not necessarily the ones with the lowest opportunity costs regarding the foregone benefits from firewood.

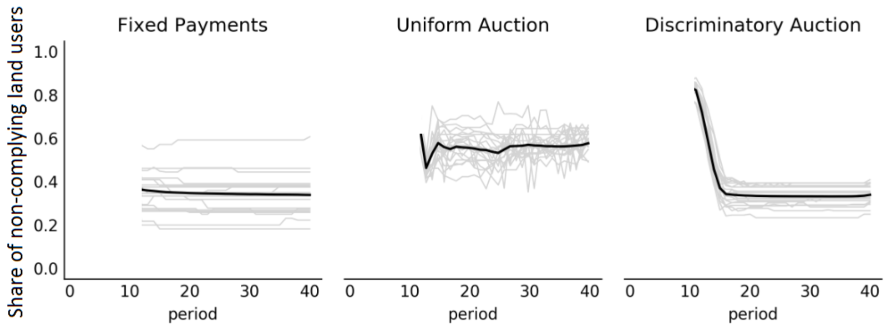

Figure 5.13: Non-compliance in short-term contracts

According to our results, discriminatory auctions provide the highest value of environmental services and the highest additionality, if short-term contracts are offered. The environmental value provided exceeds the one under fixed payments when long-term contracts are offered.

5.4 Discussion

In this study we investigated the potential of auctions to allocate contracts requiring specific investments. We considered long and short-term contracts for reforestation and further conservation of the trees, and we considered the use of uniform and discriminatory auctions as an alternative to fixed payments.

Our results show that land users with high time preferences are willing to enter into long-term contracts, even though their opportunity costs of conservation exceed the conservation payments implied in the contract, once the trees can be harvested. This leads to inefficiencies because land users who benefit more from the use of the trees for firewood than from conservation won't have an incentive to comply with the contracts. Non-compliance results in lower environmental services, and thus in a quasi-rent loss for the agency. Furthermore, these land users are not willing to re-convert their land back to crop-production in the absence of the payments, implying a low additionality. This might be especially true for non-complying land users in auctions, because auctions target the land users with the lowest costs. The lower the foregone benefits from crop-production, the lower the profitability of land-use re-conversion, and thus the lower the additionality of the conservation of those trees.

If long-term contracts are offered, fixed payments offer the highest additionality and the highest environmental value in the long-run. Auctions lead to conservation payments that are lower than the fixed ones, and thus to a higher number of contracts. However, almost all land users contracted under auctions have an incentive to cut off trees for firewood once the trees can be harvested for that purpose. Higher conservation payments in fixed payment schemes ensure a higher number of land users complying with the contract requirements in the long run. In order to reduce non-compliance, reforestation payments should not overcompensate land users. This would prevent land users with high time preferences from participating in the scheme, unless their opportunity costs would be covered by the payments ex post.

In the short run, auctions have a higher potential for cost-effectiveness, compared to fixed payments. Uniform auctions would be the most cost-effective mechanism to allocate contracts for reforestation and conservation, as long as the contracts would be offered during the period where land users do not have any benefits from reforestation. If however short-term contracts are offered, discriminatory auctions ensure a higher environmental value in the long run, because uniform auctions lead to high re-conversion rates and low compliance. Auctions allow contracting the land users with low-opportunity costs for reforestation. These however, are not necessarily the ones facing the lowest-opportunity costs of conservation once trees can be harvested, because the benefits from crop-production are not correlated with the benefits from firewood. Discriminatory auctions allow land users to adapt their bids over time, and to use the information gathered in order to increase their rents. This ensures a higher compliance.

Our results are framed by the data we use, and thus by the context in the region in Malawi, where the tree planting trial was implemented. Land users have very high time preferences, such that they would ask for rather low compensation payments in order to secure reforestation payments. High non-compliance rates result under long-term contracting. This would not be the case in settings where land users have lower time preferences.

Moreover, in this particular context, it would be the agency and not the land users who would face a quasi rent appropriation, because reforestation requires initial payments due to liquidity constraints. We only observe land users suffering quasi rent losses in repeated discriminatory auctions. The agency clearly suffers quasi rent losses from non-compliance and from re-conversion, the latter being a result of the allocation dynamics and not of opportunism.

To prevent non compliance, contracts have to be monitored and have to include sanctions that are high enough to make the expected net benefits from non-compliance become negative. In practice it is difficult to ensure contract compliance in long-term contracts. It is not always feasible to make land users reimburse payments in case of non-compliance. Moreover, payment schemes can face the dilemma of making participation attractive through higher initial payments, but of reducing leverage for contract compliance. Compliance can be enhanced through payments that are high enough to provide land users with the necessary incentives (Wunder & Albán 2008, pp.692-693).

Our results are also framed by how we modeled the bidding strategies of land users. If land users participating in repeated uniform auctions would be aware of the collective effect that would result from their adapted expectations about future conservation benefits, uniform auctions would not lead to a decrease of the level of the payments over time. However, in reality, knowing that all other land users might reduce their bids to ensure participation, there might not be any reason to risk participation by not lowering the own bid. Therefore, this problem might not be overcome in reality.

We did not take into account, that land users are likely to face uncertainty about their future opportunity costs. In this context trust would play an important role in their decision to invest in reforestation. Thus, social interaction and its effect on the reputation of the agency would play a relevant role as well. If crop prices are subject to volatility, so would opportunity costs of conservation be. The latter would have to be taken into account in the level of conservation payments if long-term contracts would be offered.

From this study we conclude that discriminatory auctions could be a cost-effective mechanism to allocate contracts in the presence of asset specificity if short-term contracts are offered. Long-term contracting through auctions is only cost-effective during the time when land users do not profit from reforestation. Long-term contracts should be allocated by means of fixed payments if land users have high time preferences. Fixed conservation payments in long-term contracts should be established at a level that does not compromise compliance. The latter might however be challenging given the presence of asymmetric information.

Appendix

Figures 5.14 and 5.15 show the number of contracts allocated, and the share of non-complying land users, under different assumptions on the level of discount rates, respectively. The higher the time preferences of land users, the more they discount future income, and thus the lower their willingness to accept for conservation. Figure 5.14 shows the results of the simulations, assuming the empirical values and assuming that all land users discount at rates equal to 10, 30 and 90 percent. As it can be appreciated in this figure, the higher the discount rates, the lower the willingness to accept for conservation. This leads to a higher number of land users willing to enter into a long-term contractual relationship for the offered fixed conservation payments. In auctions, it leads to lower bids and thus to a higher number of contracts allocated. Figure 5.15 shows the share of non-complying land users. This number increases with the discount rate. The higher the time preferences, the higher the likelihood of non compliance due to lower payments.

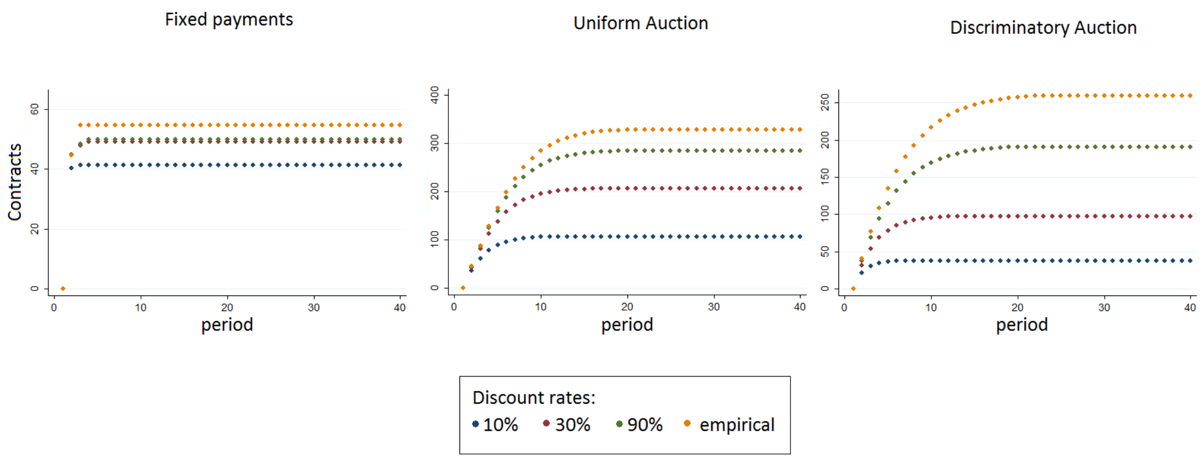

Figure 5.14: Number of long-term contracts for different discount rates

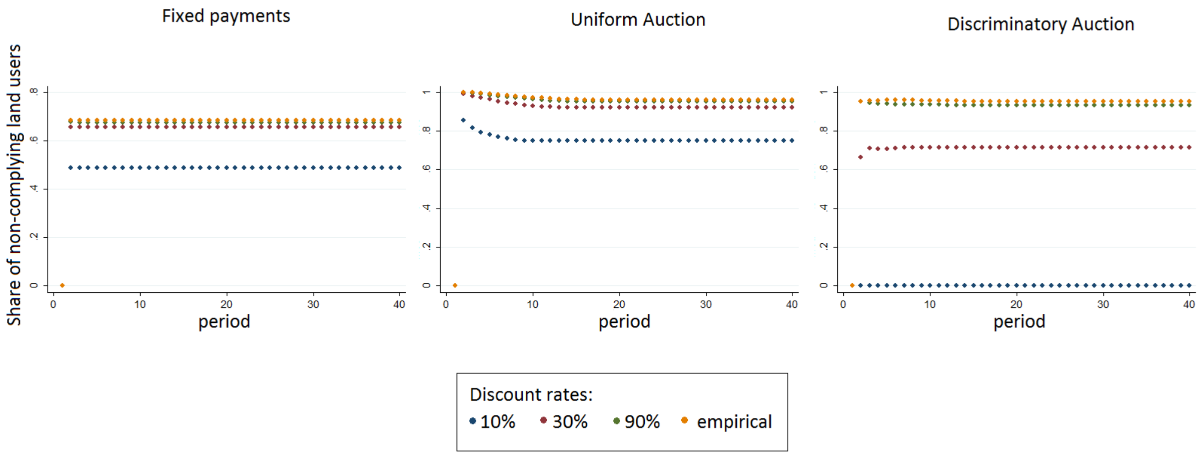

Figure 5.15: Share of contracted land users that do not comply under long-term contracting for different discount rates

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6

Conclusion

The purpose of this thesis was to study the use of auctions for the allocation of contracts in schemes of payments for environmental services (PES). Although auctions are claimed to increase the cost-effectiveness of payment schemes through the reduction of the rents paid to land users (Ferraro 2008, p.813), their performance is claimed to deteriorate if they are repeated over time. Bidders can learn and adapt their strategies in order to secure higher rents (Latacz-Lohmann & Schilizzi 2005, p.29). This does not necessarily mean that repeated auctions are less cost-effective than schemes with posted offers. Their rent-reducing potential is an empirical issue, and it can be tested through laboratory and computational experiments (Ferraro 2008, p.816).

Studies using laboratory experiments to investigate learning effects in repeated auctions include Cason and Gangadharan (2004), and Latacz-Lohmann and Schilizzi (2007). In other studies, repeated auctions are simulated by means of agent-based modeling, such as in Hailu and Schilizzi (2004), Hailu and Thoyer (2006, 2010), Hailu et al. (2010) and Lundberg et al. (2018). These models allow simulating interactions between bounded-rational heterogeneous individuals, such that the dynamics of repeated auctions can be analyzed (Hailu & Schilizzi 2004, pp.153-154). Although land users are likely to gather information from the experiences of their acquaintances in order to understand their possibilities to increase their own rents (Hailu & Schilizzi 2004, p.165), so far, Lundberg et al. is the only study considering learning effects to be a result of social interaction.

This thesis contributes to the literature by taking into account the role of social interaction in the use of repeated auctions to allocate payments for environmental services. Two types of environmental services were considered: biodiversity and carbon sequestration. The thesis analyzes how learning effects are framed by the structure of the social network, and their effect on the cost-effectiveness of biodiversity conservation. Furthermore, it addresses the use of repeated auctions in low-income countries, where payment schemes have the additional goal of alleviating poverty. So far, the use of auctions in low-income countries is only limited to a couple of trials with single-shot auctions (Jack *et al.* 2009; Jack 2010; Jindal *et al.* 2013; Narloch *et al.* 2013; Andeltová *et al.* 2014; Khalumba *et al.* 2014).

A further contribution of this thesis is the assessment of the use of auctions to allocate contracts requiring specific investments. Although many payment schemes require land users to make investments that are specific to the provision of environmental services, to date, only a couple of studies assessed the problem of asset specificity in this context. These studies include Ducos and Dupraz (2007), and Vogt and Bizer (2013). This thesis provides an analysis of the design possibilities that agencies have in order to overcome the problem of asset specificity, considering schemes where land users are paid for reforestation and further conservation of the forest. Moreover, it addressed the potential of auctions to allocate such contracts cost-effectively.

Three different agent-based models were built in order to simulate the allocation of contracts. In all three models, we integrated a small world network through which land users were able to interact with their neighbors and with land users they know from other neighborhoods. We implemented the Watts-Beta-Small-World Generator by Jung Project and Nick Collier, a graph generator using the beta-model, as proposed by Duncan Watts (1998). Social interaction allowed land users to optimize their strategies. The first model simulated a payment scheme for biodiversity conservation, through which the role of social interaction on the performance of discriminatory auctions was analyzed. The second model simulated a payment scheme for biodiversity conservation in a low-income country. Participants were assumed to be risk averse land users facing uncertainty about their future opportunity costs of participation. This model allowed us to analyze the use of repeated uniform and discriminatory auctions to allocate conservation contracts and their potential to alleviate poverty. The third model simulated a payment scheme for carbon sequestration, where participants were paid for planting trees on their land, and for conserving them afterwards. In this model, long- and short-term contracts were allocated by means of single-shot and repeated auctions with discriminatory and uniform pricing. The reputation of the agency was assumed to be framed by social interaction. We implemented the opinions model of Sun and Mueller (2012), through which land users exchanged information about their trust in the agency. This model includes empirical data from the tree-planting project implemented by Jack (2010).

Hailu and Schilizzi (2004) proposed that social interaction would increase the speed of learning, compared to settings were land users can only learn from their own experiences. This would imply that the performance of auctions would deteriorate faster (Hailu & Schilizzi 2004, p.165). However, this thesis shows that the cost-effectiveness of auctions does not necessarily deteriorate faster when bidders learn through social interaction. According to our results, social interaction can dampen the learning effects over time, as long as they remain conditioned to winning bids. During the first rounds, land users exhaust their rent-gaining possibilities, leading to an increase in the payments, and thus to a deterioration of the cost-effectiveness of the scheme. However, bidders might not have an incentive to change their bidding strategies, once their bids are close to their approximation of the bid cap, because this would imply risking participation. As long as land users' bids do not exceed their expected bid cap, payments will reach a steady state, and the cost-effectiveness of discriminatory auctions won't deteriorate any further. This means that, even in the presence of learning effects, repeated discriminatory auctions can outperform posted offers with fixed payments. The results confirmed that the cost-effectiveness of auctions increases with the level of competition among land users.

Auctions could be particularly interesting in low-income countries lacking properly functioning land, labor and credit markets, because estimating the opportunity costs of land users might imply additional challenges (Ajayi *et al.* 2012, p.3). However, there are concerns regarding the implementation of auctions in low-income countries. These include the claim that poor land users would receive lower payments, and that they might face highly uncertain opportunity costs (Ajayi *et al.* 2012, p.3). This could result in non-profitable bids (Khalumba *et al.* 2014, p.865), and thus in low compliance rates (Ajayi *et al.* 2012, p.9). Poor risk averse land users might see in conservation contracts an option to insure themselves against low profits. Therefore, they might be willing to accept low fixed conservation payments. This can lead to low compliance rates once uncertainty is resolved. Land users would not comply with the contract if their actual opportunity costs exceed the level of the payments. The results show that uncertainty and risk aversion do not necessarily play a role in the bidding strategies of land users in discriminatory auctions. Over time, bids become a function of the available information land users have regarding the bid cap. Bidders increase their bids as long as this does not imply risking participation. Thus, poor land users can secure higher rents over time, which has in turn a positive effect on compliance. However, our results show that uniform auctions lead to a higher compliance, and thus to a higher cost-effectiveness over time, compared to auctions with discriminatory pricing. Uniform auctions allow the agency to contract only poor land users, but at rather low rents.

Our results shows that repeated auctions can induce "pro-poor" effects, while providing biodiversity conservation cost-effectively. Given a fixed budget, uniform and discriminatory auctions can offer a higher level of biodiversity conservation than fixed payments even in the long run. While uniform auctions allow only for the participation of poor land users, discriminatory auctions promise higher rents for poor land users. These results are interesting for schemes in low-income countries, where there is concern that the goal of maintaining biodiversity can be in conflict with the goal of poverty alleviation (Adams *et al.* 2004, p.1146).

The presence of asset specificity in the provision of environmental services can act as a deterrent to participation in payment schemes. Asset specificity can imply a high risk for land users. If the investment is non-redeployable in an alternative use without losses, they would face the risk of losing their quasi-rents (Ducos & Dupraz 2007, p.7). Unless they are compensated ex ante, they could fear being harmed by opportunism. However, paying land users ex ante can imply losses in the agency's quasi rents. Because these payments would not be conditional on the provision of environmental services, they would not ensure their provision. In this context, trust plays an important role. Land users would agree to make specific investments in the absence of ex ante payments if they trusted the intentions of the agency to compensate them after the investment is made (Ducos & Dupraz 2007, p.23).

A literature review shows that long term contracts can allow the agency to overcome the problem of asset specificity. Long-term contracts provide land users with certainty about future compensation for their investment, when promises are not credible. Long-term contracts have to go hand in hand with incentives for compliance. Offering conditional long-term payments ensures compliance. Two aspects have to be taken into account when designing the contracts: whether land users face liquidity constraints, and whether they face uncertainty about the relative profitability of participation. In the presence of liquidity constraints, ex ante payments are necessary to finance the investment. However, monetary sanctions for non-compliance are not feasible in the presence of liquidity constraints, such that compliance has to be ensured through on-going result-oriented payments. The latter should compensate land users for their opportunity costs, but also for their maintenance costs.

If participants have high time preferences, schemes with fixed payments offer a higher cost-effectiveness and a higher additionality in the provision of carbon sequestration through long-term contracts (where participation implies asset specificity). Land users with high time preferences might accept low future conservation payments, in order to secure high initial reforestation payments. Whenever the payments for conservation do not exceed the benefits from non compliance, land users will have an incentive to use trees for firewood. This means, moreover, that non-complying land users' conservation would not necessarily be additional. They might not be necessarily willing to re-convert their land back to crop-production in the absence of payments. This is more likely in auctions targeting low-cost land users. Nevertheless, this thesis provides evidence for gains in cost-effectiveness through discriminatory auctions in short-term contracting. The results show that they allow land users to adapt their bids over time in order to increase their rents, ensuring thereby a higher compliance.

This thesis shows that learning effects, claimed to have a negative effect on the cost-effectiveness of payments, might actually be advantageous. Learning effects can allow agencies to provide biodiversity conservation cost-effectively, while alleviating poverty, whenever risk averse land users with uncertain opportunity costs are the potential participants of the scheme. The repetition of auctions allows them to secure rents that do not only improve their well-being, but that can also ensure their compliance. Learning effects were also proved to be beneficial in settings where land users with high time preferences are required to make specific investments. The repetition of auctions allow bidders to learn and thus to increase their rents. This leads to payments that exceed their opportunity costs once the trees are high enough to be harvested, leading to a higher likelihood of compliance. This implies that, in the presence of learning effects, repeated discriminatory auctions can still outperform uniform auctions and fixed payments under certain conditions.

The results are sensitive to different levels of competition among land users. The higher the level of competition among participants, the higher the cost-effectiveness of auctions but the lower the rents paid to the poor. The rents paid to the poor under discriminatory auctions increase with the level of uncertainty. Low initial bids allow many land users to win a contract. This increases the information flow in the network, leading to a steeper learning curve, and thus to higher rents for the poor. When contracts imply asset specificity, the results of repeated auctions are sensitive to interactions between the number of participants, the level of budget and the distribution of opportunity costs. The higher the heterogeneity among land users, the higher the benefits from the use of discriminatory auctions. If participants are likely to face low opportunity costs, uniform auctions allow contracting more land users, the lower the budget is, and the higher the number of land users. Nevertheless, the resulting low uniform payments could lead to non-compliance once trees can be harvested. If the opportunity costs of land users follow a normal distribution, discriminatory auctions can lead to a higher number of land users contracted the lower the smaller the budget. Compliance would not be compromised because repeated discriminatory auctions would allow land users to increase their rents over time.

The results are framed by the assumptions made in the models. As already discussed in previous chapters, the cost-effectiveness of auctions will always be dependent on the bidding strategies of land users. If low-cost land users increase their bids despite of not having information about higher accepted bids, the deterioration of the cost-effectiveness of auctions won't be dampened by social interaction. The implication for the implementation of repeated auctions in low-income countries would be a trade-off between the goal of alleviating poverty and the goal of biodiversity conservation. Increasing conservation payments would imply higher "pro-poor" effects but a lower provision of biodiversity conservation. In our study we assume that the provision of biodiversity conservation is homogeneous among participants. However, if the value of biodiversity conservation correlates positively with the provision costs, agencies could also face a trade-off between both goals and a low additionality, especially if uniform auctions are implemented. Our results show that discriminatory auctions can allow high-cost land users to participate in the scheme for relatively lower rents. This means that the highest rents would still be paid to the poorest land users, but also land users offering a higher additionality would provide biodiversity conservation. Another crucial assumption in our study is the positive correlation between wealth and provision costs, which allows for a "pro-poor" biodiversity conservation through auctions.

The gains in cost-effectiveness through auctions could be diminished by their administrative costs because they are more complex than fixed payment schemes (Ferraro 2008, p.814). So, although these study provides evidence for potential gains in cost-effectiveness through auctions, the transaction costs implied would have to be assessed. The differentiation of payments, rather than the use of fixed uniform payments might involve higher transaction costs. This might be especially the case in low-income countries where potential participants are not literate and are dispersed in remote rural areas (Ferraro 2008, p.818). In a scheme where land users offer different combinations of management options in their bids, contracts have to be heterogeneous. Devising a multi-criteria bid scoring system to include all dimensions of a bid is likely to involve high transaction costs (Latacz-Lohmann & Schilizzi 2005, p.xv). Moreover, auctions might also imply high transaction costs for land users. If these are fixed initial costs, they might prevent the poor from participating in the scheme (Latacz-Lohmann & Schilizzi 2005, p.10). The results of an outcome-based payment scheme in Germany showed that the transaction costs implied in formulating bidding strategies were relatively small in comparison to the payments (Latacz-Lohmann & Schilizzi 2005, pp.54-55). However, this result cannot be generalized for low-income countries, where payments are likely to be lower.

Despite the high transaction costs that auctions imply, the net gain could still be higher, compared to fixed payment schemes. One example is the BushTender pilot in Victoria, Australia, where transaction costs for the first auction round implied about 60 percent of the total amount spent. Transaction costs comprised on-site research, ecological scoring and auction administration costs (Latacz-Lohmann & Schilizzi 2005, p.xiii). A study showed that fixed payments would have been less efficient in that scheme than auctions, even allowing for some savings in transaction costs (Latacz-Lohmann & Schilizzi 2005, p.6). Moreover, because of the complexity of ecological systems, and thus all potential contingencies and eventualities, the transaction costs of a fully specified contract might be very high (Latacz-Lohmann & Schilizzi 2005, p.15). In this respect, the results about the performance of repeated auctions in the presence of uncertainty and asset specificity suggest that repeated discriminatory auctions could be more cost-effective than fixed payments. Repeated discriminatory auctions could not only reduce the burden of transaction costs implied in the specification of long-term contracts, but they could also ensure compliance and induce "pro-poor" effects in low income countries.

Further studies are necessary in order to assess the implications of land heterogeneity in terms of the value of environmental services, when schemes are implemented in low-income countries. The relevance of social interaction should also be further assessed for settings where participation implies asset specificity, and opportunity costs are uncertain. Even though more studies are necessary in order to assess the cost-effectiveness of auctions, as well as their potential to alleviate poverty, including the assessment of the transaction costs implied, this thesis provides evidence for potential gains through auctions. This thesis shows that learning effects in repeated auctions can induce higher rents for the poor, without compromising the provision of environmental services, especially if potential participants are risk averse land users facing uncertainty, or whenever they face high time preferences and participation requires specific investments.

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