ABSTRACT

JAMES, NATASHA A. Costa Rica’s Payments for Ecosystem Services Program: Understanding the Implications of Implementing Targeting Mechanisms and Procurement Auctions on Cost-Effectiveness and Equity of Participation. (Under the direction of Dr. Erin O. Sills).

Payments for ecosystem services (PES) programs make payments (in-kind or cash) to voluntary participants who follow agreed rules of natural resource management that are expected to generate ecosystem services valued by either a specific user or society at large. PES programs have been established in a variety of contexts to address environmental issues such as forest degradation, watershed management, and biodiversity protection. Implementing agencies may pay landowners to implement new conservation practices or to protect existing native ecosystems.

PES programs established by governments in developing countries often have objectives that stretch beyond just the provision of ecosystem services. Specifically, many have dual environmental and social goals of ecosystem service provision and poverty alleviation or rural development. The idea is that the providers of the ecosystem services are often relatively poor, and therefore could particularly benefit from a system that pays for those ecosystem services.

While PES programs been widely advocated for tropical forest conservation, there are barriers to creating a cost-effective program in practice. One such barrier is information asymmetries. In theory, a cost-effective program would pay landowners an amount equal to their cost of participation. However, participation costs are private information, making it difficult for implementing agencies to determine this cost for each landowner. This is one reason that many PES programs, including Costa Rica’s PSA program, pay a flat, per-hectare rate. This flat rate offers rents to landowners whose costs are low and potentially excludes landowners who could offer high value ecosystem services but have opportunity costs above the fixed rate.

This dissertation examines how changes in the PSA forest protection program over the past decade -- in the form of targeting for social and environmental goals -- and how potential changes, such as the introduction of a conservation procurement auction, have affected and could affect “cost-effectiveness”, or the environmental benefits captured per unit of expenditure, as well “equity”, or the distribution of contracts.

Over the past 10 years, the PSA program has implemented targeting through (i) differentiated payments that offer higher per-hectare rates where forests are expected to generate
higher value ecosystem services and (ii) scoring of application based on a matrix that awards points for both environmental and social objectives. The trends in contracts issued between 2005 to 2014 suggest that the targeting mechanisms may have had the desired effects on equity in participation. However, these targeting mechanisms do not directly address information asymmetries regarding the opportunity cost of participation.

To examine potential further changes to increase the cost-effectiveness of the PSA program, I develop agent-based models (ABMs) that reflect the structure of the program and use data on actual program participants to create the agents. I use these ABMs to examine the implications of possible auction mechanisms for the distribution of participation, informational rents captured by participants, and environmental benefits generated per dollar. Results show that a first price, discriminatory auction with targeting for both environmental and social benefits has the best combination of outcomes, including greater cost-effectiveness and more equitable participation. However, when agents in the model are able to learn the results of previous auctions and use this information to strategically increase their bids, the cost-effectiveness of the auction decreases over time. In all scenarios, auctions targeting for both environmental and social benefits do effectively award more contracts to landowners in the targeted categories.
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Costa Rica’s Payments for Ecosystem Services Program: Understanding the Implications of Implementing Targeting Mechanisms and Procurement Auctions on Cost-Effectiveness and Equity of Participation

by
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A dissertation submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

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APPROVED BY:

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DEDICATION

To my mother, Daniela Agnes Marcia James-Morian.
“All that I am, or hope to be, I owe to my angel mother”- Abraham Lincoln

To my first teacher and my father, Nicholas Arlington Morian.

To my most vocal cheerleader and my sister, Jenel LaToya Morian.
BIOGRAPHY

Natasha James was born in Brooklyn, New York to parents who immigrated to the United States from the small South American country of Guyana. As a child, Natasha always strived to learn more and do more. After learning something new, she would always ask her father if she was finally smarter than her older sister.

When enrolling in the University of Georgia, Natasha had every intention of becoming a pharmacist. However, early in her academic career she was offered the opportunity to conduct research in a molecular infectious disease lab focusing on the effects of anthropogenic changes to the environment on the Costa Rican song bird population. Although this was her first research experience, the opportunity turned her interests to the environment and she changed her major to Environmental Economics and Management.

After completing a summer program after her sophomore year in the Department of Forestry at North Carolina State University, Natasha knew that she would continue her studies. She completed her Masters of Science in 2013 and promptly enrolled in the Forestry PhD program. In her PhD program, her research took her full circle in terms of geography, as she studied payment for ecosystem services programs in Costa Rica. Focusing specifically on forest economics, she is striving to learn more, do more, and to continually contribute to her field of research.
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CHAPTER 1: Introduction

Payments for ecosystem services (PES) are advocated as a policy tool for promoting tropical forest conservation while reducing rural poverty in tropical forest regions. PES programs have been defined as “voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating off-site services” (Wunder 2015). Economists consider PES to be more effective, efficient and equitable than alternative approaches (e.g., command and control, or promoting new technologies and markets) (Wunder 2006; Pattanayak et al. 2010). Because payments are conditional on following “agreed rules of natural resource management,” PES are expected to be effective at achieving compliance. The efficiency argument is based on a Coasian view of PES as payments negotiated directly between beneficiaries and producers of ecosystem services, resulting in an equilibrium price and quantity that maximize welfare. PES programs are said to be equitable because rather than regulation, they offer incentives for voluntary participation by the relatively poor rural populations who manage natural resources.

While conditional payments, direct negotiations, and voluntary participation are characteristics of PES programs in theory, in practice PES programs often look quite different. For example, governments often administer PES programs, using public revenues to make payments on a defined per-hectare schedule to landowners who apply for the programs (Wunder et al. 2008). In this setting, there is no direct negotiation between beneficiaries and producers of ecosystem services to set prices, and no incentive to identify and pay for hectares that are at risk. Additionally, while rural landowners or managers do typically receive the PES, the combination of flat transaction costs per contract and flat payments per hectare may give an advantage to landowners with large parcels of land. They effectively face less transaction costs per hectare for their application, and receive a larger total payment if they place more hectares in the program. Thus, PES in the real world may be less cost-effective and equitable than expected by advocates.

As the first national PES system for tropical forest conservation, the Pagos de Servicios Ambientales (PSA) program in Costa Rica attracted much research and policy attention in the years following its creation in 1996. In particular, researchers focused on the forest protection program, which pays landowners a flat, per-hectare fee to conserve existing natural forest on their properties for a given number of years (5 or 10 in different years of the program). Researchers, donors, and the national auditor have all lauded the performance of the program
administrator, the Fondo Nacional de Financiamiento Forestal (FONAFIFO), in establishing contracts and making payments to landowners under this program, but criticized its design as “inefficient” (e.g. Hartshorn et al. 2005). More specifically, the concern was that the program design did not maximize the additional ecosystem services that can be achieved with a given budget, i.e. it was not cost-effective. The Costa Rican government responded to those criticisms, first by adding new sub-programs (protection of hydric resources and forest protection in conservation gaps) that make higher payments in areas where forest conservation is expected to generate more valuable ecosystem services, and then by changing the process of reviewing applications from “first-come, first-serve” to ranking based on priorities (as summarized in a matriz or Matrix).

While seeking to increase the cost-effectiveness of generating ecosystem services, the Costa Rican government would also like the program to contribute to rural development, e.g. through payments that make a significant contribution to the income of poor landowners (Ortiz et al. 2003). Rural development and poverty reduction are common goals of government-financed PES programs in developing countries, such as the Sloping Land Conversion Program in China and the National Programme for Hydrological Environmental Services in Mexico (Wunder et al. 2008). The coupling of environmental and social goals, and the potential for “win-win” outcomes, have been the focal point of many studies (Pagiola et al. 2005; Wunder 2006; Wunder 2008; Pascual et al. 2010; Porras et al. 2013; Pascual et al. 2014). However, analyses of participation in the PSA program have found relatively wealthy landowners with larger properties capture more of the program funds than relatively poorer landowners with smaller properties (Zbinden and Lee 2005; Porras et al. 2013), thus raising concerns about the equity of participation.

In the context of these dual environmental and social objectives, this dissertation presents three essays that examine how changes in the program over the past decade and how potential changes such as the introduction of a conservation procurement auction have affected and could affect “cost-effectiveness,” or the environmental benefits captured per unit of expenditure, as well as “equity,” or the distribution of participation. Data used in each chapter presented below was collected and assembled by the Costa Rican Institute of Technology in 2015. The spatial database included information on all new PSA contracts signed from 2005 to 2014, which included the type of contract, the location of the property, the size of the property, and the
number of hectares conserved in the PSA program. These contract data were obtained from applications to the program and FONAFIFO’s Integrated Project Administration System used to manage contract payment information. These contract data were combined with spatial secondary data on the Matrix components (Aguilar 2015). In addition, Chapter 3 and Chapter 4 use information about landowner’s opportunity costs. These opportunity cost estimates were constructed by Vega (2014) under a contract with FONAFIFO. Vega constructed opportunity cost estimates of participation in PSA for Costa Rica based on the productivity of land, accessibility to markets and services, and available infrastructure and public services.

The first essay (Chapter 2) introduces the concept of PES, explains the underlying theory, and describes common issues with implementation of this theory. Costa Rica’s PSA program is presented as a case study of the implementation and institutional evolution of a PES program with both social and environmental objectives. Using data on new contracts signed from 2005 to 2014, this case study examines the targeting methods implemented by FONAFIFO and presents a description of trends that provide some insight to answer the question: have the targeting mechanisms introduced by FONAFIFO successfully shifted the number of contracts awarded to forests in priority areas and targeted social groups? Theory proposes targeting mechanisms such as those implemented by FONAFIFO should increase cost-effectiveness and equity in participation. However, it is an empirical question whether the cumulative effect of these institutional changes actually shifted the distribution of contracts toward higher priority areas and disadvantaged landowners. This case study does not provide a statistical analysis to answer the question, but provides a description of trends that can inform future analysis. However, this trend analysis does test the hypothesis that there will be positive trends in allocation of contracts to targeted social groups and priority areas.

Chapter 3 examines the barriers to implementing PES in a cost-effective manner and proposes procurement auctions as a way to overcome those barriers. Focusing specifically on the issue of information asymmetries, this chapter makes the case for using procurement auctions to increase cost-effectiveness. I develop an agent-based model based on the structure and data from Costa Rica’s PSA forest protection program to answer the question: what are the implications for cost-effectiveness and equity in participation when an auction mechanism is implemented in an existing PES program? Auction theory suggests that both first price, discriminatory auctions and second price, uniform auctions will increase cost-effectiveness relative to fixed price systems.
However, when comparing the two types of auctions, the second price, uniform auctions have informational rents built into the auction mechanism. Therefore, this analysis tests two hypotheses: (1) either type of auctions will be more cost-effective compared to the first come, first served baseline and (2) the first price, discriminatory auction will outperform second price, discriminatory auctions.

Building on Chapter 3, Chapter 4 examines the barriers of implementing a PES program that allocates contracts using repeated auctions. In PES programs where procurement auctions are repeated, it is possible for participants to learn the winning bids from previous auction years. Landowners could then strategically use this information to increase their bids and thus, increase informational rents collected. In this chapter, I develop an agent-based model to answer the question: what are the implications cost-effectiveness and equity in participation when auction participants use information from previous auction results to bid strategically and gain information rents? Theory and limited empirical evidence suggest learning can lead to strategic behavior and that this can diminish the cost-effectiveness of the auctions over time. However, theory also suggest targeting for environmental benefits should increase cost-effectiveness. Therefore this analysis tests the hypothesis that strategic behavior to increase informational rents through learning will have a larger negative effect on cost-effectiveness in auctions without targeting compared to auctions with targeting.
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CHAPTER 2: Payment for Ecosystem Services: Program Design and Participation

Introduction

Natural ecosystems provide a variety of services, including the provision of fresh water, food, raw materials, climate regulation, as well as aesthetic beauty. However, between 1960 and 2000, two-thirds of these, often necessary, global ecosystem services were in decline (MEA 2005). Recognition of the value of these services and concern about negative anthropogenic impacts led to reinforced efforts to reduce ecosystem degradation and re-framing of those efforts as measures to secure the supply of ecosystem services.

Many ecosystem services are a positive externality supplied by nature that has no traditional market, and thus, no market value. Economic theory suggests that the degradation of ecosystem services is a result of this market failure (Bulte, Lipper, Stringer 2008; Pattanayak, Wunder, Ferraro 2010). Specifically, the concern is that the public value of services lost is often greater than the private returns generated by activities that degrade ecosystems. One way to correct this market failure is to create a mechanism that will internalize the cost of providing ecosystem services by having the users of ecosystem services pay the providers. This system has been deemed ‘payment for ecosystem services’ (PES) (Engel, Pagiola, Wunder 2008).

This article is presented in three sections. The first section of this article, discusses the theory of PES programs, focusing on how PES has been defined in both the environmental economics and ecological economics perspectives. This section also describes common characteristics of PES programs. The second section reviews implementation issues with translating the theory into practice. Because this approach has been advocated for conserving tropical forests, I focus on the implementation and participation of PES programs in developing countries (Muradian et al. 2010). The final section presents a case study of Costa Rica’s Pagos por Servicios Ambientales (PSA) program, the longest-running national PES program in a developing country. By highlighting the structure and institutional changes made over the 20 year existence of the program, this case study presents an example of a PES program adopting an adaptive management strategy in an effort to achieve its objectives. This case study examines the addition of new programs under the forest protection umbrella and the matrix scoring system, both targeting methods implemented by FONAFIFO to increase cost-effectiveness and equity in participation. Using data on new contracts signed from 2005 to 2014, this case study presents a
description of trends in contract allocation to higher priority areas and disadvantaged landowners over the time period of these changes.

What is PES?

Economists’ views of PES generally fall into two different camps. The first sees PES from the environmental economics perspective built on the tenets of the Coase Theorem. The second perspective relaxes many of the Coasian assumptions and has been labeled the ecological economics perspective (Farley and Costanza 2010; Tacconi 2012).

Environmental Economics

Much of the PES literature from the environmental economics perspective broadly defines ecosystem services as “the benefits people obtain from ecosystems” (MA 2005). As there often is no market for the ecosystem services benefits people receive, the environmental economics approach to PES programs builds on the conceptual foundation provided by the Coase Theorem which suggests negative environmental externalities can be reduced through voluntary, market-like transactions, as long as transaction costs are low and property rights are clearly defined (Pattanayak et al. 2010; Pascual et al. 2010). In the context of PES, the Coase Theorem suggests payments negotiated directly between beneficiaries and producers of ecosystem services could result in an equilibrium price and quantity that maximize welfare; thus creating an efficient conservation program (Martin et al. 2014).

PES Definition

The environmental economics approach based on this Coasian framework led to the earliest and most cited definition of PES (Tacconi 2012). Wunder (2005) defines PES as “a voluntary transaction where a well-defined ES (or a land-use likely to secure that service) is being ‘bought’ by a (minimum one) ES buyer from a (minimum one) ES provider, if and only if the ES provider secures ES provision (conditionality)”. This definition highlights five specific characteristics of a PES program. The first characteristic is that participation must be voluntary. Unlike the command-and-control approach to conservation, PES must be a voluntary transaction from the environmental economics perspective. Second, the ecosystem service being provided must be well defined, in the sense that it should be directly measurable (e.g. water quality). While in practice the ecosystem service may be provided by specific and measurable land management practices (e.g. retiring marginal agricultural land to reduce soil erosion), the PES is still considered to be for the ecosystem service. Third, there must be at least one buyer and one
seller, who agree that payments are delivered based on a conditionality agreement. In other words, the payment will only be awarded to the seller if the ecosystem service is provided (Wunder 2005). Although transaction costs are not explicitly addressed in the definition of PES programs, the environmental economics perspective does suggest that low transaction costs are necessary for buyers and sellers of ecosystem services to negotiate and reach an agreement that maximizes welfare. If transactions costs are greater for one party, then the cost of negotiation may be too high to reach an agreement that maximizes welfare.

*Rural Development and Poverty Reduction*

In addition to the provision of ecosystem services, the environmental economics perspective also addresses equity concerns. This is due to the fact that there is a high spatial correlation between areas that could supply ecosystem services and areas where poverty is high (Pagiola et al. 2005; Sunderlin et al. 2008). In addition, poverty can be a driver in leading communities to deplete their natural resources, which can lead to negative environmental externalities as well as long term losses (Bulte, Lipper, Stringer, Zilberman 2008). One example of this is the use of wood as a means of fuel. In poor communities where the only option for fuel is wood, communities can deplete their natural forest ecosystems. If the harvesting of firewood is done at an unsustainable rate, the availability of wood will decrease over time as well as the other ecosystem services the forests provides.

Due to the aforementioned connections between poverty and the provision of ecosystem services, the objectives for PES programs often stretch beyond just the cost-effective provision of ecosystem services. Many programs have dual environmental and social goals of ecosystem service provision and poverty alleviation or rural development (Tallis et al. 2008). The underlying principle is that if the providers of ecosystem services are poor or living in poverty, then it is only just for them to reap the financial benefits of providing ecosystem services to society. Additionally, in communities where poverty is the driver of ecosystem degradation, paying poor people to improve the management of their environment could increase the provision of ecosystem services both directly (by increasing the value of ecosystem services) and indirectly (by increasing income) (Bulte, Lipper, Stringer, Zilberman 2008). Thus, poverty alleviation could be both a mechanism and a positive externality of the PES program. The logical conclusion from the environmental economics perspective is that PES programs can be a
‘win-win’, simultaneously reducing negative environmental externalities and helping the poor (Muradian et al. 2010; Engel, Pagiola, Wunder 2008).

**Ecological Economics**

The ecological economics perspective also acknowledges the role of market failure (i.e. the lack of a market for ecosystem services) in the degradation of ecosystems and the services they provide. However, this perspective offers a different definition of ecosystem services and understanding of how PES could correct market failures.

**PES Definition**

From the ecological economics perspective, ecosystem services are generated from stock-flow resources such as trees and are thus “fund services.” For example, reduced soil erosion is a result of the increased presence of trees, but it does not result in the physical transformation of the trees (Farley and Costanza, 2010). From this perspective, many PES programs are paying for the ecosystem funds (e.g. trees) rather than the ecosystem service itself (e.g. reduced soil erosion). Thus, PES is defined as the “transfer of resources between social actors, which aims to create incentives to align individual and/or collective land use decisions with the social interest in the management of natural resources” (Muradian et al. 2010). PES programs can vary along three axes according to the ecological economics approach. The first axis is how funds for the economic incentives are generated and determined. All PES programs offer economic incentives, but they may be generated through market-like transactions or through other structures, such as public subsidies. The second axis is the directness of transfer between the buyer and seller of ecosystem services. Essentially, this measures the degree of mediation between buyers and sellers of ecosystem services (Muradian et al. 2010; Tacconi 2012). Muradian et al. (2010) note “the most indirect situation would be then when the State represents buyers, there is one intermediary between the State and providers and the latter do not receive individual payments for their individual environmental protection efforts”. Ideally, PES programs should ensure a direct transfer of benefits to those providing ecosystem services, to ensure the individuals providing ecosystems services are compensated for their efforts. The final axis is commodification, or the degree to which the ecosystem service can be measured. While from an environmental economics perspective, this is a requirement, the ecological economics approach recognizes that the ability to measure ecosystem services varies along a spectrum from services
can easily be measured (like carbon) to those that are much more subjective and therefore difficult to measure (like aesthetic beauty) (Muradian et al. 2010; Tacconi 2012).

Rural Development and Poverty Reduction

Similar to the environmental economics approach, the ecological economics approach acknowledges the connection between the provision of ecosystem services and the poor. However, proponents of the ecological economics perspective note that the environmental economics perspective creates a distinct separation between the cost-effectiveness of the program and equity concerns, such as poverty alleviation. In the environmental economics perspective, poverty alleviation is essentially a positive externality of market-like transactions that may benefit the poor (Muradian et al. 2010). Conversely, the ecological economics perspective is that poverty alleviation and ecosystem services are not separate, but intertwined. Especially in developing countries, it may be difficult to present equity and poverty alleviation as externalities and those implementing PES programs in these countries are often faced with the need to meet both the social and environmental goals simultaneously (Muradian et al. 2010).

Additionally, the environmental economics approach notes that in some contexts, participation in PES programs may not be voluntary. When PES programs are managed by the government, users of ecosystem services (e.g. the public) may be taxed to provide funds to pay ecosystem service providers. In such a situation, participation on the part of the public may not be voluntary (Tacconi 2012). The voluntary nature of PES programs could also be examined in the context of offering payments to the poor. It is possible that the poor may not be in a position to refuse payments due to their status. Therefore, PES payments in these situations raise concerns about whether poor landowners agreeing to participate in the program are doing so voluntarily with free agency, or if this is essentially a forced trade (Muradian et al. 2010).

PES Program Characteristics

The environmental economics perspective and the ecological economics perspective differ in their definition of ecosystem services and PES, including what is required for a program to meet the definition of PES. However, despite differences on the specifics, both perspectives accept the same general framework for PES: there must be (1) buyers, (2) sellers, and (3) a defined level of management to generate the desired ecosystem service.
Buyers

The buyers of ecosystem services can fall on a spectrum of two extremes based on the financing of the PES program. In a user-financed PES program, the buyer of the ecosystem service is the actual user of the ecosystem service (Engel, Pagiola, Wunder 2008). An example of this would be a group of farmers who live downstream, paying the farmers who live upstream to reduce emissions of pollutants into the water. The second category is a third party buyer acting on behalf of service users. The third party can be a government agency, non-governmental organization, international donor, or some combination thereof (Engel, Pagiola, Wunder 2008; Tacconi 2012).

Sellers

Engel, Pagiola, and Wunder (2008) define the sellers of ecosystem services as those who “are in a position to safeguard to the delivery of the ecosystem service”. Generally, sellers in PES programs are private landholders or communities with communal property rights to land.

Generating Ecosystem Services

In PES programs, the buyer and seller of ecosystem services agree on a payment (cash or in-kind) that will be made when and if the ecosystem service is generated. PES programs are categorized by the objective of the program. The first type of PES program pays for changes in land management that reduce pollution, such as the reduction of animal waste in streams. The second type of PES program pays for change in land management that generate environmental amenities that are public goods, e.g. planting trees to sequester carbon or generate aesthetic. There are also programs that pay for the conservation of existing natural resources (Bulte, Lipper, Stringer, Zilberman 2008). One example of this is Costa Rica’s Pagos por Servicios Ambientales (PSA) forest protection program, which pays landowners a flat, per-hectare rate to conserve forests on their private land.

To achieve the objectives stated above, PES programs usually require the sellers to implement some level of land management to generate the desired ecosystem services. For PES programs that require land diversion, the program pays ecosystem service providers to convert their land from one use (usually agriculture) to other land uses that will generate the desired ecosystem service. In contrast, working land programs require the implementation of new management practices, such as the decreased use of chemical pest controls to reduce harmful
impacts to the natural biodiversity (Bulte, Lipper, Stringer, Zilberman 2008; Zilberman, Lipper, McCarthy 2008).

**Cost-effectiveness Concerns**

Over the past 20 years PES programs have grown in popularity in developing countries (Pattanayak, Wunder, Ferraro 2010; Wegner 2015) and there have been several reviews of PES programs in developing countries (e.g., Bulte et al. 2008; Neef and Thomas 2009; Rebelo 2009; Robalino and Pfaff 2013). In many of the PES programs in developing countries international donors provide a great deal of funding. For many of these donors it is imperative that the programs being funded are meeting the program objectives in a cost-effective manner. However, some reviews have highlighted the lack of cost-effectiveness in some PES programs. Many of these issues stem from the principal-agent problem.

**Principal-Agent Problem**

Applying principal-agent theory to PES, the agent is the seller or the landowner and the principal is the buyer or the institution implementing the PES policy. The principal’s goal is to maximize conservation activity (i.e., hectares of forest conserved) for a given budget (Platteau 2000). The agent’s goal is to conserve land and/or receive incentives for doing so. To apply this theoretical framework to PES, I use the typology of agents established by Persson and Alpizar (2013):

A — those who apply for payments, but would conserve with or without payments

B — those who apply for payments and will not fulfill the conditions of the policy intervention without payments

C — those who do not apply for payments but will meet the conditions regardless (due to the fact that they are already fulfilling or planning to fulfill the conditions)

D — those who do not apply and will not meet the conditions

However, there could be an agent who applies for a program, but will not or cannot fulfill the conditions of the contract. For the sake of completeness, this article adds a fifth agent:

E — those who apply for payments, but will not fulfill the conditions of the policy

For any given PES program (with specified conditions and payment level), the agents know their own types, but this is private information. Gathering the information required to
determine each agent’s type is costly (in both time and money) for the principal and thus agents are typically allowed to self-identify. This information asymmetry and the interactions between the types of agents can decrease the cost-effectiveness (and hence efficiency) of PES programs through decreased additionality, inability to impose conditionality, and spillover effects.

**Additionality**

PES programs are often criticized for limited additionality. In the context of PES, additionality means that payments should generate additional ecosystem services above and beyond the services that would have been generated without payments. Additionality is considered to be a fundamental requirement of climate change mitigation policies by ensuring a policy is meeting the conservation targets with economic efficiency. From an economic standpoint, it is seen as inefficient to pay to conserve land which would have been conserved in the absence of the policy intervention (Bennet 2010; Alpizar et al. 2013). To meet the strictest definition of additionality, only Type-B agents can be included in interventions (Norden et al. 2013).

Adverse self-selection occurs when Type-A agents “pretend” to be Type-B agents. This is possible because of information asymmetries (the agent’s type is known by the agent but not the principal) and is particularly easy when the agent is not currently meeting the PES conditions but plans to. Thus, the principal’s inability to distinguish between these types of agents can be problematic. If the principal erroneously accepts too many Type-A agents into the program, additionality can be substantially diluted (Norden et al. 2013; Moon et al. 2012).

**Conditionality**

In many PES programs, the participating agents are bound by contract to implement a management plan that is expected to generate ecosystem services. Both the environmental economics and ecological economics perspective place some emphasis on the conditionality of payments. In other words, payments should only be rendered to the ecosystem services provider if the management plan is implemented and the ecosystem services are generated. To determine if an ecosystem services provider is compliant with the contract and management plan agreed upon, some level of periodic monitoring is necessary.

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1 More specifically, additionality is key to the integrity of carbon offset mechanisms that are designed to help meet targets for reductions in net carbon emissions
However, there are times when an agent is not able or not willing to meet the conditions of the contract. This Type-E agent is difficult to identify due to the fact that an agent could self-identify as a Type-B agent or circumstances could create a condition where a Type-B agent cannot comply and becomes a Type-E agent. In both cases, these agents should not receive payments under the conditionality requirement. Yet, Wunder (2007) found that PES programs in developing countries often fail to impose this conditionality requirement. In some programs, payments were made upfront and on good faith that the ecosystem services providers would comply. One possible reason is that program implementers recognize that monitoring and withholding payments would strain their relationships with landowners (often poor and rural) that participate in the program (Wunder 2006). In other programs where monitoring was supposed to occur, monitoring was either done infrequently or not done thoroughly. This may be due to the fact that monitoring can be expensive, especially of criteria that cannot be easily observed via remote sensing (FAO 2004; Farley and Costanza 2010).

**Price and Behavioral Spillover**

Most analyses of PES focus on the behavior of the agents participating in the program. Those who participate are under contract to either conduct or forego some activity on their land. Agents who are generating ecosystem services but are not participants are not obliged directly by the PES principal to maintain their land management regime.

The introduction of a PES program creates a new dynamic between participants and non-participants within a community. As budgets for these programs are limited, there will almost always be some members of the community who apply for, but are not awarded PES contracts. There will also be members of the community who will not apply to the program. These non-participants may still be subject to spillover effects of the program operating through two channels: prices and behavior.

Price spillover may occur when the introduction of a PES program changes the price of a particular resource. To demonstrate how this can occur, consider a simple example of a forest preservation PES program being implemented in a closed economy with Type-B agents (those who apply for payments and will not fulfill the conditions of the policy intervention without payments) and Type-D agents (those who do not apply and will not meet the conditions). The Type-B agents apply and some are selected to receive payments to set-aside and not harvest timber from their forestland. As illustrated in Figure 1, a decrease in supply (assuming demand
for timber does not change) results in an increase in timber prices. The rejected Type-B agents and the Type-D agents may increase harvest to benefit from the increase in timber price. Thus, it is possible that in areas isolated from the broader market, the introduction of PES will cause a shift in harvesting to other properties rather than a reduction in timber harvesting, resulting in a lower-than-estimated net conservation (Alpizar et al. 2013, Norden et al. 2013).

PES could also have spillover effects through behavioral channels. For example, non-participants may feel slighted due to their exclusion from the program. One example of behavioral spillover is the crowding out of intrinsic motivations. Again consider a forest preservation PES program, but in this community there are Type-B agents (those who apply for payments and will not fulfill the conditions of the policy intervention without payments) and Type-C agents (those who do not apply for payments but will meet the conditions regardless). When Type-B agents are selected for participation in the program and receive payments, it is possible Type-C agents may feel slighted. It may be deemed unfair to pay some members of the

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2This does not imply that overall harvesting increases, only that the expected net conservation may be overestimated.
community to implement land management practices that others have always implemented. This could lead to crowding out of the motivations that led Type-C agents to implement conservation land management practices. Thus, this behavior spillover could lead to increased degradation of forest that was previously protected because Type-C agents feel unfairly treated (Alpizar et al. 2013; Norden et al. 2013).

In a field experiment involving Costa Rican landowners, Alpizar et al. (2013) tested how exclusion from incentives due to previous behavior would impact future behavior. In a two round, dictator game participants were given a sum of money that could be donated to an environmental group. If the initial donation was above a certain amount, the landowners were excluded from incentives for their second contribution. The results showed that the contributions of those who were excluded due to positive behavior in the past, declined significantly. Those who did receive the incentive, increased their contributions. These results are a prime example of how sorting agents into participants and non-participants can affect additionality: in this case, small contributors were participants in that they received incentives to increase their additional contributions, but this caused the large contributors (the non-participants) to decrease their contributions. The increase in contributions may be offset by the decrease in contribution due to behavioral spillover.

Together price and behavioral spillovers can reduce the effectiveness of PES across the entire landscape, even when payments effectively increase the compliance with conditions on the individual parcels of participants. These spillovers may shift the undesired activity to other areas or even to neighboring parcels, or postpone them to a future time. However, Alpizar et al. (2013) is one of only a few studies that consider the behavior of non-participants in PES programs.

**Poverty Reduction Concerns**

PES was originally advocated as a cost-effective way to achieve conservation, but part of its appeal was also the possibility that it would contribute to rural poverty alleviation by offering payments rather than imposing restrictions on poor rural suppliers of ecosystem services (Ferraro

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3 Landowners were given a total of 5,000 colones ($10 US) to donate to an environmental program to conserve forests. In the first round, all landowners were given the option to donate all, some, or none of their endowment to the conservation program. In the second round, another 5,000 colones was endowed to the participants and an incentive was introduced: half of the second contribution would be returned to the landowner. However, those who contributed more than 1000 colones were excluded from receiving the incentive.
and Kiss 2002). Further, many institutions that implement PES have social as well as environmental goals. National level PES program in developing countries such as China, Mexico, Vietnam, South Africa, and Costa Rica all employ some level of pro-poor targeting to ensure payments are being distributed to ecosystem service providers who are poor (Wunder 2008).

Some PES proponents argue that introducing social objectives will negatively impact the program’s cost-effectiveness at achieving conservation (Wunder et al. 2008). Others note that a PES program that does not take equity into consideration or leads to an unfair distribution of benefits has little chance of being accepted by both ecosystem service sellers and buyers (Kinzig et al. 2011; Muradian et al. 2010).

Nonetheless, the intertwining of the social and environmental goals raises questions about the implications for equity once PES programs are implemented. According to Pascual et al. (2014), there is growing concern that the focus on the cost-effectiveness of PES promised by theory comes at the expense of attention to the social equity dimensions of PES. Although equity is not a central concern of many traditional and sometimes effective conservation policies, such as protected areas and other command and control measures, Pascual et al. (2014) note that “it is increasingly accepted that integrating social considerations into environmental management planning is instrumental to achieving more-robust ecological outcomes”.

Equity can be defined as the “distribution of socio-economic factors and goods in a society according to an agreed set of principles or criteria” (Corbera et al. 2007). This suggests that one key equity issue in PES programs is who gets to participate. Following Brown and Corbera (2003), the term equity consists of three elements: equity in access, equity in decision-making, and equity in outcome. The following sections describe equity in access by examining barriers to participation and discuss equity in outcome by providing empirical evidence on the distribution of participation in PES programs.

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4 Equity in decision making is the way in which projects operate and the ability of stakeholders to have a voice in the process (Brown and Corbera 2003). While this is an important aspect of equity in any PES scheme, this essay focuses on how differential payments and targeting affect the other two dimensions of equity: access and outcomes.
Equity: Barriers to Participation

Equity can be examined in the context of access to the PES market and barriers preventing access to the market. These barriers include high transaction costs and insecure land tenure.

Transaction Costs

When participation in a PES program is voluntary, landowners seek to participate when participation makes them better off. Essentially, the landowner will only participate when their expected gains from participation (including the payment), covers their opportunity and transaction costs. McCann et al. (2005) define transaction costs as “the resources used to define, establish, maintain, and transfer property rights”. Transaction costs for PES sellers, who are often landowners, are determined by various factors including what legal paperwork is required, negotiation of the PES contract, and any costs that they must bear for assessment and monitoring of ecosystem services (Tacconi 2012).

Transaction costs can have a significant impact on whether a landowner will participate in a PES program. In particular, large up-front transaction costs can be a barrier to participation for cash-constrained landowners. When transactions costs have a large fixed component per property or per contract, they are higher per-hectare for properties enrolling a relatively small amount of land compared to properties enrolling a large amount of land (Heimlich 2005). Thus, transaction costs can become a barrier to poorer owners of smaller properties, resulting in inequity in access to the PES market (Wunder 2008; Zbinden and Lee 2005).

Land Tenure

PES programs often limit participation to landowners with some form of formal land tenure (Grieg-Gran et al. 2005). In many developing countries, poor landowners and smallholders generally have some form of informal land tenure rather than formal land titles. Thus, PES programs that require formal land tenure tend to exclude poor landowners and smallholders (Wunder 2008; Zbinden and Lee 2005).

Equity: Distribution of participation

Equity of outcomes is directly influenced by the equity of access and focuses on the distribution of project outcomes, which could be considered to include direct payments (Brown and Corbera 2003). Due to the interest in poverty alleviation and in fair compensation to poor
ecosystem service providers, the distribution of participation is often judged by the percent of participants from disadvantaged groups, including poor and smallholder households.

Overall, the evidence for equity in outcome for PES programs has varied (Wunder 2008; Calvet-Mir et al. 2015). In a PES program in Nicaragua that provides payments to landowners to adopt silvopastoral practices, program evaluations found that there was substantial participation by poorer households in the first two years compared to non-poor households (Pagiola et al. 2007). Conversely, program evaluations for PES programs in Costa Rica and Madagascar, found some evidence that poor individuals were less likely to participate than individuals with high incomes (Zbinden and Lee 2005; Porras et al. 2013; Sommerville et al. 2010). Also, there is evidence that the type of PES program could have some impact on whether the poor are likely to participate and benefit from payments. In a land diversion PES program, the poor are only likely to benefit when they have marginal agricultural land, but the potential ecosystem service provision is high. Otherwise, larger landowners often reap the benefits of land diversion PES programs (Zilberman, Lipper, McCarthy 2008).

PES programs can also have indirect effects on smallholders who supply off-farm labor: diversion programs may reduce the demand for labor, while working land programs may increase the demand (Zilberman, Lipper, McCarthy 2008).

**PES in Practice- Costa Rica Case Study**

As the longest running PES program in the developing world, a great deal of research has been conducted on Costa Rica’s Pagos por Servicios Ambientales (PSA) program, most focusing on the first ten years of the forest protection sub-program. The initial design of this program has been criticized as lacking cost-effectiveness, based on impact evaluations that show only small effects on the area of forest being conserved, and being inequitable, based on participation biased towards relatively wealthy landowners with large properties. In the wake of these criticisms, the program administrator, the Fondo Nacional de Financiamiento Forestal (FONAFIFO), has implemented several changes to improve the program through targeting for both high priority areas of ecosystem services and to disadvantaged landowners.

As the PSA program is the oldest PES program in the developing world, it was chosen as a case study to provide specific context for many of the general concepts previously presented in this article, as well as illustrate the institutional changes that have occurred over the life of this program to meet the goals of ecosystem services provision and poverty alleviation.
This case study begins with an overview of the first decade of PSA, focusing on the forest protection sub-program, which is the focus of most of the published literature on PSA. I then review common criticisms of the forest protection program, and the resulting institutional changes—specifically differentiated payments introduced in 2009 and a system for ranking applications introduced in 2011. Finally, this case study relates these criticisms and institutional changes to trends in program participation over time, considering both where contracts are allocated in terms of priority areas and who participates.

Pagos por Servicios Ambientales

In the 1970’s there was growing concern that Costa Rican timber supplies were declining. In response, this led to programs that used tax rebates to provide incentives to increase the number of timber plantations. These tax incentives were expanded in 1986 to include other landowners beyond large companies. In 1995, the Forest Protection program was created which contributed to over 150,000 hectares of forest being conserved (Pagiola 2008; Zbinden and Lee 2005).

These programs established a precedent for PES, and in 1996, PSA was created through Forestry Law 7575, which recognizes four ecosystem services made available by forests: carbon fixation, watershed protection, biodiversity protection, and the protection of natural forest ecosystems located in life zones of particular interest (Castro et al. 2000). Because these services have no traditional markets, the law introduced a system of direct payments to reward landowners for the environmental services their forests provide (Phillips 2006). The payments are based on contracts that require either protection of existing forest or the establishment of new forests (including plantations and agroforestry systems) in all or portions of properties. The exact level and distribution of payments, as well as the requirements for landowners, vary across programs of PSA. As of 2014, there were fifteen programs, with the largest budgets for various reforestation and forest protection programs.

Forest Protection Program (Prior to 2011)

In terms of the number of contracts, the forest protection program is the largest sub-program in PSA. The forest protection program pays a flat, per hectare fee to conserve and protect forest resources and the ecosystem services they provide. The payment levels were based on studies conducted by the Tropical Science Center (TSC) in San Jose, Costa Rica. TSC
analysts calculated per hectare values for the four ecosystem services\(^5\) mentioned in Forestry Law 7575 for both primary and secondary forests. For primary forests, the value of these ecosystem services ranged from $29 to $87, and $21 to $63 for secondary forests (Castro et al. 2000). However, according to Castro et al. (2000), “the regulatory strategy does not oblige the government to compensate landowners differently for each individual service.” Therefore, rather than calculating compensation for individual contracts, which would be burdensome, a uniform per-hectare payment is paid to all landowners under contract (Castro et al. 2000). At the end of the contract period, landowners were given the option to reapply for participation in the program.

**The Budget and Application Process**

The forest protection program is mainly funded through revenues from a fossil fuel sales tax. From 2001 to 2005, the program also received support from a loan provided by the World Bank and a grant provided by the Global Environment Facility (GEF). Additional funding is provided by the *Instituto Costarricense de Electricidad*, a government run electricity and telecommunications provider, and KfW, a German development bank (Pagiola 2008; Sanchez 2015).

Prior to 2011, the national FONAFIFO office would establish a budget ceiling for each regional office based on the historic, regional allocation of forest protection contracts. The regional offices then dispersed contracts on a “first-come, first-served” basis. As the demand for contracts was often higher than the budget, FONAFIFO would accept contracts until their allocation was exhausted. If the budget in one region was exhausted before others, a re-allocation of funds could be considered (Sanchez 2015).

To submit an initial application for a forest protection contract, a landowner has three options: (1) file an application for themselves, (2) file through a registered forester, or (3) file through an intermediary organization (IO). Once the application is screened against legal requirements, the landowner must submit further technical information, which requires the expertise of a registered forester to develop, certify, and register a forest management plan with FONAFIFO. While the initial application is free, the technical assistance of the forester is often associated with a fixed fee (Chacon 2015). The foresters and IOs that help landowners through

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\(^5\)Carbon fixation, watershed protection, biodiversity protection, and the protection of natural forest ecosystems located in life zones of particular interest.
the application process receive a maximum of 18% of the contract value in payment for their services (Chacon 2015; Matulis 2016). While some organizations and foresters may charge less, there is some evidence foresters can also charge more (Matulis 2016).

**PSA Forest Protection Program Critiques**

Attracted by the first national-scale and long-term implementation of the PES concept, numerous analysts have evaluated the PSA forest protection program, often focusing on forest cover in the area under contract as the outcome (Sánchez-Azofeifa et al. 2007; Robalino et al. 2008; Robalino and Pfaff 2013; Miranda et al. 2003; Zbinden and Lee 2005; Arriagada et al. 2012). The findings of these studies are summarized below.

**Impact Evaluations**

Numerous studies have been conducted to determine the impact of the PSA forest protection program and the efficiency with which it increases forest cover. At the landowner level, a survey conducted by Zbinden and Lee (2005) in northern Costa Rica found that PSA participants had 61% of their farm under forest while compared to 21% for non-participants. However, Miranda et al. (2003) found that many PSA participants in the Huetar Norte Region noted they would have protected their forests even in the absence of payments. To account for self-selection into the program, Arriagada et al. (2012) applied matching techniques to survey data from participants who signed contracts in 1997 and 1998 and non-participants in the same region. They found that issuing a PSA contract on a farm led to a 10% to 15% increase in forest cover on the farm.

When examining forest cover at larger scales the results are mixed. Sills et al. (2006) found that from 1997 to 2000 PSA had a significant positive impact on mature forest cover. However, when examining deforestation rates from 1997-2000, Sanchez-Azofeifa et al. (2007) found deforestation rates were not significantly lower in areas that received payments compared to those that did. Similarly, Robalino et al. (2008) found that forest protection contracts in place from 2000 to 2005 only mitigated the deforestation on about 0.4% of the parcels enrolled. Another study also showed that during the 1997 to 2000 time period, the PSA program only had a 0-0.002% impact on forest cover (Robalino and Pfaff 2013).

While some studies have found that PSA has little impact on forest cover, it is important to note one key reason for this is that deforestation rates were already low prior to the implementation of PSA (0.06% per year in the period from 1986 to 1997) and it is therefore, and
it is difficult to disentangle the impacts of PSA from the impacts of prior programs (Robalino et al. 2008).

**Cost-effectiveness**

The most consistent critique of the PSA program has been low additionality. However, additionality can be defined in several different ways. The impact evaluations in the previous section have assessed additionality in terms of forest cover. However, this case study will adopt the more standard definition of additionality. In the case of PSA, additionality means that a contract results in more ecosystem services provided by the participating property than would have been the case without the PSA contract.

A fundamental reason often cited for low additionality in PES programs is information asymmetries, which allow for adverse self-selection. The landowner’s planned land use without PES and therefore his opportunity cost of participation in PES is private information, creating an information asymmetry with the program administrator. Implementing agencies typically do not have enough information to determine the opportunity cost of each landowner, given constraints on data collection budgets and the landowner’s incentive not to reveal this information (Chan et al. 2003; Ferraro 2008). This is one reason that PES programs in developing countries typically pay landowners an undifferentiated (flat) per-hectare fee for participation. The combination of a flat rate payment and adverse self-selection means that participants in the program can capture substantial informational rents. Participants whose costs of participation are lower than the payment levels, including those who would have conserved forest in the absence of payments and thus face zero opportunity cost, will self-select into the program. These landowners with opportunity and transaction costs below the payment level extract informational rents (Ferraro 2008; Deng and Xu 2015; Salas et al. 2012). Informational rents are often considered a source of inefficiency, in that the implementing agency generates fewer ecosystem services per dollar than it would if landowners were paid their true opportunity costs\(^6\) (Ferraro 2008; Deng and Xu 2015).

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\(^6\) It is worth noting that while additionality is generally considered an important measure of conservation success, FONAFIFO has argued that their objective is to compensate landowners for their production of ecosystem services, without necessarily increasing the provision of those services. It is also important to note, that around the time PSA was implemented, deforestation was deemed illegal in Costa Rica. Therefore, an alternative view of PSA and the informational rents is compensation for the restrictions on the use of private forested lands.
Equity in participation

Although many evaluations of PSA have focused on the cost-effectiveness of payments at protecting forests that are assumed to provide ecosystem services, the distribution of participation in the program has also been considered. Because of transaction costs and other barriers to participation, the concern is that relatively wealthy landowners with larger properties capture more of the program funds than relatively poorer landowners with smaller properties (Zbinden and Lee 2005; Porras et al. 2013). This undermines the claim that PSA is a mechanism for compensating the rural poor for providing ecosystem services benefitting the broader population. The following sections will: (1) examine the institutional factors that can affect equity in access and (2) provide empirical evidence on the distribution of participation.

Equity in Access: Transaction costs

Equity in access, as aforementioned, is often related to the costs of participating in the program. In the context of PSA, one barrier to participation is high transaction costs which include the cost of obtaining a land title or other necessary paperwork, as well as the fees to the forester who assists in creating the management plan to be submitted after the acceptance of the initial application.

For any landowner wishing to participate in PSA under the forest protection program, a forester is required to prepare the management plan that will be used during the time period of the contract. Foresters are essentially responsible for the on the ground implementation of PSA. The creation of a management plan during the application stage is a fixed fee. After a contract is awarded, foresters receive 10-12% of the contract amount. As many of these foresters work independently and seek out their own clients, they often look for larger properties that will generate the most revenue. Although it may be more expensive in time and effort to generate a management plan for larger properties, contracts on larger properties are more lucrative (Matulis 2016). It is possible for a landowner to submit their application through an IO, however, these organizations can charge up to 18% of the contract value. Additionally, IOs tend to provide support to PSA programs other than forest protection that extend to conservation coupled with agriculture (Chacon 2015). While, submitting an application through an IO may be an alternative

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for some landowners, for many landowners the required assistance of a forester is a barrier to entry, as foresters may choose to work with landowners with large land holdings over smallholders to increase income.

**Equity in Outcomes: Distribution of payments**

Equity of outcomes describes the distribution of project outcomes. In the PSA context equity of outcomes can be analyzed based on the amount of dollars being awarded to smallholders. Figure 2 below shows the percent of dollars awarded to largeholders (using FONAFIFO’s definition of largeholders as those having greater than 50 hectares on their land). The 2014 agricultural census in Costa Rica shows that only 10% of all properties are greater than 50 HA (INEC 2014). From 2005 to 2014, more than 85% of the forest protection budget for new contracts has been allocated to properties larger than 50 hectares. This intuitively makes sense: owners with larger parcels will have more land to enroll in the program and thus receive more funds. This distribution of funds could also indicate that largeholdings are managed less intensively, resulting in lower opportunity costs of forest conservation. On the other hand, the costs of participation may be a greater barrier for smallholders and poor landowners, as wealthier landowners with larger properties can better afford the transactions costs associated with obtaining a PSA contract both because they are more capitalized and because their transactions costs are lower on a per hectare basis.

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7 This includes all properties. Data in the 2014 agricultural census does not provide data on the size class or location (rural or other) of properties with forest cover. A description of the distribution of the farm sizes in Costa Rica is located in Appendix C.
Addressing Critiques

Most evaluations of PSA have called for Costa Rica to take steps to increase the environmental services provided per dollar spent. To directly address the issue of adverse selection, FONAFIO would need information about the opportunity cost of each landowner and knowledge about whether or not they would conserve without payments. This information is private and would be difficult for FONAFIFO to obtain. Further, if FOFNAFIPO tried to obtain this information, this could lead to landowners signaling that they have higher opportunity costs compared to their true opportunity cost or that they have an intent to deforest when they actually do not. FONAFIFO, therefore, has focused on increasing the value of ecosystem services secured through PES contracts and to encourage participation by disadvantaged landowners through targeting.

Theory suggests targeting as a way to increase the cost-effectiveness of PES programs (Hartshorn et al. 2005; Sanchez-Azofeifa et al. 2007; Pagiola 2008; Wunscher et al. 2008; Porras et al. 2013). Targeting refers to any method of identifying and actively encouraging enrollment
of prioritized areas (often areas deemed environmentally sensitive) in a voluntary conservation program (Norden et al. 2013; Alix-Garcia et al. 2008). While this approach does not directly address the issues associated with adverse self-selection, it does provide a mechanism for program dollars to be spent in areas where a higher quality or quantity of ecosystem services will be provided. There are various ways in which targeting can take place. One way is through offering higher payments to priority areas. Often referred to as differentiated payments, factors such as land productivity, land value, deforestation risk, and presence of biodiversity can be considered when determining the price a landowner should be offered (Salzman 2009; Alix-Garcia et al. 2008). Another method is to prioritize applications (e.g. through scoring) that provide the most valuable ecosystem services, rather than simply awarding contracts on a first-come, first-serve basis.

Differentiated payments

One way to increase the cost-effectiveness of the PSA program in providing ecosystem services is through differentiated payments. In theory, differentiated payments allows for landowners who provide higher value ecosystem services to be paid a higher price per hectare. Rather than assessing the value of ecosystem services for each parcel of land offered to the forest protection program, FONAFIFO created two new programs in 2009 under the forest protection umbrella (shown in Table 1) that offer higher per-hectare rates where forest protection is expected to generate higher value ecosystem services, compared to the general forest protection program. The first is the protection of hydric resources, which conserves forests protecting hydrological resources in priority river basins (e.g. that generate hydroelectricity). The second is forest protection in conservation gaps, which conserves forests in buffer zones around protected areas or designated biological corridors (FONAFIFO).

As with the general program, payments for each contract are distributed evenly over the length of the contract, with either 1/5 or 1/10 paid when the contract is signed. The total payment per hectare for conservation gaps was decided based on the same considerations as for the forest protection program.

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8 Another program, protection within protected areas, was also added in 2009. This program works to conserve forests on private inholdings in protected areas. However, the payment level was identical to that of the forest protection program.
The Matrix for Evaluating Applications to PSA

Another significant innovation in the forest protection program was the centralization of the application process and the introduction of a scoring system called the matriz or Matrix in 2011. Prior to 2011, applications were accepted on a first-come, first-served basis in each region. Because there was not a sufficient budget to accept all applications, ranking applications based on their potential provision of ecosystem services was an obvious way to increase cost-effectiveness. Reflecting the dual environmental and social objectives for the program, the Matrix that was put in place in 2011 prioritizes applications based on both environmental and social objectives. However, it does not explicitly consider additionality in the sense of providing additional ecosystems services compared to what would have been provided without payments.

The Matrix assigns points based on the environmental benefits the forest can provide. Table 2 depicts the scoring system used since 2012. The Matrix contains three environmental criteria based on whether a forest is located in priority areas that include: protected areas, conservation gaps, and biological corridors. The Matrix also awards points to applications for new contracts on properties that previously had a forest protection contract.

In addition to the environmental priorities, the Matrix also addresses social objectives by awarding additional points to applications for contracts on properties that are small or located in districts of lower socio-economic standing based on the Social Development Index (IDS). The IDS is calculated by the Ministry of National Planning and Economic Policy (MIDEPLAN).
approximately every five years and is used as a measure of relative wealth. It is often used by the Costa Rican government in social policy and budget allocation (Porras et al. 2013). The IDS is constructed from a set of 11 socioeconomic indicators reported in public statistics grouped into four areas: health, electoral participation, education, and economics (Figure 3). The score is standardized to range between 0 and 100, with 100 indicating the highest socio-economic status. The median IDS\textsuperscript{9} score of new forest protection contracts (both prior to and after the introduction of both targeting mechanisms) is approximately 40 (Figure 4). The rationale for prioritizing applications from districts with an IDS score lower than 40 is that this will increase participation by poor landowners, without requiring data on the socioeconomic status of each applicant.

To address concerns smallholders and poor landowners were not receiving many PSA contracts, the Matrix awards 25 points to applications for contracts on properties that are small (< 50 ha) and 10 points for properties located in districts where the IDS is less than 40\textsuperscript{10}.

Table 2. Matrix scoring system used for forest protection contracts starting in 2012.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Priorities</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forests on farms located in areas defined in the Conservation Gaps within Indigenous Territories of the country.</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>Forests on farms located within the officially established Biological Corridors. Forests that protect water resources or where the importance of protecting the forest is evident</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>Forests on farms located within Protected Areas that have not been bought or expropriated by the State</td>
<td>75</td>
</tr>
<tr>
<td>4</td>
<td>Forests outside any of the above priorities</td>
<td>55</td>
</tr>
<tr>
<td>I</td>
<td>Forests in the Forest Protection modality complying with the provisions of the above points, which have signed contracts for payment of environmental services in previous years, provided they meet other requirements</td>
<td>10 additional</td>
</tr>
<tr>
<td>II</td>
<td>Forests in farms located in districts with less than 40 on the Social Development Index</td>
<td>10 additional</td>
</tr>
<tr>
<td>III</td>
<td>Forests in any of the above priorities, with application to enter the PSA where the size of the farm is equal to or less than 50 hectares</td>
<td>25 additional</td>
</tr>
</tbody>
</table>

\textsuperscript{9}Based on the 2007 IDS scores
\textsuperscript{10} FONAFIFO has noted the cut off points of 50 hectares and an IDS score of 40 were based on “common knowledge”. A smallholder is defined as one that owns land less than 50 hectares (Sanchez, 2016). The two lowest quintiles of the IDS distribution fall below 40.
Figure 3. Factors considered in the measurement of the Social Development Index (IDS).

Figure 4. Boxplot of IDS scores for new contracts in the Forest Protection program. The length of the box represents the interquartile range. The whiskers represent the minimum and maximum values. The horizontal line represents the group median. The dots represent outlier values.
Description of Trends

To address the concerns about cost-effectiveness and equity, FONAFIFO has introduced both differentiated payments and ranking of applications for the forest protection program. Both changes can impact a landowner’s decision to participate in the program. For a landowner with property in a prioritized area, those who own less than 50 hectares, or those with land in districts with an IDS less than 40, the higher potential payments through the specialized programs and additional points through the Matrix may increase their desire to participate and submit an application. Additionally, both institutional changes may encourage government officials, intermediary organizations, and foresters to focus their efforts to disseminate information about the program and recruit applicants who have properties in priority areas and smallholders. While theory does support that targeting mechanisms such as the Matrix and differentiated payments, should increase cost-effectiveness and equity, it is, however, an empirical question whether the cumulative effect of these institutional changes actually shifted the distribution of contracts toward higher priority areas and disadvantaged landowners. This case study does not provide a statistical analysis to answer the question, but provides a description of trends that can inform future analysis.

Database

Data used in this analysis were obtained from two sources. The first source is FONAFIFO records, which were used to identify the number of new PSA contracts signed from 2005 to 2014. FONAFIFO records include the type of contract, the location of the property, the size of the property, and the number of hectares enrolled in PSA. To compile this information, data from FONAFIFO’s application database and Integrated Project Administration System, which they use to manage payments were combined with the IDS of each district in the dataset, as well as the calculated the Matrix score of each property enrolled from 2011 onward.

Cost-effectiveness

Both differentiated payments and the Matrix scoring system are intended to increase the number of contracts being awarded to landowners in priority areas. Because contracts in these areas protect forests that generate higher value ecosystem services, they can potentially increase the cost-effectiveness of payments at generating ecosystem services. It is expected the number of new contracts awarded to properties inside prioritized areas will increase as a result of
differentiated payments and the Matrix, as both offer an advantage to any application for contracts in these areas (regardless of the size of the area offered).

Figure 5 shows the number of new contracts awarded within priority areas by year. In 2009, when differentiated payments were first introduced, there is a noticeable increase in the number of new contracts being awarded in priority areas, after a decreasing trend from 2007 to 2009. This increase continued through 2012, thus spanning the introduction of the Matrix in 2011. From 2013 to 2014, there was a decline in the number of new contracts awarded to landowners in priority areas.

Due to the fact that FONAFIFO’s budget fluctuates from year to year, examining the share of contracts being awarded within priority areas may also provide some insight. As shown in Table 3, the percent of new contracts signed each year from 2005 to 2014 that lie inside priority areas varies very little. There is a low point (83%) in 2008, the year prior to the introduction of differentiated payments, and a high point (93%) in the following year. New contracts awarded for land in prioritized areas then declined from 93% in 2009 to about 85% in 2014. While it is possible that without differentiated payments or the Matrix, the distribution of contracts may have shifted away from prioritized areas, I am not aware of any evidence suggesting that would have been the counterfactual trend.

Figure 5. The number of new contracts for each year awarded within priority areas (protected areas, conservation gaps, biological corridors, or some combination thereof.)
Equity in Participation

The Matrix provides an advantage to smallholders and owners with land in districts with low socio-economic status. This scoring mechanism can be seen as a means to address equity by shifting the distribution of participants towards landowners with low socioeconomic status. While it does not directly affect equity of access, it may encourage foresters and intermediary organizations to recruit these landowners to apply for PSA contracts. Additionally, while differentiated payments were introduced through specialized forest protection programs to increase the amount of forests protected given the program budget (or cost-effectiveness), they may have also increased participation by smallholders and poorer landowners in high priority areas. Higher per-hectare payments may cover the transaction costs for these landowners who may not have otherwise participated if they only had the option of lower payments in the general forest protection program. Higher payments could therefore lower barriers to entry for these landowners and increase equity in access. This rationale is supported by Alix-Garcia et al. (2008), who found that in the Mexican PES program, the poor receive a smaller portion of the total PES budget under a flat rate scheme compared to a differentiated payment scheme. However, it is also possible that even with higher payments, the per-hectare payments in the specialized programs are not high enough to attract landowners with property in these areas. Thus, both the Matrix and differentiated payments could have either encouraged or failed to

Table 3. The percent of contracts awarded each year to landowners in priority areas.

<table>
<thead>
<tr>
<th>Year</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>86%</td>
</tr>
<tr>
<td>2006</td>
<td>89%</td>
</tr>
<tr>
<td>2007</td>
<td>88%</td>
</tr>
<tr>
<td>2008</td>
<td>83%</td>
</tr>
<tr>
<td>2009</td>
<td>93%</td>
</tr>
<tr>
<td>2010</td>
<td>90%</td>
</tr>
<tr>
<td>2011</td>
<td>88%</td>
</tr>
<tr>
<td>2012</td>
<td>89%</td>
</tr>
<tr>
<td>2013</td>
<td>85%</td>
</tr>
<tr>
<td>2014</td>
<td>85%</td>
</tr>
</tbody>
</table>
encourage participation by smallholders. To gain some insight on the likely effect, I again examine trends over time.

Figure 6 presents the percent of new contracts awarded on properties in four size classes: smallholders who own less than 25 hectares (red solid line) and who own between 25 and 50 hectares (dashed red line), and largeholders who own 50 to 100 hectares (dashed black line) and more than 100 hectares (solid black line).

From 2005 to 2013 largeholders received a larger percent of contracts than smallholders. However, starting in 2011, when the Matrix was introduced, the gap between the percent of contracts awarded to largeholders and smallholders narrows. In 2013 and 2014 smallholders are awarded more contracts than largeholders. This temporal trend is consistent with the hypothesis that the introduction of the Matrix had a positive effect on smallholder participation in the overall forest protection program. In sum, these trends are consistent with (while not providing rigorous evidence for) the proposition that the introduction of differentiated payments and the Matrix scoring system shifted the distribution of contracts from largeholdings to smallholdings in the forest protection program.

Figure 6. The percent of contracts awarded to landowners whose properties are less than 25 hectares (solid red line), between 25 and 50 hectares (dashed red line), between 50 and 100 hectares (dashed black line), and greater than 50 hectares (solid black line).
In addition to targeting small properties, the Matrix also awards additional points to landowners in districts with an IDS below 40. Figure 7 shows the percent of contracts awarded to landowners based on the district’s IDS score and figure 8 presents a map of Costa Rica’s districts, depicting the size of the districts and their IDS scores. The percent of contracts awarded to landowners in districts where the IDS is less than 20 are depicted by a solid red line and 6% of Costa Rica’s districts fall into this category. Contracts awarded to landowners in districts where the IDS is between 20 and 40 are depicted by a dashed red line and 24% of the districts fall into this category. The percent of contracts awarded to landowners where the IDS is between 40 and 60 and districts where the IDS is greater than 60 are depicted by a dashed black line and a solid black line, respectively. Forty-nine percent of districts in Costa Rica have an IDS between 40 and 60. Districts with an IDS score over 60 are 21% of Costa Rica’s districts.

Generally, landowners in districts where the IDS is less than 20 or greater than 60 receive the smallest percent of contracts during the 2005-2014 time period. Landowners in districts where the IDS is between 40 and 60 receive the largest percent of new contracts. However, there is a general trend towards more contracts being awarded in districts with an IDS score between 20 and 40 from 2009 to 2012. These trends do not suggest any obvious influence of the differentiated payments or the Matrix on participation from landowners in low IDS districts.

![Percent of New Contracts Awarded by IDS](image)

Figure 7. The percent of contracts awarded to landowners whose properties are in districts where the IDS is less than 20 (solid red line), between 20 and 40(dashed red line), between 40 and 60 (dashed red line), and greater than 60 (solid black line).
Conclusions

Payments for ecosystem services have been touted as both more cost-effective and more equitable than other tools for conserving and generating ecosystem services. However, program evaluations for PES programs in developing countries have questioned whether these advantages are actually realized when PES programs are implemented. The lack of additionality, the difficulty of imposing conditionality, as well as possible price and behavioral spillover are often discussed as impediments to cost-effectiveness. There are also concerns that significant barriers to participation, such as a large fixed transaction cost per contract, prevent the poor from reaping the potential financial benefits of participation.

To emphasize and provide context for many of the characteristics and concerns of PES programs, a case study of Costa Rica’s PSA program for forest protection is presented. I explain the initial design of the program, and criticism of that design. I then show how the program administrator responded to those criticisms within the constraints imposed by asymmetric information by targeting contracts through differentiated payments introduced in 2009 and
through a system for ranking applications introduced in 2011. Results show that trends in participation in the program are consistent with the desired effects of those institutional changes on the proportion contracts going to relatively small properties.

While there has been a great deal of research on the PSA program and PES programs in general, future work should address many of the concerns presented in this article. Questions such as: 1) What is the role of the additionality requirement in PES programs in the developing world and what mechanisms could be used to increase additionality? 2) What tools can be used to increase monitoring or compliance? and 3) How can programs control for and assess spillover effects? Questions such as these could provide information that could allow for stronger PES institutions for future programs. Future work should also address the barriers that prevent equity in access for the poor as well as examine the trade-offs between achieving social and environmental objectives.
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Introduction

Payment for ecosystem services (PES) programs have been established in both developed and developing countries to encourage private provision of public goods, such as carbon sequestration, watershed management, or wildlife habitat. Specifically, the goal is to encourage provision of ecosystem services that are worth more to the public than the private cost of providing them. In many PES programs, the government or other implementing agency pays the service providers, often landowners, to implement specific management practices that are expected to generate ecosystem services for the community at large. In the tropics, the management practice is often to conserve existing natural forest, foregoing conversion to alternative uses. Although economists advocate for PES as more cost-effective than indirect incentives, it has proven challenging to implement PES programs that achieve this cost-effectiveness. Further, some PES programs have social objectives, such as rural development or poverty alleviation, which may limit cost-effectiveness from the perspective of generating ecosystem services. One barrier to realizing the theoretical advantages of PES programs is information asymmetries.

This paper begins with a description of the role of information asymmetries in PES programs, focusing on informational rents. Next, this paper provides an overview of how procurement auctions can be used to overcome the issues associated with information asymmetries, including a brief overview of procurement auctions that have been implemented in PES programs in both developed and developing countries, considering their design features and previous findings about both their cost-effectiveness for conservation and the distribution of participation relative to other ways of distributing payments. I then review prior research that utilizes agent-based models (ABMs) to examine PES for conservation of natural ecosystems. The third section presents the ABM for the Costa Rican PES system, following the ODD framework: overview, design concepts, and detailed protocol. This includes a description of the study area and the PSA program, as well as the structure of the agent-based model. The final sections present the results and draw conclusions.
Information Asymmetries and Informational Rents

In theory, a cost-effective program would pay each landowner an amount as close as possible to their cost of participation; for PES to conserve existing natural forest, this is the opportunity cost (assuming no private transactions costs). However, opportunity cost is private information, making it difficult for implementing agencies to determine the opportunity cost of each landowner (Chan et al. 2003; Ferraro 2008).

At least partly due to this information asymmetry, in many PES programs, the government pays a flat, per-hectare rate for conservation. Ignoring any conservation motives and transaction costs of landowners, this means that only landowners with a per-hectare opportunity cost below the fixed price participate in the program. This is problematic both because it overpays landowners with low opportunity costs and excludes landowners who have high opportunity costs but could provide high levels of ecosystem services. In the first case, the difference between payments received by landowners and their actual costs of participation are informational rents. Informational rents reduce cost-effectiveness, in that the implementing agency conserves fewer hectares per dollar than it would if landowners were paid their true costs (Ferraro 2008; Deng et al. 2015). The second case also undermines cost-effectiveness because lands that have high opportunity costs but can provide even higher levels of ecosystem services are not enrolled in the program.

In the case of PES programs to protect native forests, such as Costa Rica’s Pagos por Servicios Ambientales (PSA) forest protection program, fixed rates inherently offer rents to landowners whose opportunity costs of forest conservation are low. Since 1997, the PSA program has offered landowners contracts to conserve forest for a fixed rate per hectare and per year. It is illegal to clear most privately owned forest in Costa Rica. Thus, landowners may also factor the risk of legal sanctions into their decisions whether to participate in PSA, effectively discounting their opportunity cost of forest conservation by the expected value of sanctions for illegally clearing forest. In this context, a cost-effective PES program would pay landowners an amount equal to this discounted opportunity cost, if there is an assumption that any transactions costs of participation in the program are offset by any private conservation benefits of participation.

As previously noted, it is difficult for implementing agencies to determine the exact cost of participation for each landowner who would like to participate in the program. However, in
Costa Rica the agency responsible for the PSA program. FONAFIFO, contracted a study of the opportunity costs of forest conservation (Vega 2014). The estimated opportunity costs were based on the potential agricultural profits foregone, the productivity of land, accessibility to markets and services, and available infrastructure and public services, resulting in the map shown in Figure 1, which depicts the country divided into zones with different opportunity costs. While this estimate can provide some indication of what a landowner’s opportunity cost could be, it is only an estimate. Individual landowners may consider some or none of these factors when determining their own opportunity costs. Additionally, this study does not take into consideration the private benefits of retaining forests, such as provision of locally valuable ecosystem services (e.g. shade and water quality), or intrinsic motivations for wanting to conserve forests on their land. Both of these factors would impact a landowner’s opportunity cost of participation. Despite these drawbacks, the estimation of opportunity cost of participation in the PSA forest protection program does provide some insight into the relative opportunity costs of participation across the entire country. In the following study, the values calculated by Vega (2014) are used as estimates of each landowner’s opportunity cost.

Figure 1. Opportunity costs of forest conservation in colones/hectare/year calculated by Vega (2014).
Based on typical fees charged by foresters and intermediary organizations, I assume that the private transactions cost for participation in the program is equal to 15% of the payment awarded to landowners. Based on those estimated opportunity costs and transactions costs and information about the size of contracts issued in the past 10 years (2005 – 2014) (Aguilar 2015),\(^\text{11}\) Table 1 shows: (1) the percent of contracts that were overpaid based on a comparison of the flat, per hectare fee to an estimate of the opportunity and transactions costs per hectare of enrolling the land in the program, (2) the estimated total informational rents gained by participating landowners whose opportunity costs per hectare were below the payment rate, and (3) the estimated total underpayment of landowners whose opportunity costs per hectare were above the payment rate. I find that more than half of the contracts awarded in each year from 2005 to 2011 (and more than a third in each year from 2005 to 2011) were overpaid compared to the opportunity cost calculated by Vega (2014) plus transaction cost of 15% of program payments. The informational rent\(^\text{12}\) in each year was over $1 million (USD) and in 2008 was as high as $6 million. While these informational rents could be interpreted as a failure of the program to achieve cost-effective conservation, FONAFIFO has argued that their objective is to compensate landowners for their production of ecosystem services, without necessarily increasing the provision of those services (Sanchez 2015). Another possible interpretation is that the informational rents are compensation to private landowners in Costa Rica affected by the restrictions on use of their private forested lands. However, while most contracts resulted in an overpayment, the total amount underpaid\(^\text{13}\) on forest protection contracts is greater than the amount overpaid in most years. Thus, some mechanism that could reduce informational rents for

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\(^{11}\) Note that I do not discount the opportunity costs by the expected value of sanctions for clearing forest, nor do I account for other private benefits of retaining forest, such as provision of locally valuable ecosystem services such as shade or water quality. Both of these factors would encourage landowners to voluntarily participate in the program at lower payment levels. Thus, I underestimate the fraction of contracts that were overpaid relative to the amount that would have been sufficient to induce participation.

\(^{12}\) The informational rents for each year is calculated as the amount paid to the landowner minus the opportunity and transaction cost (15%) of participation.

\(^{13}\) Table 1 reflects underpayments based on opportunity costs. While economic theory suggests that landowners will only participate when the payment levels are greater than their opportunity costs, there are several reasons why a landowner will participate in a PES program when the payment level is less than their opportunity costs, including that landowners underestimate their true opportunity costs, that they actually have lower opportunity costs due to legal or economic restrictions on land use, and that they have conservation motives.
those being overpaid and transfer the savings to fairly compensate landowners who are being underpaid could result in a more fair and cost-effective program.

Table 1. The percent of contracts that were overpaid when comparing the flat, per hectare cost used in the PSA forest protection program to the opportunity cost of enrolling the land in the program and the estimated informational rents paid in each year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Percent of Contracts Overpaid</th>
<th>Estimated Informational Rents</th>
<th>Estimated Under Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>58%</td>
<td>$5,394,765</td>
<td>-$7,313,132</td>
</tr>
<tr>
<td>2006</td>
<td>56%</td>
<td>$1,906,995</td>
<td>-$3,251,766</td>
</tr>
<tr>
<td>2007</td>
<td>56%</td>
<td>$5,122,859</td>
<td>-$9,013,718</td>
</tr>
<tr>
<td>2008</td>
<td>57%</td>
<td>$6,895,033</td>
<td>-$9,635,509</td>
</tr>
<tr>
<td>2009</td>
<td>64%</td>
<td>$3,122,911</td>
<td>-$3,756,077</td>
</tr>
<tr>
<td>2010</td>
<td>52%</td>
<td>$3,025,961</td>
<td>-$6,160,481</td>
</tr>
<tr>
<td>2011</td>
<td>52%</td>
<td>$4,720,807</td>
<td>-$8,644,884</td>
</tr>
<tr>
<td>2012</td>
<td>48%</td>
<td>$4,362,913</td>
<td>-$9,499,928</td>
</tr>
<tr>
<td>2013</td>
<td>44%</td>
<td>$1,963,418</td>
<td>-$3,755,494</td>
</tr>
<tr>
<td>2014</td>
<td>39%</td>
<td>$1,149,346</td>
<td>-$3,727,534</td>
</tr>
</tbody>
</table>

Using Procurement Auctions to Reduce Informational Rent Seeking

To increase cost-effectiveness, the implementing agencies for PES programs need a mechanism that both reduces informational rents and attracts participants who offer high ecosystem services (Deng et al. 2005). Procurement auctions can potentially deliver both (Ferraro 2008). Unlike a traditional auction where goods are sold to a relatively large number of bidders by one seller, a procurement auction involves goods being bought by one seller from a relatively large number of bidders. These auctions are well-suited to the typical PES system in which an implementing agency purchases multiple units of a heterogeneous good (i.e. environmental services) from multiple suppliers (Doole et al. 2014).

In a typical conservation procurement auction, interested landowners determine the payment they will request for implementing the land management practice that is expected to provide the environmental service. The landowners then submit their requested payments as bids. In some programs, bids are submitted along with some measure of the level of the environmental services that would be provided. In programs such as the Conservation Reserve Program in the US, BushTender in Australia, and the Steinburg County Biodiversity Auction in Germany, these metrics of environmental services are developed and validated by government officials or natural resource professionals. The metrics are then used to rank the bids. The basic concept is that bids
providing the highest environmental benefit per dollar are selected first, with bids accepted according to rank until the budget is exhausted (Reeson et al. 2011).

The competitive nature of an auction creates an incentive for landowners to bid close to their opportunity cost (Deng et al. 2014; Amdur et al. 2011). In general, with competitive bidding, a high bid may increase the net payoff to a landowner, but a bid that is too high reduces the likelihood a landowner will be selected for the program. The result is that the landowners’ optimal strategy is to bid close to their actual opportunity cost (depending on the exact rules of the auction). Thus, the implementing agency can more effectively allocate ecosystem services dollars without having prior knowledge of landowners’ private costs or using resources to collect information about each landowner’s opportunity cost (Chan et al. 2000).

**Objective**

Theory suggests that with appropriate design features, procurement auctions can increase the cost-effectiveness of the typical PES program that pays a flat, per-hectare rate for conservation of natural ecosystems. Using the structure of Costa Rica’s PSA forest protection program and data about program participants, I develop an agent-based model to explore the implications of incorporating conservation auctions with different design features into Costa Rica’s PSA forest protection program. Specifically, I examine the implications for cost-effectiveness by quantifying the informational rents and environmental benefits per dollar achieved with each type of auction. Additionally, I examine implications of the auctions for the distribution of participation by quantifying the number of contracts issued to landowners with different sized parcels of land and in districts at different levels of development.

**Procurement Auctions in Practice**

Procurement auctions have been incorporated into PES programs in at least 8 countries. Table 2 describes the auction mechanisms used in PES programs that have been the subject of scientific literature. As described in Table 2, there are two main types of procurement auctions have been used in the context of PES programs. The first type is a first price, discriminatory auction. In this type of auction, a landowner submits a confidential bid that represents the minimum payment that she would accept to implement the management activity required by the

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14 Net payoff is the difference between the payment received and the opportunity and transaction costs associated with participation in the program.
PES program. Winning bidders are paid the rate per hectare that they bid. The second commonly used type is a second price, uniform auction, in which all winning bidders are paid the rate of the lowest rejected bid (Latacz-Lohmann and Schilizzi 2005).

**Developed Countries**

As listed in Table 2, programs in the United States, the United Kingdom, Australia, and Germany have used procurement auctions to solicit voluntary proposals for conservation on private land. Applicants submit bids (or tenders) signifying their desired payment. All of these are first price auctions that paid selected participants the amount that they bid. The Conservation Reserve Program in the United States is the only one that continues to use procurement auctions. The other auctions were all terminated after less than 5 years, either because of policy changes or because they were intended as short-term pilots. Specific programs are briefly described below.

Researchers have assessed many of these first price auctions by comparing their cost to the cost of conserving the same number of hectares with a single flat rate per hectare.

**United States: Conservation Reserve Program**

The Conservation Reserve Program (CRP) is administered by the United States Department of Agriculture. The objective of the program is to remove environmentally sensitive land from agricultural production and implement a management plan that improves environmental quality, typically by allowing natural regeneration or restoring vegetative cover. Landowners who sign up for the program receive annual payments. When introduced in 1985, the CRP only required applicants to state the per hectare amount that they would accept for conserving a portion of land by retiring it from agricultural production. Five years later, the Environmental Benefits Index (EBI) was added to the application, so that the requested payment could be compared to the environmental value of the area offered to the program. Applications, or bids, are now evaluated based on both the requested payment and the EBI (Claasen et al. 2008; Vukina et al. 2008). The CRP has retired over 30 million acres of cropland since its inception and has significantly reduced soil erosion (Sullivan et al. 2004). Additionally, positive impacts on wildlife have been found in some areas where CRP management plans have been implemented (Sullivan et al. 2004; Drum et al. 2015). The CRP is widely seen as a model for incorporating a procurement auction into a PES system, in both other developed and developing countries.
Scotland: Woodlands In and Around Towns (WIAT) Challenge

In 1997, the Scottish Forestry Commission created a fund to support the Woodlands In and Around Towns (WIAT) Challenge, which accepted bids for the creation, management, and expansion of woodlands within 1 km of settlements of over 2,000 people (Forestry Commission Scotland 2015). Each proposed project was scored to determine the environmental benefits it would provide and how well it met the objectives of the program. In this first price auction, projects with the highest benefit per dollar were selected first. Analyses following the auction found that if a fixed-rate payment had been offered, the budget would have needed to be 33% to 36% greater in order to secure the same number of hectares. However, some participants reported that they felt the auction mechanism was unfair and they would have preferred a fixed, per hectare rate (Latacz-Lohmann and Schilizzi 2005).

Australia: BushTender

In 2001, Australia launched its BushTender program in Victoria. Administered by the government of Victoria, the aim of the program is to improve vegetation management on private lands. Landowners submit management proposals for their land and bids (tenders) in a first price auction (State of Victoria Department of Sustainability and Environment 2011). To determine the winners of the auction, a Biodiversity Benefits Index (BBI), which indicates the value of different habitats present on the land, was compared to the bid submitted by the landowner. Bids were ranked by the highest BBI per dollar and winners chosen until the budget was exhausted (Latacz-Lohmann and Schilizzi 2005). Stoneham et al. (2003) compared a fixed-price scheme to the results from the BushTender auction and found the budget would have to be seven times higher under a fixed-price scheme to achieve the same level of environmental benefits.

Germany: Northeim Agri-Environmental Scheme Auction

In the district of Northeim in Lower Saxony, Germany, 20% of permanent grasslands had been lost between 1987 and 2007 due to replacement by forests on marginal soils and by agriculture on more productive soils. To reduce land-use conversion and protect grassland species, local stakeholders and researchers developed an auction that would pay farmers for introducing plant diversity to managed grasslands. In this first price auction, farmers submitted bids that represented the payments required to establish the plant varieties on their grasslands.
Bids were grouped by the type of ecological good\textsuperscript{15} that would be provided and auctions were run for each ecological good group. While the cost-effectiveness of this auction has not been quantified, Klimek et al. (2008) argues that the outcomes of the auction demonstrate that farmers were willing to diversify land to provide environmental goods when payments were made available (Klimek et al. 2008).

*Germany: Steinburg County Biodiversity Auction*

In Steinburg County of northern Germany, an auction was implemented by the non-profit Stiftung Naturschutz Schleswig-Holstein (Foundation for Nature Conservation Schleswig-Holstein) to encourage maintenance of grasslands on marginal soils in order to promote species rich grasslands and conserve rare plants. Farmers in the study area could submit bids for implementing management plans on their grasslands in first price auctions that took place in 2007 and 2008. Their bids were compared to an ecological quality classification system used to measure the level of environmental benefits that could be expected from implementing the management plan on each farm. Bids with the highest environmental benefit per dollar were chosen until the budget was exhausted. Groth (2011) compared the results of these auctions to a hypothetical fixed-flat rate payment scheme and found the cost advantages of auctions ranged across the years from 41% to 50%.

*Developing Countries*

Conservation auctions in developing countries have also generally been operational for just a short period of time. Of the five auctions discussed in the scientific literature, two auctions (China and Kenya) were used to test the cost-effectiveness of implementing a procurement auction compared to an existing conservation program. Auctions conducted in Bolivia and Peru are unique in that bids were placed by community based groups rather than individuals, and the auctions integrated the number of farmers in the community that would be participating in the conservation activity as part of the bid selection process. The auction conducted in Tanzania was designed to explore the tradeoffs between cost-effectiveness and pro-poor targeting. Finally, the pilot auction in Indonesia was conducted to obtain information on the ecosystem services supply

\textsuperscript{15}Ecological goods, often discussed in the context of the agricultural sector, result from managing the environment in a way that is valued to society, but does not necessarily enhance the market of the crops grown on the land (Gerowitt, Isselstein Marggraf 2003).
curve in order to estimate the costs of a scaled up program. Unlike the literature on procurement auctions in developed countries, the literature about auctions in developing countries often considers both the cost of conservation (cost-effectiveness) and the distribution of participation (equity). Both first and second price auctions have been tested. This literature is briefly summarized below in chronological order based on the year the auction was implemented.

**Indonesia: Sumberjaya Soil Conservation Auction**

In Sumberjaya, a sub district of South Sumatra, Indonesia, much of the agricultural land is planted in coffee. In the uplands, the coffee plantations are prone to erosion. In 2007, in a project let by the World Agroforestry Center (ICRAF), a second price, uniform price auction took place in which farmers submitted bids for payments for implementing techniques to control erosion on their land. This was one of the first uniform price conservation auctions in a developing country. The rate of success for implementing all contracted techniques was more than 80% (Jack et al. 2008; Leimona et al. 2009).

**Tanzania: Tanzania Tree Planting Auction**

In the Uluguru Mountains of Tanzania, traditional agricultural practices were pushing out native species and leading to erosion and heavy sediment flows. Research showed that these negative trends could be mitigated by growing trees on agricultural lands. However, planting and growing trees on agricultural land imposes a significant cost on farmers in an area where poverty rates are high. Thus, the non-governmental organization Pro-Poor Rewards for Environmental Services in Africa (PRESA) planned to cover the costs by providing seedlings and direct payments. To allocate these resources to farmers, second price, uniform auctions were held for each of the two seedling varieties offered. The results of the auction were compared to a counterfactual auction where the poor were targeted. It was shown that implementing an auction that targeted poorer landowners would require a larger budget to achieve the same area of trees planted compared to the auction without targeting that was actually implemented (Jindal et al. 2013).

**Kenya: Kenyan Forest Enrichment Auction**

The Kakamenga National Forest in Western Kenya is a protected area of approximately 24,000 hectares of Guineo-Congolian rainforest. Researchers, along with the Kenyan Forest Service, held first price, sealed bid auctions in communities neighboring the Kakamenga National Forest to adopt forest enrichment activities, including tree planting and land tending in
a buffer around the National Forest. Researchers found that the poor were over represented in the auction winners (70% of winners were poor vs 49% of the population who are poor), suggesting that auctions can have positive equity outcomes (Khalumba et al. 2013).

China: Sichuan Ecological Restoration Auction

In 2009, a first price auction took place in the Sichuan Province of China. Landowners submitted bids representing the price they were willing to accept for implementing a land management plan, including afforestation and other management activities. Bids were compared to the expected environmental benefits each plan could produce. The auction approach was found to be 15% more cost-effective than the Conversion of Cropland to Forest and Grassland Program, which offers a fixed payment to landowners to adopt afforestation activities (Wang et al. 2015).

Bolivia and Peru: Payments for Agrobiodiversity Conservation Services (PACS)

In the farming communities around Uyuni, Bolivia and Puno, Peru traditional quinoa crops were being replaced with more commercially favored quinoa species. To prevent the loss of genetic diversity among quinoa varieties being grown in this area, researchers along with several local NGOs implemented an auction to offer payments to community based groups for the conservation/cultivation of neglected quinoa species. Community based groups submitted applications that detailed the in-kind payment required for cultivating the quinoa, the total land area that they would allocate to cultivating neglected varieties of quinoa, and the number of farmers within the community based group that would take part in the cultivation of the quinoa.

In both farming communities, a first, price discriminatory auction and a second price, uniform auction were conducted. Bids were accepted based on the amount of area conserved, number of farmers conserving the area, the number of community based groups participating, or some combination of these factors. The first price, discriminatory payment auction outperformed the second price, uniform payment auction when considering conservation outcomes as well as distributional equality in terms of the number of community based groups receiving payment. (Narloch et al. 2013).
<table>
<thead>
<tr>
<th>Name of Program</th>
<th>Country</th>
<th>Auction Location</th>
<th>Program Aim or Objective</th>
<th>Length of Contract</th>
<th>Year(s)</th>
<th>Auction Employed</th>
<th>Type of Auction</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodlands In and Around Towns Challenge Funds</td>
<td>UK</td>
<td>Scotland</td>
<td>Sustainable management of woodlands near towns</td>
<td>Variable; Max 5 years</td>
<td>1997-2002</td>
<td>First Price, Discriminatory, Sealed</td>
<td>Latacz-Lohmann and Schillizzi (2005)</td>
<td></td>
</tr>
<tr>
<td>Northeim Agri-Environmental Scheme Auction</td>
<td>Germany</td>
<td>Lower Saxony</td>
<td>Delivering vascular plant diversity</td>
<td>1 year</td>
<td>2004-2006</td>
<td>First Price, Discriminatory, Sealed</td>
<td>Klimck et al 2008</td>
<td></td>
</tr>
<tr>
<td>Steinburg County Biodiversity Auction</td>
<td>Germany</td>
<td>Steinburg County, Germany</td>
<td>Provision of region-specific plant biodiversity</td>
<td>Not Discussed</td>
<td>2007, 2008</td>
<td>First Price, Discriminatory, Sealed</td>
<td>Groth 2011</td>
<td></td>
</tr>
<tr>
<td>Tanzania Tree Planting Auction</td>
<td>Tanzania</td>
<td>Villages in Kikonde catchment, Mongoro District</td>
<td>Plant trees on agricultural land to reduce erosion and produce carbon offsets</td>
<td>3 Years</td>
<td>2008</td>
<td>(1) Second Price, Uniform (2) Second Price, Uniform with Sequential Bidding</td>
<td>Jindal et al 2011</td>
<td></td>
</tr>
<tr>
<td>Kenyan Forest Enrichment Auction</td>
<td>Kenya</td>
<td>Kamkenke, Cherobani, and Isecheno Communities</td>
<td>Forest enrichment (tree planting and land tending)</td>
<td>N/A</td>
<td>2009</td>
<td>First Price, Discriminatory, Sealed with 7 rounds</td>
<td>Khalambha et al 2014</td>
<td></td>
</tr>
<tr>
<td>Sichuan Ecological Restoration Auction</td>
<td>China</td>
<td>Sichuan Province, China</td>
<td>Afforestation and other land management activities</td>
<td>3 years</td>
<td>2009</td>
<td>First Price, Discriminatory, Sealed</td>
<td>Wang et al 2014</td>
<td></td>
</tr>
<tr>
<td>Payments for Agrobiodiversity Conservation Services (PACS)</td>
<td>Bolivia and Peru</td>
<td>Uyuni, Bolivia Puno, Peru</td>
<td>Conserving neglected crop varieties</td>
<td>N/A</td>
<td>2010</td>
<td>First Price, Discriminatory, Sealed and Second Price, Uniform with targeting for amount of area conserved, number of farmers conserving the area, and/or the number of community based groups participating</td>
<td>Narloch et al 2013</td>
<td></td>
</tr>
</tbody>
</table>
Using ABM to Learn About Procurement Auctions

While trial runs of procurement auctions in developing countries have led to valuable insights on cost-effectiveness and equity issues, they require significant financial and political support. An alternative way to explore auctions is by simulating participation and conservation outcomes using an agent-based model (ABM). These models can incorporate spatially explicit data on landowners where available.

ABMs are computation models where agents (individuals, households, groups, etc.) interact within a closed system. ABM uses a bottom-up approach that allows for the analysis of “evolving systems of autonomous interacting agents” (Tesfatsion 2002). ABM consists of purposeful agents who interact over space and time, according to set rules, and whose micro-level interactions create emergent patterns (e.g. increased/decreased provision of ecosystem services). Each ABM contains: (i) diverse agents (ii) situated in an interaction structure (iii) whose actions create externalities and can (iv) adapt, evolve, or learn (Page 2005). Therefore, behaviors of agents emerge and can be observed. ABMs allow for a better understanding of policy outcomes, by incorporating realistic assumptions about behavior, structure, and timing of micro-level interactions, and simulating how those can create emergent macro-level patterns.

While ABMs have been used to understand multi-unit procurement auctions (Hailu and Schilizzi 2004; Hailu and Thoyer 2007), only one study at the time of writing focuses specifically on implementing auctions in PES programs. Lundberg et al. (2018) use an ABM to examine the cost-effectiveness of a hypothetical forest protection PES program with payments allocated through a procurement auction compared to a fixed payment scheme with and without targeting. They find that first price auctions with environmental benefits targeting can provide higher environmental benefits than either a uniform price auction or a fixed-price payment.

In these previous studies of procurement auctions, agents are initialized based on assumptions about distributions and correlations between landowners and characteristics of the land. This means that the results are only valid where the assumptions accurately reflect the participants and the landscape where the procurement auction will take place. One way to mitigate this concern is to use real world data about possible participants and characteristics of their land. For this study, I utilize data about landowners and characteristics of the land that have been enrolled in Costa Rica’s PSA forest protection program over the past decade to model and
predict the results of using an auction mechanism to allocate contracts across landowners. A description of Costa Rica’s PSA program and the data used in this analysis are presented next.

**Study Area and PSA Program Description**

Costa Rica’s PSA program was established in 1996 to reward landowners for the environmental services their forests provide through 5 - 10 year contracts for forest parcels. As the first national program of direct payments for tropical forest conservation on private lands, the PSA program, and more specifically, the forest protection sub-program, received much research and policy attention in its first decade. While many researchers praised the implementing agency, Fondo Nacional de Financiamiento Forestal (FONAFIFO), researchers also criticized the program design for lack of cost-effectiveness, in that it does not maximize the additional ecosystem services that can be achieved with a given budget. Specifically, concerns were raised about the “first-come, first-served” allocation process, and the flat payment rate for all hectares accepted into the program. Additionally, as is often the case with PES, many stakeholders expect PSA to also fulfill the social goal of rural development and poverty alleviation, leading to critical examination of the distribution of participation in the program. Researchers found that relatively wealthy landowners with larger properties capture more of the program funds than relatively poorer landowners with smaller properties (Zbinden and Lee 2005; Porras et al. 2013), even though the program was often described as benefitting the rural poor. In 2011, the Costa Rican government responded to the criticisms by changing the process of reviewing applications from “first-come, first-serve” to a scoring process using a “Matrix” that reflects both environmental and social priorities.¹⁶

The Matrix assigns points based on the expected benefits of a contract. Table 3 depicts the scoring system used since 2012 (slightly updated from the first year that it was used). The Matrix contains three environmental criteria based on where the forest parcel proposed for the program is located, with points awarded for parcels located in priority areas: protected areas, conservation gaps, and biological corridors. Each application can only receive points for being in one priority area. If the forest is located in several priority areas, the landowner receives the

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¹⁶ FONAFIFO also introduced “specialized programs” that award higher payments for conserving forests in conservation gaps and that protect water resources. These specialized programs are not addressed here, as our focus is the forest protection sub-program.
amount of points from the highest scoring area (e.g., 85 points for forests in conservation gaps). The Matrix also awards points to applications for new contracts on properties that previously had forest protection contracts, effectively rewarding contract renewals. In addition to the environmental priorities, the Matrix also addresses social concerns by giving more points to applications for contracts on small properties and properties in underdeveloped districts. Specifically, applications for contracts on properties that are small (< 50 ha) are awarded 25 additional points. Underdeveloped districts are identified based on the Social Development Index (IDS), which is calculated by the Ministry of National Planning and Economic Policy (MIDEPLAN) as a measure of relative wealth. Applications for contracts on properties in districts with an IDS less than 40 receive an additional 10 points. None of these point allocations are weighted by the number of hectares being enrolled. Thus, the lowest score possible is 55 (forests outside priority areas) and the highest score is 130 (forests in conservation gaps within indigenous territories (85 points), that had a contract in previous years (10 points), located in a low IDS area (10 points), on a parcel of land less than 50 hectares (25 points)).

Table 3. Matrix scoring system used for forest protection contracts starting in 2012.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Priorities</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forests on farms located in areas defined in the Conservation Gaps within Indigenous Territories of the country</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>Forests on farms located within the officially established Biological Corridors, Forests that protect water resources or where the importance of protecting the forest is evident</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>Forests on farms located within Protected Areas that have not been bought or expropriated by the State</td>
<td>75</td>
</tr>
<tr>
<td>4</td>
<td>Forests outside any of the above priorities</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>Forests in the Forest Protection modality complying with the provisions of the above points, which have signed contracts for payment of environmental services in previous years, provided they meet other requirements</td>
<td>10 additional</td>
</tr>
<tr>
<td>6</td>
<td>Forests in farms located in districts with less than 40 on the Social Development Index</td>
<td>10 additional</td>
</tr>
<tr>
<td>7</td>
<td>Forests in any of the above priorities, with application to enter the PSA where the size of the farm is equal to or less than 50 hectares</td>
<td>25 additional</td>
</tr>
</tbody>
</table>
ABM and ODD Protocol

Following previous studies, I examine two types of auction: first price, discriminatory and second price, uniform. I consider three variations on each type of auction. The first variation includes no social or environmental targeting, but selects winners based on the lowest per hectare price. The second variation targets environmental priorities based on the Matrix scoring system. The final auction variation targets both environmental and social priorities as defined by the Matrix. A first come, first served mechanism where landowners are awarded contracts in random order is used as the baseline, reflecting the actual system in Costa Rica during the first decade of PSA.

I assess each model on the basis of both cost-effectiveness and equity of participation. There are two metrics of cost-effectiveness. The first is the total informational rent captured by landowners in each auction. To increase cost-effectiveness in program implementation, informational rents should be kept to a minimum. The second metric is the environmental benefits per dollar. To compare across auctions, I use an index of environmental benefits based on the first four factors in the Matrix. A cost-effective system should maximize the environmental benefits gained per dollar spent. Equity of participation is also measured based on the Matrix: I calculate both the percent of contracts issued to smallholders who own less than 50 hectares, and the percent of contracts issued to landowners in districts with an IDS less than 40. The metrics for equity in participation, referred to as “bias in representation”, are the percentages of these targeted groups among the winners relative to their percentages among all applicants.

Auction theory suggests that both first price, discriminatory auctions and second price, uniform auctions will increase cost-effectiveness relative to fixed price systems. Thus, I hypothesize that either type of auctions will be more cost-effective compared to the first come, first served baseline. However, when comparing the two types of auctions, I hypothesize the first price, discriminatory auction with environmental and social benefit targeting will outperform second price, discriminatory auctions. This is due to the fact that second price, uniform auctions have informational rents built into the auction mechanism. Each landowner awarded a contract receives the lowest rejected bid, not the bid they submitted. Spending more of the budget on informational rents will lead to less being spent on capturing environmental benefits. Theory does not offer clear predictions about how different auction types will affect the distribution of
participation. However, it is logical to expect that the auctions with social targeting will increase participation by landowners in the targeted categories.

Over the past decade, the “Overview, Design concepts, and Details (ODD) protocol” has become the standard way of describing ABMs. The ODD protocol was established as a means to standardize the structure for reporting ABMs in the literature. The generic format of the protocol not only creates a uniform structure for authors to follow when publishing ABMs, but also creates a standard for making model descriptions more understandable and complete for researchers who would like to replicate the ABM in their work. The protocol requires seven sections in sequential order, which are: (1) the purpose of the model, (2) the state variables and scales, (3) an overview of the processing and scheduling implemented in the model, (4) a description of the design concepts, (5) the factors used to initialize the model, (6) a description of the input data, and (7) the submodels used. The following model description follows the ODD protocol (Grimm et al. 2006, Grimm et al. 2010).

Model Description

Purpose

The purpose of this study is to develop an ABM to explore how auctions could be incorporated into an existing PES program and understand possible implications for cost-effectiveness and equity in participation. Unlike previous studies that use simulated data in an ABM to examine the cost-effectiveness of auctions, this model utilizes landowner data from PSA forest protection contracts that were awarded from 2005 to 2014. Thus, this ABM is based on the actual joint distribution of property characteristics, rather than their assumed distribution. Specifically, I use data on PSA participants, which is both an advantage, in that they clearly represent properties that are potential participants, and a disadvantage, in that I cannot assess whether auctions will expand the number or the type of landowners that will participate in PSA. Thus, I focus on how various auction types and targeting mechanisms can increase or decrease the cost-effectiveness of the program and re-distribute participation among participants.

The design concepts include: (1) a description of the basic principles used in the model, (2) descriptions of emerging and adaptive behavior in agents, (3) the objectives of the agents, (4) the ability of the agents to learn, predict future behavior, sense, and interact with each other, (5) a description of stochastic variables, and (6) what data is being observed and collected from the model.
State Variables and Scales

The Landowner Agent is the only agent in this model. Each agent is heterogeneous in the:

1. Size of their parcel of land
2. Amount of land offered to the PES program
3. Opportunity cost of participation
4. IDS of the district where the parcel of land is located
5. Environmental benefits of land offered to the program
6. The year that they participate in the auction.

Each agent is aware of their own opportunity cost, the size of their parcel of land, the IDS of their location and the transaction costs of participating (15% of the payment as a fee to the forester or intermediary that creates the management plan that is necessary for being awarded a forest protection contract). In the first price auctions, agents also know the cost of the parcel with the highest enrollment cost. As is typical of PES programs, only the administrator, and not the landowner agents, knows the environmental benefits of land offered to the program. The Landowner Agents in the model are created based on the location and characteristics of land enrolled in the PSA forest protection program from 2005 to 2014. That is, I use the actual participants in the program, who have revealed that they are eligible and willing sign up for PSA contracts, to define the pool of Landowner Agents who participate in our auction in each year. For each year, I know the locations of all parcels of land where contracts were issued (Figure 2), which allows us to identify the environmental benefit, opportunity cost, and IDS of contracts issued in that year. Further, I know the number of hectares of both the entire parcel of land and the amount of land under contract.

Process Overview and Scheduling

This model represents a landscape of individual parcels of land that range in size and location, each comprised of a forested land that can be submitted into the PES program, also ranging in size. Each Landowner Agent owns one property with a fixed area of forest appropriate for the PSA program (based on amount of hectares actually enrolled in the program). The landowner decides, based on the potential agricultural profits from their land as estimated by Vega (2014), a per hectare bid to be submitted for a forest conservation contract on that fixed area. Each time step is one year and the auction runs for 10 years.
Each Landowner Agent is assigned a year in which they can participate in the auction (based on the year they were awarded a PSA forest protection contract). In each time step, all eligible Landowner Agents submit their optimal bid for a forest protection contract. The bidding strategy is based on the type of auction and is detailed in the ‘Submodels’ section. Bids are sorted based on the targeting rules and accepted until the budget is exhausted. The auction is nationwide.

![Figure 2. The location of all parcels of land (marked in red) included in this analysis](image)

**Design Concepts**

**Basic Principles**

The modeling for this ABM was done with R, using the RStudio interface and the base package.

The design of this ABM draws on the work done by Hailu and Schilizzi (2004) and Hailu and Thoyer (2007) on multi-unit procurement auctions. This model also draws from the work done by Lundberg et al. (2018) to examine the cost-effectiveness gains from a procurement auction compared to a fixed payment scheme in a forest protection PES program. In these previous ABMs, the landowner data are simulated.

The basic principles of the ABM are based on auction theory, which is used to design the auction and define bidding strategies used by Landowner Agents. For a second price, uniform
auction, the weakly dominant bidding strategy is for the landowners to bid their opportunity cost (Vickrey 1961; Vickrey 1976). For a first price, discriminatory auction, the optimal bidding strategy is based on the work of Iftekari and Latacz-Lohnman (2017).

This model also draws the basic auction design from previous works discussing the use of auctions in allocating contracts for PES programs (e.g. (second price, uniform auctions) Jindal et al 2011; (targeting) Ferraro 2008).

**Emergence**

The key results of the model, including the categorization of the auction winners (smallholders or low IDS landowners) and the characteristics of the land enrolled in the program emerge from the variation in both the auction environment and the level of targeting. The first level of variation is in the auction environment as presented in Table 4. Each auction environment results in a different optimal bidding strategy for the Landowner Agent. Additionally, each type of targeting results in a different winner (Landowner Agents awarded contracts) selection process. The second level of variation is in the heterogeneity of the Landowner Agents participating in the auction for each time step\(^{18}\). Therefore, the overall cost-effectiveness of each environment emerges from both levels of variation. The variations in each environment as well as the number and characteristics of Landowner Agents in each time step also allow for the emergence of equity in participation, i.e. percentage participation by smallholders and landowners in low IDS districts compared to the percentage of winners in each category.

**Adaptation**

Each Landowner Agent adapts their bidding strategy based on the auction environment as outlined in Table 4. Additionally, as the Landowner Agents that are able to participate in the auction in each time step are heterogeneous and bidding strategies vary across auction environments, Landowner Agents in each time step will adapt their bid based on their environment.

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\(^{18}\)This is discussed in detail in the “Initialization and Input” section as well as Table 6.
**Objectives**

The objective of the Landowner Agent is to maximize profits if selected as an auction winner. To do so the Landowner Agents follow the optimal bidding strategy as described in Table 4 and the Submodel section of this paper.

**Interaction**

The Landowner Agents do not interact directly. However, information about the highest opportunity cost of any property in that auction year is known. This cost information is used in the optimal bidding strategy.

Table 4. An outline of the variation in auction environments for the models being examined, including a description of the optimal bidding strategy for the Landowner Agent, the level of targeting, and how winners are selected. The environmental benefit score is determined by the first four factors of the Matrix scoring system. The environmental and social benefit score is determined by all factors of the Matrix.

<table>
<thead>
<tr>
<th>Auction Environment</th>
<th>Optimal Bidding Strategy</th>
<th>Targeting</th>
<th>Winner Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline: First Come, First Served</td>
<td>Bid Opportunity Cost Plus Transaction Costs</td>
<td>No Targeting</td>
<td>Random</td>
</tr>
<tr>
<td>First Price, Discriminatory</td>
<td>Optimal Bid Based on Opportunity Cost, Transaction Costs, and the highest opportunity costs of any property in that auction year</td>
<td>Environmental Benefit Targeting</td>
<td>Lowest Dollar per Environmental Benefit Score based on the first four factors in Matrix Scoring System</td>
</tr>
<tr>
<td></td>
<td>Environmental Benefit and Social Targeting</td>
<td></td>
<td>Lowest Dollar per Environmental and Social Benefit based on all factors in Matrix Scoring System</td>
</tr>
<tr>
<td>Second Price, Uniform</td>
<td>Bid Opportunity Cost Plus Transaction Costs</td>
<td>No Targeting</td>
<td>Lowest Dollar per Hectare</td>
</tr>
<tr>
<td></td>
<td>Environmental Benefit Targeting</td>
<td></td>
<td>Lowest Dollar per Environmental Benefit Score based on the first four factors in Matrix Scoring System</td>
</tr>
<tr>
<td></td>
<td>Environmental Benefit and Social Targeting</td>
<td></td>
<td>Lowest Dollar per Environmental and Social Benefit based on all factors in Matrix Scoring System</td>
</tr>
</tbody>
</table>
Stochasticity

Stochasticity is present in each of the auction environments. For the first come, first served scenario, winners are chosen at random. In each of the discriminatory and the uniform auction, bids that are tied are randomly selected.

Observation

To understand the cost-effectiveness of each auction variation the total number of hectares, the dollars spent, and the environmental benefit gained from each auction is recorded for each time step. To understand the equity of participation in each auction environment, the total number of winners, the number of winners who are smallholders, and the number of winners who are low IDS landowners will also be recorded for each time step.

Initialization and Input

In this model Landowner Agents are initialized and parameterized based on contract data from the PSA program in the 2005 to 2014 time period.

Data

Data used in this analysis are drawn from two sources: (1) spatial data on contracts signed from 2005 to 2014 and (2) opportunity cost estimates. These data are used to parametrize the characteristics of the agents and the property being auctioned in the model.

Contract Data 2005-2014

In 2015, the Costa Rican Institute of Technology compiled data on all PSA contracts signed from 2005 to 2014 including: the contract number, the sub-program, the location of the property (canton and district), the number of hectares on the property, the number of hectares enrolled in PSA, the IDS of the district where the property is located, and the score based on the Matrix (Aguilar 2015). Contract data were obtained from FONAFIFO’s Integrated Project Administration System and combined with spatial secondary data on the Matrix components.

Opportunity Cost

FONAFIFO contracted Vega (2014) to estimate the opportunity cost per hectare of participation in PSA for all of Costa Rica’s rural land. Vega (2014) quantified opportunity costs based on the productivity of land, accessibility to markets and services, and available infrastructure and public services. The opportunity cost of each parcel in the contract database is identified by overlaying the contract and opportunity cost databases. The opportunity cost of
contracts on properties that fall into more than one opportunity cost zone are based on an area-weighted average.

Data Description

Rather than making assumptions about the joint distribution of property and owner characteristics, I create agents reflecting the characteristics of landowners actually enrolled in the PSA forest protection program from 2005 to 2014. Thus, I have empirical data on the correlations among property characteristics, as shown in Table 5. These correlations are key to the ABM, because a strong correlation between two attributes, such as opportunity cost and the environmental benefits provided, can strongly affect the outcome of an auction. However, in our case, most of the correlations are small, even though many of them are statistically significant at the 1% level¹⁹.

<table>
<thead>
<tr>
<th>Opportunity Cost</th>
<th>Farm Size</th>
<th>IDS Score</th>
<th>Environmental Benefits Score</th>
<th>Environmental Benefits and Social Objectives Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opportunity Cost</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Size</td>
<td>-0.0342</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDS Score</td>
<td>-0.0158</td>
<td>-0.0665 ***</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Environmental Benefits Score</td>
<td>-0.1155 ***</td>
<td>0.0507 ***</td>
<td>-0.0314</td>
<td>1</td>
</tr>
<tr>
<td>Environmental Benefits and Social Objectives Score</td>
<td>-0.0656 ***</td>
<td>-0.0128</td>
<td>-0.1473 ***</td>
<td>0.5871 ***</td>
</tr>
</tbody>
</table>

Table 5. A correlation matrix of the characteristics of the land that will be used in the agent-based model. *** indicates significance at the 1% level

For each type of auction, there are ten time steps. In each time step, the total budget from contracts is equal to the average value (in USD) of PSA forest protection contracts awarded from 2005 to 2014: $8,091,928²⁰.

A sub-set of the heterogeneous Landowner Agents are assigned to participate in each step. The time step assigned to each Landowner Agent is based on the year that their actual

¹⁹ There is a moderate correlation, between the Environmental Benefits Score and the Environmental Benefits and Social Objective Score. This is expected as the Environmental Benefits Score is a part of the Environmental and Social Objective Score. However, in this analysis these scores are never used simultaneously.
²⁰ In reality FONAFIFO does not pay out the full amount of the contract once it is awarded. When a contract is awarded for a 5 year contract, 20% of the contract value is paid to the landowner in each year. The value presented as the budget is the average of the full value of contracts awarded for each year awarded from 2005 to 2014. In other words it is the average how much would be spent each year if FONAFIFO paid the full amount to landowners at the time the contract was awarded.
contract was issued. This design reflects real world conditions in that the program design and the budget can remain the same, but there may be substantial variation in the number of landowners who bid for contracts in each year and variation the characteristics of the land being offered from year to year. The initial conditions for each time step are presented in Table 6, including the number of landowners that participate in the auction and the area of forest for which they submit bids. The first year ($t_0$) corresponds to the data on PSA contracts issued in 2005.
Table 6. Initial conditions for each time step, where time $t_0=2005$

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Participants</strong></td>
<td>375</td>
<td>176</td>
<td>400</td>
<td>442</td>
<td>179</td>
<td>251</td>
<td>362</td>
<td>439</td>
<td>224</td>
<td>267</td>
</tr>
<tr>
<td>Smallholders (&lt; 50 hectares)</td>
<td>121</td>
<td>67</td>
<td>144</td>
<td>168</td>
<td>50</td>
<td>97</td>
<td>154</td>
<td>218</td>
<td>127</td>
<td>167</td>
</tr>
<tr>
<td>Low IDS</td>
<td>164</td>
<td>75</td>
<td>152</td>
<td>152</td>
<td>59</td>
<td>108</td>
<td>154</td>
<td>203</td>
<td>110</td>
<td>124</td>
</tr>
<tr>
<td>Both</td>
<td>34</td>
<td>32</td>
<td>41</td>
<td>42</td>
<td>22</td>
<td>38</td>
<td>59</td>
<td>75</td>
<td>49</td>
<td>60</td>
</tr>
<tr>
<td><strong>Total Hectares Offered</strong></td>
<td>27335.99</td>
<td>11718.4</td>
<td>31619.4</td>
<td>38808.9</td>
<td>15593.9</td>
<td>17560.8</td>
<td>27704.5</td>
<td>27101.5</td>
<td>13002.7</td>
<td>10933.29</td>
</tr>
<tr>
<td><strong>Total Environmental Benefit Offered</strong></td>
<td>26250</td>
<td>12890</td>
<td>27965</td>
<td>31075</td>
<td>13285</td>
<td>16610</td>
<td>24925</td>
<td>30285</td>
<td>14625</td>
<td>16620</td>
</tr>
<tr>
<td><strong>Total Environmental and Social Benefit Offered</strong></td>
<td>30915</td>
<td>15315</td>
<td>33085</td>
<td>36795</td>
<td>15125</td>
<td>20115</td>
<td>30315</td>
<td>37765</td>
<td>18900</td>
<td>22035</td>
</tr>
</tbody>
</table>
**Submodels**

**Landowner Bidding Strategy**

Each auction offers a five year forest protection contract. This is based on the actual contract duration for the PSA forest protection program for contracts awarded from 2005 to 2011 and 2014. Each bid submitted by the landowner is the bid per hectare for a five year contract. The cost of participation for each Landowner Agent is:

\[ c_i = \text{transaction costs}_i + \left( \frac{\text{opportunity cost}_i}{\text{hectare}} \times 5 \right) \]

\[ \text{transaction costs}_i = \left( \frac{\text{opportunity cost}_i}{\text{hectare}} \times 5 \right) \times 0.15 \]

Where

- \( c_i \) is the total cost to the landowner (opportunity cost and transaction cost)

**First Come, First Served**

In the first come, first served environment, Landowner Agents submit bids that cover their opportunity and transaction costs. Each bid is:

\[ b_i^* = c_i \]

**First Price, Discriminatory**

The optimal bidding strategy used in the first price, discriminatory auction is based on the research done by Iftekhar and Latacz-Lohmann (2017), in which they derive the optimal bid offer for a bidder that is maximizing their net payoff, while balancing the probability of winning. The optimal bidding strategy used in first price, discriminatory auction is shown below:

\[ b_i^* = c_i + \frac{\bar{c} - c_i}{N - 1} \]

**Second Price, Uniform**

The optimal bidding strategy for a second price, uniform auction is for the agent to bid their exact cost for a five year contract (opportunity cost plus transaction costs) (Vickrey 1961):

\[ b_i^* = c_i \]

Where:

---

21 In 2012 and 2013 contracts were awarded for 10 years. However, for consistency in the model, contracts in these years will be awarded for 5 years.
$b^*_i$ is the optimal bidding strategy of the individual landowner

c_i$ is the total cost to the landowner (opportunity cost and transaction cost)

$\bar{c}$ is the cost of participation for the landowner with the highest costs

$N$ is the number of individuals participating in the auction

**Winner Selection**

First Come, First Served

In the first come, first served model, bids are selected at random. For each time step all agents are randomly assigned a participant number from 1 to the number of participants in that auction (e.g. in 2005 ($t_0$) agents are assigned a number from 1 to 375). These numbers are then sorted in ascending order. Bids are accepted starting with the agent assigned number 1 and bids are accepted in ascending order until the budget was exhausted. The results presented are the average of 50 runs. This submodel makes no assumptions about the order Landowners are chosen. In other words, there is no assumed correlation between which Landowner Agent bids first and their property characteristics (i.e. size, IDS of district, or location in environmental priority area).

First Price, Discriminatory

The first price, discriminatory auction pays the winning Landowner Agent the price they bid. When there is no targeting, bids are sorted in ascending order. Bids are accepted until the budget is exhausted. In auctions with targeting, the score is based on the Matrix scoring system. The environmental benefits (EB) a parcel of land can provide is based on the first four factors of the Matrix. The environmental and social benefits (EBS) a parcel of land can provide is based on all factors of the Matrix. As an example, if Landowner A has a forest in a conservation gap (85 points), is located in a low IDS district area (10 points), and has a parcel of land less than 50 hectares (25 points). In an auction where there is EB targeting, Landowner A will have 85 points. In the auction where there is EBS targeting Landowner A will have 120 points.

In the auction with environmental targeting, bids are analyzed as a ratio of dollar per environmental benefit ($/EB$) and these bids are sorted from lowest to highest. These bids are accepted until the budget is exhausted. The final auction accepts bids as ratio of dollar per the environmental priorities and social priorities ($/EBS$) as outlined in the Matrix. When there is a tie in bids, winners are chosen at random.
Second Price, Uniform

The second price, uniform auction pays each landowner the price of the lowest rejected bid. Just as in the first price auction, when there is no targeting, bids are sorted in ascending order. Starting with the first agent \( (agent_n) \), the model calculates the budget that will remain if this agent received the bid of the next agent \( (agent_{n+1}) \). If the budget is greater than zero, \( agent_n \) becomes a winner and the model continues and offers \( agent_n \) and \( agent_{n+1} \) the bid of \( agent_{n+2} \). This pattern of offering the next highest bid to all previous agents is continued until the budget is exhausted. For the second price, uniform auction with targeting, bids are analyzed as \$/EB or \$/EBS. As the second price, uniform auction pays the landowner the bid of the lowest rejected bid. Landowners are paid the dollar per environmental benefit \( (\$/EB) \) of the lowest rejected bid.

**Results and Discussion**

This analysis examines the cost-effectiveness and the implications for equity in participation when introducing an auction mechanism with a fixed budget into Costa Rica’s PSA forest protection program. The first type of auction is a first price, discriminatory (FP) auction with no targeting \( (FP\text{-}NT) \), environmental benefits targeting \( (FP\text{-}EB) \), and environmental and social benefits targeting \( (FP\text{-}EBS) \). The second type of auction is a second price, uniform (SP) auction with the same levels of targeting \( (SP\text{-}NT, SP\text{-}EB, SP\text{-}EBS) \). A first come, first served \( (FCFS) \) scenario where landowners are chosen at random is used as a baseline. In the following sections, cost-effectiveness and the implications for equity in participation for each auction is discussed, synthesizing the auction results. The first section discusses the cost-effectiveness of each auction and targeting level in terms of the informational rents captured by the landowners and the environmental benefits captured per dollar spent. The last section discusses the implications for equity in participation. I consider this distribution to be more equitable if there is a positive bias in representation for winners who are smallholders or landowners in low IDS districts. The bias indicator is constructed by subtracting the percent of the participants that are smallholders or have land in low IDS areas from the percent of winners in these categories. For each auction and targeting level, the bias in representation for smallholders and landowners in low IDS areas is analyzed and discussed. Tables of complete auction results for each time step are located in Appendix B.
Cost-effectiveness

Auctions are often suggested for PES programs as a way of increasing the cost-effectiveness of a program. Cost-effectiveness, in this analysis, is measured by two factors: (1) the amount of informational rents captured by landowners being awarded contracts and (2) environmental benefits generated per dollar. Each factor is discussed below.

Informational Rents

One way to measure the cost-effectiveness of an auction mechanism is to examine the informational rents captured by winners. By reducing informational rents, auctions allow for more of the budget to be used for conservation and thus be more cost-effective. Table 7 summarizes the informational rents obtained by Landowner Agents who were awarded contracts in each auction environment. In the FP auctions, informational rents are generated by the bidding strategy of the Landowner Agent. In theory, the landowner’s optimal bidding strategy is to bid higher than his opportunity and transactions costs. The difference between his bid and his costs are his informational rents. For each of the FP auctions, the informational rents captured by winners are less than $1.4 million for the ten year time period. The FP-NT auction paid a sum of $1,337,409 in informational rents across all years, the highest of all the FP auctions. Targeting did result in a decrease in the amount of informational rents captured. The FP-EB auction paid $1,336,482 in informational rents. These rents decrease to $1,336,316 in the FP-EBS auction.

Contrary to FP auctions, in SP auctions informational rents are not gained through the bidding strategy of the Landowner Agent, as the optimal bidding strategy is to bid their full costs of participation. Informational rents in an SP auction are essentially built into the auction. When bids are sorted from lowest to highest, each winning Landowner Agent receives the bid of the lowest rejected bid. While it may seem counterintuitive to use such a mechanism in a PES scheme, SP auctions can be seen as more fair as each contract winner receives the same payment level (Jindal et al. 2013). However, when comparing the SP auction results of this ABM to the FP auctions as shown in Figure 3, the difference in the amount of informational rents captured is apparent. In the SP-NT auction, $55,429,733 in rents were paid over all years. Therefore, in each

22In the FCFS baseline, agents offer their bid as their opportunity cost plus 15% transaction costs. Agents whose bids are accepted are paid the bid they submitted. Therefore, in this mechanism, no informational rents are captured.
year, the majority of the budget was used to pay informational rents of winning Landowner Agents. Unlike the FP auctions were targeting decreased informational rents, these rents were increased in SP auctions with targeting. In the SP-EB and SP-EBS auctions, informational rents increased to $66,756,390 and $65,996,410 respectively.

Table 7. The sum of informational rents captured by Landowner Agents in each auction environment

<table>
<thead>
<tr>
<th>Auction Environment</th>
<th>Informational Rents</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP-NT</td>
<td>$1,337,409</td>
</tr>
<tr>
<td>FP-EB</td>
<td>$1,336,482</td>
</tr>
<tr>
<td>FP-EBS</td>
<td>$1,336,316</td>
</tr>
<tr>
<td>SP-NT</td>
<td>$55,429,733</td>
</tr>
<tr>
<td>SP-EB</td>
<td>$66,756,390</td>
</tr>
<tr>
<td>SP-EBS</td>
<td>$65,996,410</td>
</tr>
</tbody>
</table>

Figure 3. Informational rents captured in each learning environment and each targeting level by year.

Environmental Benefits per Dollar

In this analysis, cost-effectiveness is also measured by environmental benefits per dollar spent (EB/$). The scoring for environmental benefits captured is based on the Matrix scoring
system used by FONAFIFO for the forest protection program. Figure 4 shows the environmental benefits captured per $1000 spent in each auction environment. In the FCFS baseline where landowners are chosen at random, the EB/$ over the 10 years of the auction is 2.62.

Each FP auction outperforms the FCFS baseline. The FP-NT auction generates 3.09 EB/$. Surprisingly, the FP-NT auction generates slightly more environmental benefits than the FP-EB auction which generated 3.06 EB/$. However, environmental and social targeting in the FP-EBS auction, generated the most EB/$ of all the auctions examined in this study.

Similar to the case of informational rents, there is a stark difference between the EB/$ captured by FP and SP auctions. As shown in Figure 4, FP auctions show a general improvement in cost-effectiveness and SP auctions show a general decline in cost-effectiveness. The SP-NT auction resulted in the highest EB/$ of all SP auctions, generating 2.01 EB/$. Introducing targeting into the auctions did not improve the EB/$ generated. The SP-EB and SP-EBS auctions generated 1.98 and 2.00 EB/$, respectively.

Equity in Participation

As Costa Rica’s PSA program has dual goals of forest protection and poverty alleviation, it is also important to understand how introducing various auctions can change equity in participation. For this study, equity is measured by subtracting the percent of the participants that are smallholders or have land in low IDS areas from the percent of winners in these categories. I label these indicators as “bias in representation”. A negative (< 0) bias indicates that landowners in the targeted social category were underrepresented among winners and a positive (% > 0) bias indicates an overrepresentation of the targeted group among winners. As smallholders and
landowners in low IDS districts are targeted by the Matrix, an auction that has a positive bias towards selecting landowners in these groups are ideal.

**Smallholders**

The Matrix scoring system allows for 25 additional points to be added to the application score of landowners who have less than 50 hectares on their land. Figure 5 shows the bias in representation for smallholders among winners of the auction across all auction years. This statistic is the difference between the percent of winners that were smallholders and the percent of participants that were smallholders in the auction. A negative bias therefore indicates an auction results in underrepresentation of smallholders. In the FCFS mechanism for choosing winners, there is a positive bias, indicating a slight over representation of smallholders as winners. In the FP-NT auction there is a slight negative bias in representing of -0.01%. This negative bias in participation is intensified when environmental targeting is introduced in the FP-EB auction. However, when targeting for both environmental and social goals, there is a positive bias in representation for smallholders.

Smallholders fared well in all SP auctions. When there is no targeting, there is a positive bias in representation for smallholders, however, there is a decrease in the SP-EB auction. The auction mechanisms which benefits smallholders the most is the SP-EBS auction which results in positive bias in representation of 2.52%. However, it is important to note that overall, there are less winners in the SP auctions compared to the FP auctions. Therefore, while smallholders maybe overrepresented in terms of percent, generally there are fewer landowners and fewer smallholders are being awarded contracts compared to FP auctions.
Landowners in Low IDS Districts

The Matrix scoring system also prioritizes landowners who are located in districts where the IDS is less than 40 by awarding each application from landowners in this category with 10 additional points. Figure 6 shows the bias in representation for low IDS landowners in each auction environment. Similar to the case of smallholders, there is a positive bias in representation in the FCFS mechanism for choosing winners. However, in both the FP and SP auction environments there is only a positive bias in representation for low IDS landowners when there is targeting for both environmental and social objectives.

Figure 5. Bias in equity of participation for smallholders (those owning less than 50 hectares) among winners.
Conclusion

PES programs are being established in many countries to combat a number of environmental issues. While some economists advocate for PES programs as being more cost-effective than other means of conservation, in theory, many programs are not observing these efficiencies in practice. One barrier to achieving cost-effectiveness in PES programs is information asymmetry. In a cost-effective PES program, landowners would be paid their cost of participation. However, opportunity costs, which are included in the cost of participation, are private information and as it can be difficult to estimate the opportunity cost of each landowner, implementing agencies often offer a flat, per hectare fee for participation. This flat fee can reduce cost-effectiveness in two ways. First, landowners who have opportunity costs less than the flat fee gain informational rents. These rents reduce the amount of dollars that can be used for conservation. The second barrier to cost-effectiveness is that landowners who have opportunity costs higher than the flat fee, but whose land can provide a large amount of ecosystem services will not participate as their costs are not covered.

PES procurement auctions can be used to mitigate this issue. Procurement auctions allow landowners to submit their bid for conservation contracts and winners are chosen based on the rules of the auction. The competitive bidding element of auctions can allow for the reduction of informational rents. If landowners place a bid that is too high, they may get a high net payoff if
they win, but they increase their chance of losing as well. Therefore, it is optimal for the landowner to bid close to their costs of participation. Procurement auctions have been implemented in a variety of settings and have been shown to increase cost-effectiveness in PES programs.

The objective of this paper was to examine the cost-effectiveness and understand possible shifts in equity in participation when implementing procurement auctions in Costa Rica’s PSA forest protection modality using an ABM. The two types of auctions implemented were a first price, discriminatory auction and a second price, uniform auction with various levels of targeting based on the Matrix scoring system. Cost-effectiveness was measured by the environmental benefits secured per dollar spent and the amount of informational rents paid to winning landowners. Equity in participation was measured by the representation of smallholders and low IDS landowners in the number of auction winners.

When examining cost-effectiveness, the first price, discriminatory auctions were more cost-effective than the second price, uniform auctions. One reason for this is uniform pricing auctions have informational rents built into the auction mechanism. Therefore a large amount of the budget is spent on informational rents, which could have been used to secure more environmental benefits. While uniform pricing may be perceived as more fair as all winner receive the same payment, if a PES program is looking to increase cost-effectiveness by decreasing informational rents through an auction mechanism, these result indicate that first price auctions are a better option. Of the first price auctions, environmental targeting coupled with social targeting was the most cost-effective in maximizing environmental benefits per dollar and minimizing informational rents.

As the PSA program also has a social objective to alleviate poverty, the Matrix scoring system not only targets environmental objectives but social objectives as well. This is done through assigning additional points to applications of landowners who own less than 50 hectares and landowners in areas where the IDS score is less than 40. Equity in participation for these targeted groups was also examined. There was a positive bias in representation for smallholders in both the first price and second price auctions with environmental and social benefits targeting. Low IDS landowners were underrepresented in all auction environments, except the auctions with environmental and social benefits targeting.
For PES programs such as Costa Rica’s PSA forest protection program that would like to increase cost-effectiveness and meet social objectives, results of this analysis show that a first price, discriminatory auction with environmental and social benefits targeting may be the best mechanism to achieve both goals. This auction generates the highest EB/$ and one of the lowest level of informational rents of all the auctions examined in the paper. Additionally, in the first price, discriminatory auction with environmental and social benefits targeting smallholders and landowners in low IDS areas are either exactly represented or overrepresented. However, it is important to note that this analysis does not include the cost of operating an auction mechanism to the implementing agency. It is possible the costs of running a nationwide auction in a developing country will far outweigh the efficiency gains of implementing an auction. Future work will address the possible auction scales (i.e. regional or district level) and associated costs of implementing an auction into an existing PES program.

In this chapter, the implications of introducing procurement auctions in an existing PES program were examined. Each agent behaved optimally and faced the same set of conditions and transaction costs for participation. This analysis focuses on aggregate level results. Future work will expand this analysis to examine the implications of using PSA participant information to represent all potential participants in Costa Rica. Future work will also compare the distributions of contracts awarded to smallholders, for example, to the distribution of all smallholders in Costa Rica that could potentially be participants. This could provide a more robust understanding of equity in participation. Additionally, the auction presented in the model is an ideal and may not be an accurate representation of landowner behavior in the real world. As these auctions are run annually, it is possible that landowners can learn from the results of auctions in the previous year and use this information to their advantage. In the next chapter, agents will use the auction results of previous years to adjust their bids. This scenario will be examined in the context of Cost Rica’s PSA forest protection program with a focus on implications for the cost-effectiveness of the program and equity in participation.
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CHAPTER 4: An Examination of the Implications of Learning on Bidding Behavior in a Repeated First Price Procurement Auction with Targeting

Introduction

Payment for ecosystem services (PES) programs have been defined as “voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating off site services” (Wunder 2014). The institutions that implement PES programs (often government agencies) typically pay the service providers (often landowners) to implement specific management practices expected to generate environmental benefits for the community at large. Contracts between the landowner and the implementing agency detail the specific management practice that must be put in place, the length of time the land is under contract, and the payment. These contractual choices are made in the context of information asymmetries. In particular, when contracts require landowners to maintain existing natural ecosystems, the landowner’s opportunity cost of participation is private information, making it difficult for the implementing agency to determine the cost of participation for each landowner that applies for a contract. Therefore in many PES programs, a flat payment per hectare is offered for participation in the program. For some landowners, the cost of participation is lower than the offered payment. The difference between the payment the landowner receives and their actual cost of participation, including their opportunity cost and transaction costs, is called informational rent. Informational rents reduce the cost-effectiveness of PES programs as the implementing agency conserves fewer hectares or environmental benefits per dollar than it would have if landowners were paid their true participation costs.

Procurement auctions are often discussed as a means to reducing informational rents. In these auctions, landowners determine the payment level required to implement the management practice needed to generate the desired ecosystem service. This payment is submitted as a bid to the auction. Auctions can reduce informational rents through competitive bidding. If a landowner bids too high, the net payoff may be large, but the chances of being selected for the program are reduced. Therefore, in auctions, landowners have an incentive to bid close to their opportunity cost.

Repeated Auctions

Several studies have examined the cost-effectiveness of auctions compared to fixed price schemes in PES programs. The results from trial run auctions (e.g. Scotland (Latacz-Lohmann
and Schilizzi 2005), Australia (Stoneham et al. 2003), and Germany (Groth 2011)) and computational models (e.g. Lundberg et al. 2018) show that procurement auctions can be more cost-effective in obtaining environmental benefits than fixed price schemes. However, many of these studies examine the outcomes of one shot auctions, in which the bidders cannot learn from the results of prior auctions. In practice, on-going PES programs offer contracts in multiple rounds. If a procurement auction were used in each round, it would be possible for bidders to learn from the previous auction results. The information learned could help bidders determine information that is not disclosed to them such as the program budget, the maximum allowable bid, or the implementing agency’s assessment of environmental benefits that can be gained from land enrolled in the program (Klemperer 2002). Gaining this information could generate positive or negative results depending on how bidders use this information. For example, consider a landowner that has a parcel of land that can generate a high level of ecosystem services, but her cost of participation is high. She may think her costs are too high and not participate in the auction. However, if she learns that the maximum allowable bid is greater than her cost of participation that she may enter the auction. This is a positive result for the agency in that land where valuable ecosystem services can be generated will be conserved. However it is possible that learning can lead to negative results in that bidders can use information they learn to strategically change their bids to increase their informational rents (List and Shogren 1999, Klimek et al. 2008). As learning occurs over the years of a repeated auction, this could increase the homogeneity of bids, which would diminish the cost-effectiveness of an auction over time (Klimek et al. 2008, Schilizzi and Latacz-Lohmann 2007). This paper focuses on the use of information by bidders to strategically increase their bids, and thus their informational rents, resulting to a less cost-efficient outcome.

There is little empirical evidence on the effect of learning on the cost-efficiency of procurement auctions in PES programs. This can be attributed to the fact that there is only one long standing PES procurement auction. Introduced in 1985, the United States’ Conservation Reserve Program (CRP) allows farmers to enter a bid in a first-price sealed auction for the portion of land they are willing to remove from agricultural production and place into conservation. There can be several sign-up (auction) periods within a given year. Studies examining the initial years of the program found evidence of learning. For example, in the auctions that took place in 1986, the distribution of bids decreased from May to August.
compared to the distribution of bids from March to May, suggesting that potential participants were learning about the maximum possible payment rates, or the bid caps (Reichelderfer and Boggess 1988). Considering the first four rounds of sign-ups, Shoemaker (1989) found that in the initial auctions, bids for conservation contracts were lower than the bid cap. By the fourth round of sign-ups, the average bid rate was close to or equaled the bid cap, consistent with the evidence found by Reichelderfer and Boggess (1988) that bidders were learning the bid cap.

Although empirical evidence that learning can diminish the cost-effectiveness of a procurement auction over time is limited, agent-based models (ABM) have been used to fill the gap in understanding the implications for learning and strategic behavior in procurement auctions. ABMs are computational models that allow for a bottom-up approach to analysis. Agents in ABMs interact over space and time, within a closed system, according to a set of rules. The micro-level interactions of these purposeful agents create emergent patterns (e.g. increased/decreased provision of ecosystem services) (Tesfatsion 2002; Page 2005). By allowing for more realistic assumptions about the behavior of agents and the timing of micro-level interactions, ABMs are a useful tool for understanding policy outcomes when empirical evidence is unavailable.

In an ABM developed by Hailu and Schilizzi (2004), agents (landowners) bid on conservation contracts annually. In each subsequent year, agents use information about their performance in the previous year’s auction to adjust their bids. For example, if an agent won the auction in the previous year, they might bid the same or a bit higher in the next year. If an agent lost, they might lower their bid. Similarly, Lundberg et al. (2018) developed an ABM in which agents learn their neighbors’ winning bids in previous years and use this information to adjust their own bids. In both studies, agents are initialized based on assumptions about distributions and correlations between characteristics of landowners and the land they own. Both studies showed that the cost-effectiveness of procurement auctions erode over time when agents can learn the results of past auctions and use that information strategically change their bids.

**Objective**

While a one-shot auction could be used to set payment levels for a PES program, operational use of procurement auctions is much more likely to involve multiple rounds, e.g. annual auctions. Costa Rica’s *Pagos por Servicios Ambientales (PSA)* forest protection program, for example, offers contracts on an annual basis. Thus, if the program allocated contracts via
procurement auctions, landowners could learn from previous auction results. While it is possible that learning in this context can be positive in that it strategically use that information to determine their bids. This raises two questions: (1) would the cost-effectiveness of an auction diminish over time and (2) by how much?

Using the structure of Costa Rica’s PSA forest protection program, I develop an ABM to examine the implications of strategic behavior when landowners can learn from previous auction results in an auction incorporated into an existing PES program. I examine two metrics of cost-effectiveness: the informational rents captured by landowners and the environmental benefits per dollar generated by the program. As the PSA program is also expected to contribute to rural development, I also consider the implications of the auctions on the distribution of participation by quantifying the number of contracts issued to smallholders and landowners in districts with lower socio-economic standing. Thus, I offer evidence relevant to both the cost-effectiveness and equity implications of auctions. In the next section, I review what auction theory suggests about how landowners decide on their bids, including how learning can lead to strategic behavior. The second section describes the ABM following the “Overview, Design concepts, and Details (ODD) protocol”. The final sections present the results and draw conclusions.

**Value Models and Learning**

To predict how learning previous auction results would affect bids in a procurement auction, it is important to understand how bidders estimate their participation costs. Auction theory offers two possible models for this: the independent private values model and the common value model. In the independent private values model, bidders know their exact cost of participation and any one bidder’s value is statistically independent from any other bidder’s value. In the case of a procurement auction for conservation, the bidder’s valuation includes their participation cost and their motivations for participation. Each bidder’s valuation is independent of the valuation of any other bidder. In the common value model, no one bidder knows the true value of the item being offered. In the context of a PES procurement auction, the unknown value is the PES administrator’s valuation of the expected ecosystem services generated by the land being offered into the program. Bidders do not know the price the administrator is willing to pay for the generated ecosystem services, but each bidder has access to information that could inform guesses about the value of ecosystem services that could be generated through conservation. (McAfee and McMillan 1987).
The private information values model and the common value model are based on the two extremes of possible assumptions about bidder information and behavior. For example, if a bidder were to learn that his neighbor was awarded a contract via a procurement auction in the previous year and was told his bid, the bidder would change his bid based on this new information according to the common value model. Conversely, in the independent private values model, learning about a neighbor’s winning bid would not affect a landowner’s bid in the next round because valuations are independent of each other. In reality, bids in an auction are likely to reflect both an independent private values component and a common value component. This can be especially true for procurement auctions.

In procurement auctions for conservations, there are often two factors considered when selecting winners. The first factor is the landowner’s bid. Each landowner assesses their opportunity cost and their other costs of participation (e.g. transactions costs of obtaining the contract and implementation costs of complying with the contract). Using this information, landowners calculate a bid to be submitted to the auction. The second factor is a metric that describes the level of environmental benefits that will be generated if a contract is awarded to a specific landowner. This metric is often determined by the agency implementing the auction and not revealed to the landowner (e.g. Conservation Reserve Program
text cannot be interpreted correctly due to incomplete transcription).

In procurement auctions where environmental benefits are a factor in how contracts are awarded, learning can impact bidding as described in the following scenarios. First, consider a landowner who has assessed her participation costs and prepared her bid for an upcoming auction. During some interaction with her neighbor, the landowner learns about the neighbor’s winning bid in a previous round of the auction. If the neighbor’s winning bid is higher than that of the landowner, the landowner takes this as a signal that her planned bid is too low based on the actual costs of participation and/or the environmental benefits that her land can provide. This

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23In the CRP landowners are told the score for each component of the EBI score, however, landowner will not know their exact EBI score because the precise weight given to each component of the score is not revealed (Claassen, Cattaneo, Johansson 2008)
is based on the premise that neighboring lands are likely similar in terms of potential environmental benefits. Thus, in our example, the landowner would increase her bid.

In the second scenario, the landowner assesses his costs and prepares his bid. Before submitting his bid, the landowner learns that in previous years other landowners in the region have won conservation contracts with higher bids. In this setting, the landowner does not know how similar his land is to the land where conservation contracts were established in previous rounds. Nonetheless, the information that higher bids resulted in contracts acts as a signal that he may be able to increase his bid thus increasing his informational rent.

In the first scenario presented, the common value model applies. As Waldo Tobler’s (1970) first law of geography states, “everything is related to everything else, but closer things are more closely related.” The scenario starts with the landowner assessing her own cost with little or no knowledge of the environmental benefits that her land could provide. However, the landowner knows that her land is similar to her neighbor’s in terms of the potential environmental benefits of conservation. Thus, learning a neighbor has won a contract with a higher bid acts as a signal about the level of environmental benefits her land can provide. Armed with this new information, the landowner changes her bid. This scenario has been observed in experimental settings. For example, Cason and Gangadharan (2004) observed that when landowners were made aware of the level of environmental benefits their land can generate, their bids increased.

In the second scenario, the private information values model applies. Unlike in the first scenario, the landowners who share information about their bids do not assume that their lands provide similar environmental benefits. However, information about the highest winning bids acts as a signal for how high bids can be and still be awarded a contract. As landowners are seeking informational rents, this new information could encourage them to engage in strategic behavior by increasing their bid, even though they have no new information on either their cost of participation or the environmental benefits potentially generated by their land.

As demonstrated by these two scenarios, repeated procurement auctions for conservation contracts provide opportunities for learning and thus strategic behavior on the part of landowners. However, there is little evidence on whether multiple rounds of bidding will actually lead to strategic bidding behavior in PES programs. The only empirical example of repeated auctions, learning, and strategic behavior is the United States’ CRP auctions previously
discussed. Other relevant studies have used ABMs to examining learning and strategic behavior in repeated auctions, however these models use agents that are initialized based on assumptions about landowner distributions and correlations between landowners and the characteristics of their land. One way to bridge the gap between the lack of empirical work and the ABMs is to create agents using real world data about participants in an existing PES program to explore how learning can occur on a real landscape. As the longest running national PES program in the developing world, Costa Rica’s PSA offers a useful test case for this approach. Thus, this study utilizes data about landowners and characteristics of the land that is enrolled in Costa Rica’s PSA forest protection program to model and understand how implementing repeated auctions could allow for learning and strategic behavior within the framework of the program. The following section describes Costa Rica’s PSA forest protection and the data used in this analysis.

**PSA Forest Protection Program**

Established in 1996, Costa Rica’s PSA forest protection program aimed to conserve and protect forest resources and the environmental services they provide. As the most popular program under PSA, the forest protection program was the subject of numerous research studies in the first decade of the program (Sánchez-Azofeifa et al. 2007; Robalino et al. 2008; Robalino and Pfaff 2013; Miranda et al. 2003; Zbinden and Lee 2005). Some of the research conducted during that time criticized the implementing agency, Fondo Nacional de Financiamiento Forestal (FONAFIFO), for the programs lack of cost-effectiveness, in that it does not maximize the additional ecosystem services captured with a given budget. Additionally, as the PSA program has dual goals environmental and social goals, researchers also examined the equity of participation in the forest protection program. Studies found that relatively wealthy landowners with larger properties capture more of the programs funds than poorer landowners with smaller properties (Zbinden and Lee 2005; Porras et al. 2013). In response to these criticisms, FONAFIFO changed the process of reviewing and selecting applications form a “first-come, first-served” process to a scoring process using a Matrix that reflects the environmental and social goals of the program.
The Matrix assigns points based on the expected environmental and social benefits of a contract. Table 1 depicts the scoring system used since 2012. The Matrix contains three environmental criteria based on where the forest parcel proposed for the program is located, with points awarded for parcels located in priority areas: protected areas, conservation gaps, and biological corridors. Each application can only receive points for being in one priority area. If the forest is located in several priority areas, the landowner receives the amount of points from the highest scoring area (e.g., 85 points for forests in conservation gaps). The Matrix also awards points to applications for new contracts on properties that previously had forest protection contracts. In addition to the environmental priorities, the Matrix also addresses concerns about the distribution of participation in PSA by giving more points to applications for contracts on small properties and properties in underdeveloped districts. Specifically, applications for contracts on properties that are small (< 50 ha) are awarded 25 additional points. The Matrix also references the Social Development Index (IDS), which is calculated by the Ministry of National Planning and Economic Policy (MIDEPLAN) as a measure of relative wealth. Applications for contracts on properties in districts with IDS less than 40 receive an additional 10 points. None of these point allocations are weighted by the number of hectares being enrolled. Thus, the lowest score possible is 55 (forests outside priority areas) and the highest score is 130 (forests in conservation gaps within indigenous territories (85 points), that had a contract in previous years (10 points), located in a low IDS area (10 points), on property that is less than 50 hectares (25 points)).

Table 1. Matrix scoring system used for forest protection contracts starting in 2012.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Priorities</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Forests on farms located in areas defined in the Conservation Gaps within Indigenous Territories of the country</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>2 Forests on farms located within the officially established Biological Corridors, Forests that protect water resources or where the importance of protecting the forest is evident</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>3 Forests on farms located within Protected Areas that have not been bought or expropriated by the State</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>4 Forests outside any of the above priorities</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>I Forests in the Forest Protection modality complying with the provisions of the above points, which have signed contracts for payment of environmental services in previous years, provided they meet other requirements</td>
<td>10 additional</td>
<td></td>
</tr>
<tr>
<td>II Forests in farms located in districts with less than 40 on the Social Development Index</td>
<td>10 additional</td>
<td></td>
</tr>
<tr>
<td>III Forests in any of the above priorities, with application to enter the PSA where the size of the farm is equal to or less than 50 hectares</td>
<td>25 additional</td>
<td></td>
</tr>
</tbody>
</table>
ABM and ODD Protocol

In this analysis there are two variations of the ABM presented that represent different learning environments based on the independent private values model and the common value model. In the common value learning environment, agents acquire information about winning bids from their neighbors who were awarded contracts in previous years. In the private values learning environment, agents acquire information about winning bids in the previous year only, from all other landowners in the region (defined as a canton). Agents use the information to develop their bids for a 5 year conservation contract. This analysis builds on the first price, discriminatory auctions presented in the previous chapter. Three variations of a first price auction are presented: (1) no social or environmental targeting, with winners selected based on the lowest per hectare price, (2) targeting based on environmental priorities defined by the Matrix scoring system, and (3) targeting based on both environmental and social priorities as given in the Matrix. For each learning environment and each variation based on different targeting rules, a first price auction with no learning is the baseline.

The outcome of each model is assessed in terms of cost-effectiveness and equity of participation. Cost-effectiveness could be measured in two ways. As a program administrator, FONAFIFO can measure cost-effectiveness by maximizing the environmental benefits gained per dollar spent. This can be done partly by minimizing informational rents. Therefore, I examine the total amount of informational rents captured by landowners in each auction and an index of environmental benefits captured per dollar. Environmental benefits are based on the first four factors in the Matrix Scoring system used by FONAFIFO. Equity in participation is examined in terms of the percent of contracts issued to smallholders who own less than 50 hectares and landowners in areas where the IDS is less than 40. Specifically, I consider the bias in representation of these targeted groups among the winners. Bias, for the purposes of this study, compares the percent of bidders in the auction that are smallholders or located in low IDS areas and the percent of winners who also fall in each category.

In this study, I implement repeated, first price auctions with various targeting rules to examine the implications of learning and strategic behavior. Theory and limited empirical

24This contract length is based on the actual contract lengths for contracts awarded for the majority of the years from 2005 to 2014. Only in 2012 and 2013 were contracts awarded for 10 years.
evidence suggest learning can lead to strategic behavior and that this can diminish the cost-effectiveness of the auctions over time. Thus, I hypothesize that learning and strategic behavior will decrease the cost-effectiveness of auctions through agents increasing the informational rents collected over time in both scenarios presented. However, theory also suggests that targeting should increase cost-effectiveness, therefore I hypothesize that learning will have a larger negative effect on cost-effectiveness in auctions without targeting compared to auctions with targeting. In addition to understanding the implications for strategic behavior via learning in repeated auctions, this study also explores the implications for strategic behavior on equity of participation. To date, no work has been done to understand how strategic behavior can shift equity in participation, therefore I do not pose specific hypotheses about how learning affects the distribution of participation. However, I do hypothesize that targeting social as well as environmental goals will lead to greater participation by disadvantaged landowners.

Established in 2006, the ODD protocol was published as an attempt to standardize the descriptions of ABMs. The ODD protocol provides a generic format and a standard structure for all ABMs to be documented, thus allowing for more complete model descriptions that are easier and more efficient for both the writer and others who seek to replicate the ABM in their work. The protocol requires seven sections in sequential order, which are: (1) the purpose of the model, (2) the state variables and scales, (3) an overview of the processing and scheduling implemented in the model, (4) a description of the design concepts\(^{25}\), (5) the factors used to initialize the model, (6) a description of the input data, and (7) the submodels used in the models processes. The following model description follows the ODD protocol (Grimm et al. 2006, Grimm et al. 2010).

**Model Description**

**Purpose**

The purpose of this ABM is to explore how agent strategic behavior via learning affects outcomes in repeated auctions for a PES program. Expanding on previous studies, I examine

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25 The design concepts include: (1) a description of the basic principles used in the model, (2) descriptions of emerging and adaptive behavior in agents, (3) the objectives of the agents, (4) the ability of the agents to learn, predict future behavior, sense, and interact with each other, (5) a description of stochastic variables, and (6) what data is being observed and collected from the model.
outcomes relevant to both efficiency and equity, specifically cost-effectiveness and participation by disadvantaged landowners.

There are two variations of the ABM presented in this analysis that represent different learning environments based on the independent private values model and the common value model. In the common value learning environment, agents acquire information about winning bids from their neighbors who were awarded contracts in previous years. In the private values learning environment, agents acquire information about winning bids in the previous year only, from all other landowners in the region (defined as a canton). Agents use the information to develop their bids for a 5 year conservation contract. This analysis builds on the first price, discriminatory auctions presented in the previous chapter. Three variations of a first price auction are presented: (1) no social or environmental targeting, with winners selected based on the lowest per hectare price, (2) targeting based on environmental priorities defined by the Matrix scoring system, and (3) targeting based on both environmental and social priorities as given in the Matrix. For each learning environment and each variation based on different targeting rules, a first price auction with no learning is the baseline.

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26This contract length is based on the actual contract lengths for contracts awarded for the majority of the years from 2005 to 2014. Only in 2012 and 2013 were contracts awarded for 10 years.
In this study, I implement repeated, first price auctions with various targeting rules to examine the implications of learning and strategic behavior. Theory and limited empirical evidence suggest learning can lead to strategic behavior and that this can diminish the cost-effectiveness of the auctions over time. Thus, I hypothesize that learning and strategic behavior will decrease the cost-effectiveness of auctions through agents increasing the informational rents collected over time in both scenarios presented. However, theory also suggests that targeting should increase cost-effectiveness, therefore I hypothesize that learning will have a larger negative effect on cost-effectiveness in auctions without targeting compared to auctions with targeting. In addition to understanding the implications for strategic behavior via learning in repeated auctions, this study also explores the implications for strategic behavior on equity of participation. To date, no work has been done to understand how strategic behavior can shift equity in participation, therefore I do not pose specific hypotheses about how learning affects the distribution of participation. However, I do hypothesize that targeting social as well as environmental goals will lead to greater participation by disadvantaged landowners.

**State Variables and Scales**

There are two agents in this model: the Landowner Agent and the Winner Agent. Landowner Agents are heterogeneous in the:

1. Size of their parcel of land
2. Amount of land to be enrolled in the PES program
3. Opportunity costs of participating
4. IDS of their location
5. The environmental benefits obtained by enrolling their land
6. The year that they participate in the auction
7. Who their neighbors are

When the model is initiated, each agent is aware of the size of their parcel of land, the IDS of their location, and their cost of participating including both her opportunity cost per hectare and the transaction costs of participating (15% of the payment as a fee to the forester or intermediary organization that creates the management plan necessary for being awarded a forest protection contract). Further, the model assumes that each agent knows the cost of the parcel with the highest enrollment cost in their auction year as well as the number of participants. This
information is used to calculate their optimal bid\textsuperscript{27}. As this is a spatially explicit model, agents are also aware of who their neighbors are and who lives in their canton. Landowner Agents are not aware of the environmental benefits provided by their land.

The setting for this model includes all land parcels enrolled in the PSA forest protection program from 2005 to 2014. Figure 1 shows these parcels on a map of Costa Rica’s cantons. In the database used for this analysis, 69 (85.2\%) of Costa Rica’s cantons are represented in this model\textsuperscript{28}.

Winner Agents are the second type of agent in this model. These are agents that were Landowner Agents in a previous year, but submitted a winning bid for a five year contract. Winner Agents are responsible for providing Landowner Agents who are participating in the current year’s auction with information about their winning bids\textsuperscript{29}.

\textit{Process Overview and Scheduling}

The heterogeneous Landowner Agents are initialized and parameterized based on contract data from the PSA program from 2005 to 2014. Each Landowner Agent owns one parcel with a fixed area of forest that is offered for enrollment in the PSA program (based on number of hectares actually enrolled in the program). These contract data include the size and location of each parcel of land with forest enrolled in the PSA program. Thus, I can identify both parcels located within the same canton as well as neighboring parcels. Neighbors are defined as parcels where the boundaries of each parcel cross or touch.

\textsuperscript{27}It is possible that in a procurement auction bidders would not have access to information about the costs and values of other bidders. While this uncertainty of other bidder’s costs and values are present in the real world, this model does not examine the implications for this uncertainty. Rather, I examine the implications of targeting and strategic behavior.

\textsuperscript{28}The distributions of the size and population of the cantons in this analysis are presented in Appendix C.

\textsuperscript{29}Although Winner Agents are only under contract for 5 years, they do not re-enter the auction as Landowner Agents once their contract has expired. Future work will examine the implications for cost effectiveness when landowners are able to re-enter the auctions and learn from their own experience.
Each Landowner Agent is assigned a year in which they can participate in the auction (based on the year they were awarded a PSA forest protection contract). Each time step is one year and there is only one auction per time step. For each auction type, there are 10 time steps reflecting the 10 years of data on landowners who participate in the program. The budget for each auction is fixed across each time step. This design is set to reflect real world conditions in that the program design and the budget can remain the same but there may be substantial variation in the number of landowners who bid for contracts.

**Schedule for Learning Model**

There are two learning environments presented in this analysis: the private independent values (IPV) environment and the common value (CV) environment. As outlined in Figure 2, the schedule for each time step takes place in three stages. First, the Landowner Agents participating in that year’s auction set their initial bid. This stage is the same for both learning environments. In the second stage, each Landowner Agent interacts with Winner Agents who provide information about their winning bids. In the third stage, Landowner Agents have the ability to change their bids before submission to the auction.
In the second stage of the IPV environment (left side of Figure 2), each Landowner Agent\(^{30}\) interacts with all Winner Agents in their canton who submitted winning bids only in the previous year’s auction. However, Winner Agents do not provide Landowner Agents with their exact bid. Instead they give the Landowner Agent a “rough idea” of their winning bid by shading their bid by a random factor drawn from a uniform distribution between -10% and +10%. If a Landowner Agent hears of a winning bid that is higher than her optimal bid, this is taken as a signal that the auction can tolerate higher bids. By increasing her bid, the Landowner Agent can increase her informational rent. Therefore, the agent increases her bid calculated in the first stage by up to 10\(^{\%}\).\(^{31}\) In this model, bids are only increased by up to 10\(^{\%}\) to reflect the fact that Landowner Agents know the information they are given may not be accurate. Therefore, the Landowner Agent does not want to increase their bid by too much based on this information and risk losing the auction. If a Landowner Agent does not have any Winner Agents in her canton or if she does not hear of any winning bids higher than her initial bid, her bid stays the same. Each Landowner Agent increases her bid only once.

In the CV environment (right side of Figure 2), Landowner Agents only interact with Winner Agents that are their neighbors. However, Winner Agents provide Landowner Agents with their exact bids from any previous auction year. Because Landowner Agents are aware that the land they are seeking to enroll in PSA may be similar to any land their neighbors have enrolled in the program, if the Landowner Agent hears of a winning bid that is higher than their initial bid, this is taken as a signal that their initial valuation of their land is low based on actual costs of implementing the management plan or the environmental benefits their land can provide. Unlike the IPV learning environment, the Landowner Agent knows their neighbor is providing accurate information about their winning bid and the information can provide insight into the actual value of the land they are planning to enroll in the program. Therefore, rather than increasing her bid by some percent, the Landowner Agents updates her bids by adopting the bid of her neighbor with the highest winning bid. If the Landowner Agent does not have any neighbors that are Winner Agents or if they do not hear of any winning bids higher than

\(^{30}\)In the first time step, there are no previous auctions winners, thus these Landowner Agents do not have the opportunity to learn.

\(^{31}\)This 10\(^{\%}\) increase is consistent with other work done by Hailu and Schilizzi (2004) and Lundberg et. al. (2018)
their initial bid, their bid stays the same. Landowner Agents are able to update their bids until they obtain the highest bid of their neighbors who are Winner Agents.

Schedule for Auction Model

Once each eligible Landowner Agent has determined their bid, their bids are submitted to the nationwide first price auction. Bids are sorted based on the type of targeting and accepted until the budget is exhausted. There are three variations in targeting as presented in Table 2. When there is no targeting (FP-NT), bids are sorted in ascending order and accepted until the budget is exhausted. In auctions where there is environmental benefits (FP-EB) or both environmental benefits and social (FP-EBS), targeting bids are sorted from the highest to lowest ratio of benefits per dollar. The bids with the highest benefits per dollar are accepted until the budget is exhausted.
Design Concepts

Basic Principles

The learning environments are based on auction theory and the design of previous ABMs. Auction theory has posited the independent values model and the common value model as two alternative views of how agents develop their bids. These models inform how Landowner Agents respond to information gathered from Winning Agents. Hailu and Schilizzi (2004) modeled repeated conservation auctions in which agents can learn from their own previous bids, and Lundberg et al. (2018) examine the implications of agents learning from neighbors in a conservation auction.

The design of the auction mechanism for this ABM is based on auction theory, including the optimal bidding strategy discussed by Iftekar and Latacz-Lohmann (2017). I also draw on the models of multi-unit reverse auctions presented by Hailu and Schilizzi (2004) and Hailu and Thoyer (2007), and the model of a forest protection PES with either fixed payments or a procurement auction presented by Lundberg et al. (2018). The modeling for this ABM was done using Repast with an Eclipse interface.

Emergence

The key results of the model, including the categorization of the auction winners (smallholders or low IDS landowners) and the characteristics of the land enrolled in the program emerge from the variation in both the learning environment and the level of targeting. The variation in targeting is presented in Table 3. Each variation has a different selection process for choosing winners. These variations are magnified through the learning process, because the initial choice of Winner Agents determines which Landowner Agents have the opportunity to learn and how many Winner Agents they learn from.

Table 2. A description of each level of targeting and how winners are selected.

<table>
<thead>
<tr>
<th>Targeting</th>
<th>Winner Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Targeting</td>
<td>Lowest Dollar per Hectare</td>
</tr>
<tr>
<td>Environmental Benefit Targeting</td>
<td>Highest Environmental Benefit per Dollar</td>
</tr>
<tr>
<td>Environmental Benefit and Social Targeting</td>
<td>Highest Environmental and Social Benefit per Dollar</td>
</tr>
</tbody>
</table>
The second level of variation is based on the number, heterogeneity of characteristics, and the spatial distribution of parcels of the Landowner Agents and the properties offered in the auction for each time step\(^ {32} \). The cost-effectiveness and distribution of participation of each learning environment emerges from both levels of variation.

**Adaptation**

Each Landowner Agent adapts their bid based on the learning environment as outlined in Figure 2.

**Objectives**

The objective of each Landowner Agent is to maximize their informational rents, which requires both being selected as auction winners and receiving a high payment. To accomplish this objective, the Landowner Agents use information from Winner Agents to strategically set their bids. The Landowner Agents that do not have the opportunity to learn from Winner Agents follow the optimal bidding strategy described in the Submodel section of this paper.

**Interaction**

Landowner Agents and Winner Agents interact directly. In the CV environment, Landowner Agents learn directly from Winner Agents who are their neighbors. In the IPV environment, Landowner Agents learn directly from Winner Agents who are in their canton.

**Stochasticity**

Stochasticity is present in the IPV learning environment. When the Winner Agent shares their winning bid with the Landowner Agent, the bid is shaded by a random factor drawn from a uniform distribution between -10% and +10%. Additionally, if the Landowner Agent does learn of a bid that is higher than theirs, they will increase their bid by a random factor drawn from a uniform distribution of up to 10%. There is also stochasticity in the auction model. If bids are tied in the auction, winners are chosen at random.

**Observation**

In each time step, the total number of hectares, the dollars spent, the environmental benefits gained, and the total informational rents collected by the Winner Agents are recorded to analyze cost-effectiveness. To understand the equity of participation in each learning

\(^ {32} \)This is discussed in detail in the “Initialization and Input” section as well as Table 4.
environment, the total number of winners, the number of winners who are smallholders, and the number of winners who live in low IDS districts are also recorded for each time step.

*Initialization and Input*

*Data*

Data used in this analysis are drawn from two sources: (1) spatial data on contracts signed from 2005 to 2014 and (2) opportunity cost estimates.

**Contract Data 2005-2014**

The new contract data was collected in 2015. This spatial database created by the Costa Rican Institute of Technology includes information on all new PSA contracts signed from 2005 to 2014 including: the contract number, the program the contract covers, the location of the property (canton and district), the number of hectares on the property, the number of hectares enrolled in PSA, the score based on the Matrix, as well as the IDS of the district where the property is located (Aguilar 2015). This spatial database was constructed from data acquired from applications to the program and the Integrated Project Administration System used to manage contract payment information.

**Opportunity Cost**

The opportunity cost used in this analysis was constructed by Vega (2014) under a contract with FONAFIFO. Vega constructed opportunity cost estimates of participation in PSA for Costa Rica based on the productivity of land, accessibility to markets and services, and available infrastructure and public services. The opportunity cost of contracts on properties that fall into more than one opportunity cost zone are based on an area-weighted average.

*Data Description*

This ABM utilizes new contract data for the forest protection program to create agents for this ABM. Unlike previous studies that initialize agents based on assumptions about distributions and correlations, the advantage of real world data negates the need to make these assumptions.

One important aspect of these data are the possible correlations between the characteristics of the land that are essential to the auction. This is important as a strong correlation between two attributes, such as opportunity cost and the environmental benefits provided, could skew the result of the auctions. A correlation matrix for the data being used in this analysis is presented in Table 3. While there are some characteristics that show statistical
significance at the 1% level, each of the correlations show a weak positive or negative relationship\(^{33}\).

For each type of auction that takes place in the learning environments, there are ten time steps. In each of these time steps, the total budget for contracts is equal to the average value (in USD) of PSA forest protection contracts awarded from 2005 to 2014: $8,091,928\(^{34}\).

A sub-set of the heterogeneous Landowner Agents are assigned to participate in each step based on the year that their actual contract was issued. This design reflects real world conditions in that the program design and the budget can remain the same, but there may be substantial variation in the number of landowners who bid for contracts in each year. The initial conditions for each time step are presented in Table 4, including the number of landowners that participate in the auction and the area of forest for which they submit bids. The first year \((t_0)\) corresponds to the data on PSA contracts issued in 2005.

Table 3. A correlation matrix of the characteristics of the land that will be used in the agent-based model. *** indicates significance at the 1% level

<table>
<thead>
<tr>
<th></th>
<th>Opportunity Cost</th>
<th>Farm Size</th>
<th>IDS Score</th>
<th>Environmental Benefits Score</th>
<th>Environmental Benefits and Social Objectives Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opportunity Cost</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Size</td>
<td>-0.0342</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IDS Score</td>
<td>-0.0158</td>
<td>-0.0665 ***</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Benefits Score</td>
<td>-0.1155 ***</td>
<td>0.0507 ***</td>
<td>-0.0314</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Environmental Benefits and Social Objectives Score</td>
<td>-0.0656 ***</td>
<td>-0.128</td>
<td>-0.1473 ***</td>
<td>0.5871 ***</td>
<td>1</td>
</tr>
</tbody>
</table>

\(^{33}\) There is a moderate correlation, between the Environmental Benefits Score and the Environmental Benefits and Social Objective Score. This is expected as the Environmental Benefits Score is a part of the Environmental and Social Objective Score. However, in this analysis these scores are never used simultaneously.

\(^{34}\) In reality FONAFIFO does not pay out the full amount of the contract once it is awarded. When a contract is awarded for a 5 year contract, 20% of the contract value is paid to the landowner in each year. The value presented as the budget is the average of the full value of contracts awarded for each year awarded from 2005 to 2014. In other words it is the average how much would be spent each year if FONAFIFO paid the full amount to landowners at the time the contract was awarded.
Table 4. Initial conditions for each time step, where time $t_0=2005$

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Participants</td>
<td>375</td>
<td>176</td>
<td>400</td>
<td>442</td>
<td>179</td>
<td>251</td>
<td>362</td>
<td>439</td>
<td>224</td>
<td>267</td>
</tr>
<tr>
<td>Smallholders (&lt; 50 hectares)</td>
<td>121</td>
<td>67</td>
<td>144</td>
<td>168</td>
<td>50</td>
<td>97</td>
<td>154</td>
<td>218</td>
<td>127</td>
<td>167</td>
</tr>
<tr>
<td>Low IDS</td>
<td>164</td>
<td>75</td>
<td>152</td>
<td>152</td>
<td>59</td>
<td>108</td>
<td>154</td>
<td>203</td>
<td>110</td>
<td>124</td>
</tr>
<tr>
<td>Total Hectares Offered</td>
<td>27335.99</td>
<td>11718.4</td>
<td>31619.4</td>
<td>38808.9</td>
<td>15593.9</td>
<td>17560.8</td>
<td>27704.5</td>
<td>27101.5</td>
<td>13002.7</td>
<td>10933.29</td>
</tr>
<tr>
<td>Total Environmental Benefit Offered</td>
<td>26250</td>
<td>12890</td>
<td>27965</td>
<td>31075</td>
<td>13285</td>
<td>16610</td>
<td>24925</td>
<td>30285</td>
<td>14625</td>
<td>16620</td>
</tr>
<tr>
<td>Total Environmental and Social Benefit Offered</td>
<td>30915</td>
<td>15315</td>
<td>33085</td>
<td>36795</td>
<td>15125</td>
<td>20115</td>
<td>30315</td>
<td>37765</td>
<td>18900</td>
<td>22035</td>
</tr>
</tbody>
</table>
Submodels

Learning

- Finding Neighbors

In this model, parcels are represented as polygons. Neighbors are defined as parcels where the boundaries of each parcel cross or touch. The Polygon Neighbors tool of ArcMap 10.3.1. was used to determine the neighbors of each Landowner Agent. This tool creates statistics based on the proximity of one polygon to another. In this analysis the Polygon Neighbor tool, assigned an identification number to each polygon in the analysis and returned the identification number(s) of neighboring polygons. Table 5 provides summary information how many neighbors agents in the model have available for interaction. Approximately 52% (1627) of the agents in this model have no neighbors.

Figure 3 is a map of land parcels in a section of the canton, Osa. Using this graphic as an example, the polygon labeled 1 would be able to share information with the polygon labeled 2 and vice versa, as these parcels have boundaries that touch. However, the polygon labeled 5 has no neighbors and therefore has no one to share information with or learn information from.

<table>
<thead>
<tr>
<th>Number of Neighbors</th>
<th>Number of Agents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1627</td>
</tr>
<tr>
<td>1</td>
<td>929</td>
</tr>
<tr>
<td>2</td>
<td>394</td>
</tr>
<tr>
<td>3</td>
<td>117</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 3. Example of land parcels in a section of the canton, OSA
Finding Members of Canton

The spatial data used in this analysis include an identification code for the canton where each parcel is located. Landowner Agents in the IPV learning environment interact with Winner Agents that have the same identification code. Figure 4 is a histogram of the number of agents within each canton represented in this analysis. Of 3115 total agents, there are 8 agents who are alone in their cantons. The majority of cantons have between two and 10 agents.

![Number of Agents in Canton](image)

Figure 4. Histogram depicting the number of agents with each canton represented in this analysis.

**Landowner Initial Bidding Strategy**

Each auction offers a five year forest protection contract. This is based on the actual contract duration for the PSA forest protection program for contracts awarded from 2005 to 2011 and 2014\(^3\). Each bid submitted by the landowner is the bid per hectare for a five year contract to

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\(^3\) In 2012 and 2013 contracts were awarded for 10 years. However, for consistency in the model, contracts in these years will be awarded for 5 years
preserve the forest. The bidding strategy presented below represents how Landowner Agents determine their initial bid in stage one (see Figure 2).

The optimal bidding strategy used in the first price, discriminatory auctions for this model is based on Iftekhar and Latacz-Lohmann (2017). They derive the optimal bid to maximize the net payoff in a first price discriminatory auction, considering both the probability of winning and the payment level as follows:

\[ b_i^* = c_i + \frac{\bar{c} - c_i}{N - 1} \]

\[ b_i = \text{transaction costs}_i + \left( \frac{\text{opportunity cost}_i}{\text{hectare}} \right) \times 5 \]

\[ \text{transaction costs}_i = \left( \frac{\text{opportunity cost}_i}{\text{hectare}} \right) \times 5 \times .15 \]

Where

- \( b_i^* \) is the optimal bid of an individual landowner
- \( c_i \) is the total cost to the landowner (opportunity cost and transaction cost)
- \( \bar{c} \) is the cost of participation for the landowner with the highest costs
- \( N \) is the number of landowners participating in the auction

**Winner Selection**

The first price, discriminatory auction pays the winning Landowner Agent the price they bid for the number of forest hectares that they offer. When there is no targeting, bids are sorted in ascending order. Bids are accepted until the budget is exhausted. In auctions with targeting, the score is based on the Matrix. An index of the environmental benefits (EB) generated by conserving forest on a given parcel is obtained by summing the first four factors of the Matrix. The environmental benefits with social (EBS) targeting provided by forest on a given parcel of land are indexed by summing all factors of the Matrix. As an example, consider Landowner A who owns a farm (or parcel) of less than 50 hectares (25 points) in a conservation gap (85 points) located in a low IDS district area (10 points). In an auction with EB targeting, Landowner A will be assigned 85 points. In an auction with EBS targeting Landowner A, will have 120 points.

In the auction with EB targeting, bids are converted to a ratio of environmental benefit per dollar (EB/$) and sorted from highest to lowest. Bids are accepted until the budget is exhausted by payments of the bid times the number of hectares offered by each landowner. In the
final auction, bids are converted to ratios of the index of EBS to dollars (EBS/$). In all auctions, when there is a tie in bids, winners are chosen at random.

**Results and Discussion**

Conservation auctions are widely recommended as a way to improve the cost-effectiveness of PES programs, and specifically to reduce the informational rent captured by participants (Ferraro 2008, Deng et al. 2015). I test this recommendation by building an ABM that examines the cost-effectiveness implications of incorporating a repeated auction into Costa Rica’s PSA forest protection program. Using participant data, this model simulates auction participants’ responses to an annual procurement auction to allocate contracts. One of the key concerns with the operational use of an auction is that learning could erode the cost-effectiveness gains predicted from theory. I therefore consider two different models of how landowners might adjust their bids in response to information gained from participants in earlier rounds of the auction. In the individual private values (IPV) learning environment, Landowner Agents are able to learn the value of winning bids in the previous year from all Winner Agents in the same canton who were awarded contracts in the previous year’s auction. In the common value (CV) learning environment, Landowner Agents only learn from Winner Agents who are their neighbors, but they learn about winning bids in any previous auction year. Within each learning environment, I model three types of auctions that reflect the established priorities for PSA: a first price, discriminatory auction with no targeting (FP-NT), environmental benefits targeting (FP-EB), and environmental and social benefits targeting (FP-EBS). In the following section, I discuss the cost-effectiveness of the auctions in each learning environment in terms of the informational rents collected by Winner Agents and the environmental benefits generated per dollar spent. In the next section, I discuss the implications of auctions for the distribution of participation in each learning environment. To determine distribution of participation, I construct an indicator called “bias in representation” that compares the percent of the participants that are smallholders or have land in low IDS areas from the percent of winners in these categories. I consider this distribution to be more equitable when there is a positive bias in representation. In each case, first price auctions with no learning serve as the baseline. Tables of complete auction results for each time step are located in Appendix D.
Cost-effectiveness

Procurement auctions are often proposed as a means to decrease informational rents thereby increasing the cost-effectiveness of a program. However, learning and strategic behavior in repeated auctions may cause the cost-effectiveness of auction mechanisms to decrease over time. In this analysis, cost-effectiveness is measured by two factors: (1) the amount of informational rents captured by landowners awarded contracts and (2) the environmental benefits generated per dollar. Each factor is discussed below.

Informational Rents

When informational rents are reduced, more of the budget can be used to purchase more conservation contracts, thus more environmental benefits can be generated. In first price, discriminatory auctions, theory suggests that it is optimal for landowners to bid higher than their cost of participation. If they are awarded a contract, the difference between their bids and their cost of participation is informational rent. When learning occurs, landowners may increase their theoretically optimal bid in response to the signal they received from acquired information. Table 6 summarizes the informational rents captured over all time steps (10 years) by agents in each learning environment and for each level of targeting in the first price, discriminatory auction. When there is no learning, informational rents captured by landowners are below $1.4 million and as targeting levels increase, the amount of informational rents captured decreases. However, learning does have implications for the informational rents captured by landowners. In the IPV learning environment, informational rents captured by landowners are more than double the value of informational rents captured when learning does not occur. In the CV learning environment, informational rents captured by the landowners are more than five times the information rents captured when learning does not occur.

When comparing the CV and IPV learning environments, it is important to note that in the CV environment, Landowner Agents generally have access to less Winner Agents, but the information provided represents a longer time span and is more useful in adjusting their valuation of their property (e.g. a signal about the value of environmental benefits), and thus their bid. Therefore, these results suggest that overall, learning and strategic behavior can increase the informational rents captured by landowners. However, a larger breadth of information that is relevant to a bidder’s valuation, reduces cost-effectiveness in terms of minimizing informational rents. These results are problematic for agencies implementing
auctions in PES programs. The behaviors modeled in the CV and IPV learning environments are difficult to mitigate. It would be difficult for an implementing agency to stop landowners who are interested in participating in the auction from discussing the auction procedure with landowners in their area who were awarded contacts. This is especially true when it comes to landowners discussing these results with their neighbors.

Table 6. The sum of informational rents captured by Landowner Agents in each learning environment and for each level of targeting

<table>
<thead>
<tr>
<th>Informational Rents</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FP-NT</td>
<td>$1,337,409</td>
</tr>
<tr>
<td>FP-EB</td>
<td>$1,336,482</td>
</tr>
<tr>
<td>FP-EBS</td>
<td>$1,336,316</td>
</tr>
<tr>
<td>IPV: FP-NT</td>
<td>$3,122,576</td>
</tr>
<tr>
<td>IPV: FP-EB</td>
<td>$3,222,939</td>
</tr>
<tr>
<td>IPV: FP-EBS</td>
<td>$3,362,812</td>
</tr>
<tr>
<td>CV: FP-NT</td>
<td>$7,679,361</td>
</tr>
<tr>
<td>CV: FP-EB</td>
<td>$7,126,297</td>
</tr>
<tr>
<td>CV: FP-EBS</td>
<td>$8,210,455</td>
</tr>
</tbody>
</table>

The hypothesis stated noted that strategic behavior would erode the cost-effectiveness of an auction over time. Therefore, it is useful to analyze the informational rents captured in each time step to provide evidence for or against the stated hypothesis. Figure 5 shows the amount of informational rents captured in each learning environment by year. The Landowner Agents participating in the auction in 2005 have no Winner Agents to learn from, therefore, informational rents for all learning environments start at the same point. Using the FP auctions with no learning as a baseline, in the IPV learning environment, learning has an immediate effect on informational rents in the auctions in 2006. Rents increase through 2008, but decline from 2008 and 2009. However informational rents captured increase from 2009 to 2010 and stay roughly in the same range through 2014.

Initially, the effect of learning on informational rents in 2006 is not as high as in the CV environment. The reason there is an immediate effect in the IPV environment and not the CV environment is that there are relatively more Winner Agents available to learn from in the canton compared to the number of Winner Agents available to learn from who are neighbors. As noted...
in Table 5, there are a large number of Landowner Agents that have no neighbors. If those awarded contacts in the 2005 auction did not have any neighbors or those participating in the 2006 auctions were not neighbors with Winner Agents, learning in the CV environment would not occur. However, as more agents win the auction and there are more neighbor Winner Agents, the informational rents captured by Landowner Agents in the CV environment surpass those of the IPV environment in 2007. There is a sharp decrease in 2009 and 2010. As this decrease in informational rents captured occurs in 2009 and 2010 in both the CV and IPV model, this may be a reflection of the particular pool of Landowner Agents in the auctions for those years. These results suggest the Landowner Agents participating in the auctions for these two years either had a limited number of neighbors or canton members to learn from or their initial bids were higher than reported winning bids. After 2010, informational rents continually increase through 2014. Targeting is often recommended as a way to increase cost-effectiveness, and thus I hypothesized that the cost-effectiveness would erode more slowly in auctions with targeting. These results do not support that hypothesis. However, examining these results as a time trend support the hypothesis that learning and strategic behavior erode the cost-effectiveness of procurement auctions over time.
Environmental Benefits per Dollar

The cost-effectiveness of an auction mechanism could also be measured by the environmental benefits generated per dollar spent (EB/$). Environmental benefits are represented by the numerical score according to the Matrix used by FONAFIFO for the forest protection program. Figure 6 shows the environmental benefits generated per $1000 spent in each learning environment.

Comparing Figure 5 and Figure 6, in the auctions where there is no learning, the least amount of informational rents are collected but the highest level of environmental benefits are captured. The highest being 3.13 EB/$ in the FP-EBS auction. However as learning occurs in the IPV environment, the EB/$ decreases compared to the auctions when there is no learning. This trend continues when examining the results of the CV learning environment, where the lowest EB/$ captured was 2.86 EB/$. These results are further evidence to support the hypothesis that learning and strategic behavior erode the cost-effectiveness of procurement auctions.
Equity in Participation

The PSA program has dual goals of forest protection and poverty alleviation. Therefore, I also examine the distribution of participation from the perspective of disadvantaged landowners, i.e. landowners more likely to be poor. The program targets two group of landowners: smallholders and landowners in low IDS districts. The implications for how strategic behavior can shift equity in participation are unknown. Therefore, in this study I examine equity in participation in terms of bias in representation. This indicator measures the difference between the percent of the participants that are smallholders or have land in low IDS areas from the percent of winners in these categories. A negative ($<0$) bias indicates that the targeted social category was underrepresented among winners and a positive ($% > 0$) bias indicates an overrepresentation of the targeted group among winners.

Smallholders

The Matrix targets smallholders by awarding 25 extra points to their PSA forest protection applications. Figure 7 shows the bias in representation of smallholders among winners of the auctions at various levels of targeting, in each learning environment. In auctions where there is no learning, there is a negative bias in representation in auctions with no targeting and environmental benefits targeting. However, there is a positive bias in representation in auctions with both environmental and social targeting. The pattern is similar in both learning environments. In the IPV and the CV environments, there is a negative bias in representation.

Figure 6. The environmental benefits per $1000 spent in each auction variation.
when there is no targeting and when there is just environmental targeting. Conversely, when social targeting is implemented, smallholders are there is positive bias in representation of smallholders.

**Landowners in Low IDS Districts**

The Matrix also prioritizes landowner in low IDS districts by awarding 10 extra points to their forest protection contracts. Figure 8 shows the bias in representation for each learning environment and level of targeting. These results are similar to the smallholder analysis. When there is no learning, low IDS landowners are underrepresented in auctions where there is no targeting and when there is environmental benefits targeting. However, when there is environmental benefits and social targeting, there is a positive bias in representation, indicating an overrepresentation of landowners in low IDS districts among auction winners. The same trend occurs in the CV learning environment. The only scenario in which there was a positive bias in
representation for low IDS landowners among winners in the CV and IPV learning environments occurred when the auction targeted for both environmental and social objectives.

![Bias in Representation: Low IDS Landowners](image)

Figure 8. Bias in representation of low IDS (<40) landowners among winners for each learning environment and auction variation

**Conclusion**

Procurement auctions have been advocated as a way to increase the cost-effectiveness of PES program by reducing the informational rents captured by participants. Studies examining the cost-effectiveness of procurement auction often analyze one shot auctions. In reality, PES programs such as Costa Rica’s PSA forest protection program offer contracts on an annual basis and thus could run annual auctions. When auctions are repeated, bidders have the opportunity to learn from previous bids. This information could be used to strategically extract informational rents.

In this analysis, I develop an ABM to examine the implications of incorporating a repeated auction into an existing PES program where bidders are able to learn from previous auction results. Using the structure and data on participants in Costa Rica’s PSA forest protection program over the decade from 2005 to 2014, I model first price, discriminatory auctions in two learning environments. In the independent private values environment, Landowner Agents learn from Winner Agents in their canton who won in the previous year’s auction. However their
winning bids are shaded. Landowner Agents take this information as a signal that the auction can tolerate higher bids and increase their own bids. In the CV environment, Landowner Agents are learn from Winner Agents who are their neighbor. If the Landowner Agents learn of winning bids higher than their own, they take this information as a signal that they have underestimated either the cost of participation or the potential ecosystem services their land could provide. Thus, they increase their bid. Three auction variations were analyzed in this model: no targeting, environmental targeting, and environmental and social targeting. Outcomes were evaluated based on measures reflecting cost-effectiveness (informational rents and EB$/S) and equitable participation (percent of participating smallholders and low IDS landowners who win contracts).

Findings regarding cost-effectiveness are consistent with theory and the few other studies that have examined the implications of learning in repeated auctions. For both learning environments, informational rents generally increased over time and the EB$/S was lower in auctions where the most informational rents were collected. The CV learning environment performed worse compared to the IPV learning environment, when comparing the total amount of informational rents captured over the ten auction years. Generally, in the IPV environments, Landowner Agents have access to more Winner Agents than in the CV environment. However, in the CV environment, Landowner Agents have access to the auction results from all previous years and the information learned is a signal that impacts their own valuation. Therefore, these results also suggest that the quality (e.g. usefulness in determining valuations) and the breath (e.g. a larger timespan) of the information acquired by landowners can have serious implications for the informational rent captured and thus the cost-effectiveness of the auction.

The results of this analysis do not support the hypothesis that targeting can reduce the erosion of cost-effectiveness by learning in repeated auctions. However, auctions targeting environmental and social benefits in each learning environment did result in a positive bias in representation among smallholders and residents of low IDS districts who submitted bids.

This analysis contributes to a small, but growing set of literature examining the cost-efficiency implications for auctions where bidders use information to strategically increase their bids and thus their informational rents. The results from this analysis suggest that learning can occur in many ways. One way that is not address in this analysis is learning through social networks. As data about social networks become available. Future work will identify other possible networks for learning and incorporate principles from behavioral economics to
understand how landowners could use this information to bid strategically. Additionally, in this auction agents were only allowed to learn from the past experiences of others. However, in repeated auctions, landowners are able to participate in the auction more than once. If a landowner participates in an auction and is not awarded a contract, she may apply again in the following year. If she is awarded a contract, she may reapply once the contract period has been fulfilled. In both cases, it is possible for the landowner to learn from her own experience in the auction and use that information to increase her chances of winning and her informational rents. Future models will examine how learning from one’s own past experiences can impact the cost-effectiveness and equity of participation in PES programs. Finally, this model highlights how learning and strategic behavior can have negative implications for cost-effectiveness. However, it is possible that learning could have positive implications for cost-effectiveness. One example of this would be how learning can attract landowners who have parcels of land that can provide high levels of ecosystem services. Future models will examine how learning can be used to attract these landowners and the possible implications for cost-effectiveness and equity in participation.
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CHAPTER 5: Conclusion

Payments for ecosystem services emerged as a response to the increased degradation of the world’s ecosystem services. As many ecosystem services are a positive externality supplied by nature that had no previous market, economic theory proposed the problem of ecosystem system degradation was a result of the lack of markets, and thus a market failure. One way to correct this market failure is to create a mechanism that would internalize the cost providing ecosystem services by having the users of these services pay the providers of ecosystem services. This system is broadly known as ‘payment for ecosystem services’ (PES).

In addition to generating ecosystem services, many PES programs have the additional goal of increasing rural development or alleviating poverty. This is due to the fact that in many countries there is a high correlation between poverty and areas where ecosystem services could be generated. The driving factor for the dual goals is that if the providers of ecosystem services are poor or rely on the land that generates these services, they should reap the financial benefits for providing these ecosystem services to society.

Taking into consideration both the environmental and social objectives of PES programs, this dissertation examined the implications of past and potential changes to an existing PES program for two outcomes: cost-effectiveness in terms of the environmental benefits captured per unit of expenditure and equity in terms of the distribution of participation.

Chapter 2 provided a general description of PES programs including the environmental economics and the ecological economics perspective that guide how programs are examined. In addition to characterizing PES programs in theory and in implementation, Chapter 2 also presents Costa Rica’s PSA forest protection program as a case study. Over the 20 year existence of the program, institutional changes have been implemented in response to critiques from researchers and program auditors that the program was not cost-effective and did not favor participation by the poor. I focus on two innovations that effectively introduced targeting mechanisms: differentiated payments through sub-programs and the Matrix scoring system for applications. Trends in the allocation of contracts over the decade spanning 2005 to 2014 provides some evidence that environmental and social targeting though differentiated payments and the Matrix scoring system may have increased equity in participation.

In many PES programs, including the PSA program, the implementing agency contracts with landowners to conserve land that will generate ecosystems services for society at large.
However, these contracts are awarded in the context of information asymmetries. The landowners cost of participation is private information and it would be both time consuming and expensive for the implementing agency to determine the cost of participation for each landowner that applies to participate in the program. Therefore, in many PES programs run by government agencies, participants are paid a flat, per hectare fee for land enrolled in the program. When a participant’s cost of participation is lower than the offered payment, the difference is called informational rent. The informational rents captured by participants reduce the cost-effectiveness of a program in that the implementing agency generates fewer environmental benefits (or hectares) per dollar than it would have if participants were paid their true cost of participation.

Chapter 3 presents a case for procurement auctions as a way to increase the cost-effectiveness of PES programs by reducing informational rents captured by participants. I develop an agent-based model (ABM) using the structure of Costa Rica’s PES forest protection program and data about program participants, to explore the implications of introducing an auction into an existing PES program for cost-effectiveness, in terms of informational rents and environmental benefits per dollar, and equity, in terms of allocation of contracts to landowners identified as priorities in the Matriz. Model results suggest that a first price, discriminatory auction with environmental and social benefits targeting results in higher cost-effectiveness and more participation by priority groups, when compared to other types of auctions and targeting schemes.

Much of the literature examining the cost-effectiveness of procurement auctions used in PES programs focuses on one shot auctions. However, in practice, programs such as PSA offer contracts repeatedly, and thus a repeated auction may be more relevant. In that case, it is possible for participants in the auctions to learn the winning bids from previous auction years. While learning could lead to positive results, such as attracting landowners with parcels of land that can generate high levels of ecosystem services and high costs, it is also possible that auction participants use this information to strategically set their bids, and thus, increase the informational rents collected. In Chapter 4, I develop an agent-based model to examine how strategic behavior, specifically through learning about previous winning bids, can shift program participation and cost-effectiveness. Results of this analysis were consistent with theory and other studies conducted. When learning and strategic behavior occurs among agents in the model, informational rents increased over time and the environmental benefits captured per
dollar decreased over time. However, auctions targeting for environmental and social benefits in each learning environment did result in a more participation by targeted social groups.

This dissertation examined the past and the potential institutional changes to Costa Rica’s PSA forest protection program focusing specifically on the implications for cost-effectiveness and equity in participation. This dissertation contributes to the literature on procurement auctions in PES programs in several ways. The ABMs constructed in this analysis are the first to date to use real world, spatially explicit data to populate a model examining auctions in a PES program, thus bridging the gap between theoretical models and the empirical evidence. Additionally, while there have been other models that examine how learning can take place in a theoretical environment where auctions are used to allocate PES contracts, the model presented in Chapter 4 describes specific pathways for learning in a real world, spatially explicit environment. Finally, while previous models considered on the cost-effectiveness or efficiency of contract distribution, the results presented also provide implications for disadvantaged landowners.

As this dissertation focuses on the PSA program, it is important to note this program is unique. It is the longest running PES program in the developing world and Costa Rica is a relatively small country. Therefore, focusing on the PSA program is a limitation of this study in that it is possible that the issues presented in this dissertation are not applicable to every PES program implemented in the developing world. However, as PES programs have grown in popularity over the past 20 years, the results presented provide some insight on how mechanisms discussed in theory, such as targeting and procurement auctions, can be implemented in practice to address issues of cost-effectiveness and equity in participation. These results do not provide a formula for a successful PES program, but identify tools and provide examples of what mechanism can help programs achieve their objectives.

Future work will continue to address the gaps between the theory of PES and how it is implemented on the ground. Understanding these gaps will allow program administrators and stakeholders to create or alter programs to mitigate issues not foreseen by theory.
Appendix A: Distribution of farm sizes in Costa Rica

Size of Farms in Costa Rica

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## Appendix B - Auction Results

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## Appendix D-Auction Results

### No Learning

**No Targeting**

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### Environmental Benefits Targeting

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### Environmental and Social Benefits Targeting

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### Independent Private Value Learning Environment

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Dollars Spent and Environmental Benefit are in thousands of dollars.
## Common Value Learning Environment

### No Targeting

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### Environmental Benefits Targeting

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### Environmental and Social Benefits Targeting

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