Improving the cost-effectiveness of PES through benefit targeting & reverse auctions – what determines the gains?

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Abstract

Successfully implemented, payment for ecosystem services (PES) programs can provide both conservation of nature and financial support to rural communities. There are however concerns about efficiency losses (e.g., lack of additionality or landowners being payed above their opportunity costs of conservation) due to the information asymmetry between the government/protection agencies and landowners. To remedy this, one option is to shift from fixed payments (the most common PES format today) to auction mechanisms for allocating conservation contracts. In the empirical literature, summarized in the first part of this paper, there are few auction based PES programs, but several of them report high efficiency and/or additionality. In this paper we analyse the effectiveness gains from reverse auction and fixed payment schemes using a stylized agent-based model. The PES designs that we study are: fixed payment schemes with and without benefit targeting, an auction with uniform payment per area, an auction with uniform payments per unit of ecosystem services provided, a discriminatory auction and a discriminatory auction with benefit targeting. We explicitly account for the risk of adverse selection and non-additionality, and systematically explore how the distribution and correlation between opportunity costs and ecosystem service provision across land-owners affect the effectiveness of auctions. We find that the gains in effectiveness from reverse auction and fixed payment schemes depends on the characteristics of the landscape where they are implemented, as well as on the baseline compliance with PES conditions. When baseline compliance is high, as it often is in programs for forest conservation, and the correlation between opportunity cost and ecosystem service provision is positive, PES schemes with benefit targeting, provide significantly higher effectiveness. This effect is so strong that, under these circumstances, a fixed price scheme with benefit targeting can give twice the environmental benefit provided by a uniform auction without targeting. Discriminatory auctions, where agents are only payed their submitted bid, are theoretically the most efficient schedule, but if they are repeated over time there are incentives for the participants to learn to optimize their bids. We study these effects and find that when participants optimize their bids, the efficiency of the discriminatory auction decreases down to the level of the uniform auction. The rate of the efficiency decline depends on how opportunity cost is distributed across the landscape.

Keywords: *Payment for ecosystem services, Multiunit auctions, Additionality, Benefit targeting, Agent based modelling*

JEL Codes: Q57, Q58, D44, C63

1. Introduction

During the last decades, payments for ecosystem services (PES) has emerged as an increasingly popular policy instrument for environmental conservation, in both developed and developing countries. PES is commonly defined as a voluntary transaction between providers and users of ecosystem services (ES), whereby the former receives payments conditional on the implementation of land-use or management proxies believed to increase the provision of ES (Wunder 2015).

By directly compensating land owners for the opportunity costs of conservation, PES was originally proposed as a more efficient way of using scarce conservation funds (Ferraro and Kiss 2002; Ferraro and Simpson 2002). Despite frequent calls for impact evaluations of PES (Ferraro and Pattanayak 2006; Baylis et al. 2015; Fisher et al. 2014), hard evidence on the effectiveness of PES has been slow in coming. Recent years, however, has seen an emerging literature using rigorous impact evaluation methods for assessing the impact of PES, especially for tropical forest conservation and in particular focusing on the performance of the national PES programs in Costa Rica and Mexico (see Samii et al. 2014; Börner et al. 2016 and references therein). Although results are mixed, the general picture painted by these studies is one of relatively low efficiency of PES, in terms of measured reductions in the rates of forest loss and degradation.

A key source of inefficiency in PES programs, that partially explains the poor estimated performance of PES in forest conservation, is adverse selection: under a fixed payment scheme, agents that would meet program conditions in the absence of payments or faces low costs in doing so will self-select into programs at a higher rate (Ferraro 2008; Persson and Alpizar 2013). Adverse selection occurs as a result of information asymmetries; potential PES recipients usually have better information on the opportunity cost of participation and their baseline provision of ES, than do PES program officials. The impacts of this information asymmetry can be expected to be particularly severe in cases where baseline compliance with program conditions is high—e.g., low deforestation rates in the case of forest conservation PES, as in Costa Rica and Mexico (Persson and Alpizar 2013).

In addition to adverse selection, information asymmetries between ES providers and users may undercut program efficiency through overcompensation; since PES officials do not know the true opportunity cost of ES provision, program beneficiaries can extract information rents by receiving higher payments than needed for participation (Ferraro 2008).

One option for reducing the efficiency losses due to adverse selection and information rents is to shift from fixed payment schemes—the most common PES format today—to auction mechanisms for allocating conservation contracts. Auctions, with competitive bidding, can provide incentives for land-owners to reveal their "true" opportunity cost of conservation. This can lead to increased efficiency in two ways. First, payments might cover a higher number of beneficiaries and secondly, by getting closer to the true opportunity cost, the incentives for adverse selection are lowered. Under perfect market conditions, the outcome of auctions can be theoretically analysed and predicted. There are, however, several factors influencing conservation auctions that distort the market conditions. For instance, auctions normally are repeated over time, which give actors the opportunity to learn to strategically optimize their bids. Also, potential participants in the program may learn to optimize their bids through interactions with other program participants (e.g., neighbours). Both learning and the spatial component creates conditions that are not captured by an equilibrium analysis.

In this paper we analyse the gains in effectiveness from alternative types (uniform and discriminatory) and designs (focusing on maximizing land area versus ecosystem services) of procurement auctions using a stylized agent-based model. An agent based model allows us to bypass the fact that the existing cases to study are too few and too context particular. It also allows us to vary the context to capture important features not covered by conventional auction theory. Hence we improve upon earlier analyses by explicitly accounting for the risk of adverse selection and non-additionality, and by exploring systematically how the distribution and correlation between opportunity costs and ES provision across land-owners affect the effectiveness of auctions. We find that the gains in effectiveness of alternative auction designs depends on the characteristics of the landscape where they are implemented.

Using a payment scheme based on a uniform auction makes the applicants reveal their opportunity cost. However, if the correlation between opportunity cost and ES provision is positive, a fixed price with benefit targeting (bids ranked after ES provision) may provide a higher environmental benefit. If the baseline compliance to program conditions is high, as is common for forest conservation programs, the use of benefit targeted fixed payments may provide twice as high environmental benefits as the uniform auction.

If payments can be diversified, a discriminatory auction theoretically provides the highest environmental benefit. However, with the agent based model we capture the erosion of these benefits when actors learn to optimize their bids, by mimicking successful neighbours bid.

The rest of this paper is organized as follows. In the next section we provide a brief background on the theoretical claims for increased efficiency under auctions compared to fixed price PES schemes, as well as a brief overview of some real world examples of the use of auctions in PES schemes. Section 3 introduces the agent-based model employed to analyse the efficiency gains from different auction designs (e.g., uniform and discriminatory price auctions) and under different conditions (regarding distribution and relations between opportunity costs and ES provision in the agent population, as well as agent learning). Results from the model is presented in section 4 and the final section then discusses these results in relation to empirical findings from real PES programs, as well as earlier literature on auction efficiency.

2. Background – the theory & practice of auctions in PES

2.1 Potential efficiency gains from auctions

Administrators having a fixed budget for allocating contracts in a fixed payments PES scheme face a dilemma in setting the payment level: setting the payment too low will lead to too few contracts (and excess conservation funds) because the price do not cover the opportunity cost of participation for most land-owners; setting the price too high will lead to demand for contracts exceeding the available budget, resulting again in few contracts and large information rents for program participants (see Fig. 1a-b). As noted in the introduction, these inefficiencies result from the basic information asymmetry between ES buyers and sellers, with the former having imperfect information about the opportunity cost of providing ES for the latter.

Auctions offer a possibility for overcoming this information asymmetry: if an auction incentivizes land-owners to reveal their true opportunity costs, the payment level can be set at a level that maximizes the supply of ES (Fig. 1c). Moreover, if the auction pays successful bidders exactly the amount the bid—what is usually called a discriminatory auction—then the amount of ES received for a given PES budget will be increased even more (Fig. 1d).[1]

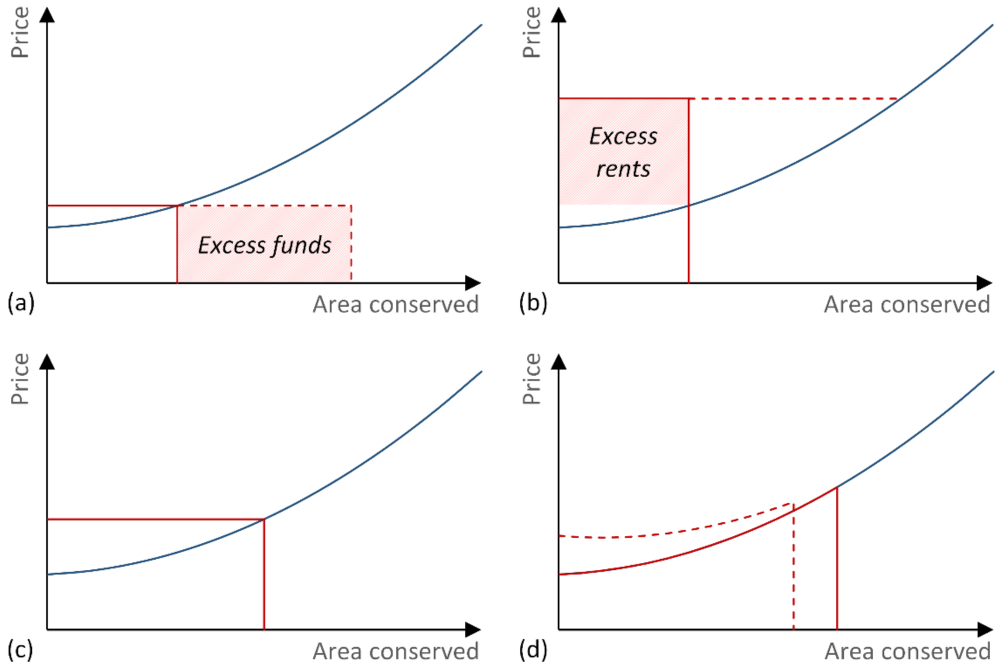


Figure 1: *Panel a-b shows how information asymmetries regarding the opportunity cost of PES participation between ecosystem service buyers and sellers is likely to result in efficiency losses, due to the payment level being set too low (a) or high (b). Note that in the latter case, it is not necessarily the lowest cost sellers that are enrolled (if contracts are allocated randomly), but the net effect is still a reduction in the area under PES contracts. A uniform-price auction (c), where the dominant strategy is truthful bidding, increases efficiency by revealing the optimal (uniform) payment level to PES administrators. In a discriminatory auction (d), where bidders are paid by bids, even larger areas can potentially be conserved for the same PES budget, but incentives for bid-shading are likely to undercut these gains, bringing outcomes closer to (or even lower than) uniform-price auctioning.*

The efficiency gains from auctions, compared to fixed price PES schemes, will thus hinge on how poorly ES buyers know the opportunity cost of potential participants (i.e., the degree of information asymmetry; Latacz-Lohmann and Van der Hamsvoort 1997) and the extent to which land-owners do reveal their true opportunity costs in auctions. There is an extensive literature on the circumstances under which auctions deliver economically efficient outcomes (see, e.g. Klemperer 1999; Wolfstetter 1996) and although the standard assumptions do not usually hold for conservation auctions where a single agent is buying multiple, heterogeneous units (Latacz-Lohmann and Schilizzi 2005), some of the basic insight still carry over (Cason and Gangadharan 2004).

For instance, we should expect land-owners to bid more truthfully under uniform-price auctions, since then the bid only determines the chance of winning a contract and not the payment received. Hence the dominant strategy is for land-owners to bid their true opportunity costs (Latacz-Lohmann and Schilizzi 2005). In contrast, under a discriminatory auction the dominant strategy for land-owners is to bid over their opportunity costs of

[1] Note that this will only be socially efficient if there is an under-provision of ES, in which case increasing PES participation for a given budget will bring ES provision closer to the social optimum. However, if conservation funds are tax based, then raising the efficiency of the money spent can also increase social efficiency since deadweight losses are reduced (Ferraro 2008).

participation, as the payment received is equal to the bid (if accepted). This effect of bid shading is likely to be higher for low cost bidders (Latacz-Lohmann and Schilizzi 2005) and learning implies that the performance of discriminatory auctions is likely to deteriorate over time, if the auction is carried out in multiple rounds, as land-owners learn (Hailu and Schilizzi 2004; Cason and Gangadharan 2004).

As a result, the relative performance (in terms of conservation outcomes) of fixed-price payments, uniform-price and discriminatory auctions will depend on a range of contextual factors, such as the degree of information asymmetries, the heterogeneity in opportunity costs and ES provisions across land-owners (and the covariance between these), and how fast land-owners learn to shade their bids under discriminatory auctions (Latacz-Lohmann and Schilizzi 2005).

While previous studies, using computational or experimental economics approaches, have shown that the gains from discriminatory auctions, relative to uniform-price auctions or fixed price schemes, tends to erode quickly as bidders learn and strategically adjust their bids upward (Cason et al. 2003; Hailu & Schilizzi 2004), they have not systematically explored how the relative performance of different auction formats are affected by the correlation between, and heterogeneity in, land-owners opportunity costs and ES provisions. In addition, given the importance of adverse selection in reducing PES additionality, they have not analysed the effectiveness of auctions in cases where some of the agents bidding for conservation contracts would supply the ES even in the absence of payments. The latter is important as the function of auctions is to reveal and select land-owners with low opportunity costs of participation, but in many cases these will also likely be the agents most likely to supply ES even if not contracted under PES.

2.2 Empirical experience of conservation auctions

In the recent meta-study by Ezzine-de-Blas et al. (2016) 55 PES schemes worldwide were incorporated in a quantitative database. Out of these 55 PES schemes, seven used auction mechanisms to allocate payments. In addition to the programs included in Ezzine-de-Blas et al. (2016) auction mechanisms have also been used in Australia, Scotland and in a recent experimental field study in Malawi (Latacz-Lohmann and Schilizzi, 2005, CJC Consultants, 2004 and Jack, 2013). A summary of PES programs using auction mechanisms can be found in Table 1. The only large scale governmental programs currently using auction mechanisms is the Conservation Reserve Program (CRP) in the US, which has been running since the mid-eighties. It is estimated to have high additionality and cost-effectiveness. Program data do however indicate decreases in cost-effectiveness due to that participants learn to optimize their bids during the repeated signups (Claassen, et al, 2008 and Reichelderfer and Boggess, 1988).

Eight out of the ten programs summarized in Table 1 use discriminatory auctions, but no program other than the CRP in the US reports clear evidence of bidder learning. This, however, is probably due to the fact that the other programs only have been run for a few (1-3) rounds. In five of the programs with discriminatory auctions, bids were evaluated by multiple criteria's (often including ES provision) and ranked after benefit per cost. The studies of the two field experiments in Indonesia and Malawi that used uniform auctions, mention uniform auctions encouraging truthful bidding as one of the reasons for choosing that auction format.

Most of the programs that have used auctions, with the exception of the CRP, are trials or field experiments. In the late 1990s and early 2000s auctions were tried in Australia, Scotland and Germany by different governmental programs. During this time the Environmental

Quality Incentives Program in the US also used an auction mechanism, but it was later abandoned even though the program itself remained, (Claassen, et al, 2008). In the case of the Scottish program the auction approach was also discarded but the information obtained from the bidding was used to set appropriate levels of payment in a fixed payment scheme that followed (Latacz-Lohmann and Schilizzi, 2005).

In the late 2000s small scale experimental field trials started using auction mechanisms for the procurement of ecosystem services in some developing countries: Indonesia, Kenya, Malawi, Peru and Bolivia. The field experiments to date present positive outcomes in terms of additionality and cost efficiency (especially the ones in Kenya and Malawi). They also show that the auction design works in rural areas of developed countries where education levels often are low. In both Kenya and Malawi, winners in the auction where often poor households, thus providing them with an extra income and contributing to poverty alleviation. However, even though these field trials of auction based PES programs in developing countries shows promising results, they are only conducted at a small scale in specific areas and exhibit large implementation costs. It is no evidence that they can be successfully scaled up to large national programs.

All of the programs included in Table.1 are oriented towards environmental services that are mainly asset building (such as tree plantations) and this orientation generally provides higher measurable additionality (Ezzine-de-Blas et al, 2016). This might be one of the reason why most of the PES programs that have used an auction approach report high additionality compared to other, large-scale, PES programs aimed at forest conservation (Samii et al. 2014; Börner et al. 2016).

2.3 Agent based modelling of PES

Determining whether gains are the results of favourable contextual factors (e.g., low baseline compliance) or to the auction format is often hard to disentangle in real world PES programs, since data so far is limited and since there's often a lack of control groups. Further experiments and field trials are an important way to increase our understanding of when auctions will be effective, but they can also be complemented—and guided—by model studies. Models have the advantage that the impact of specific parameters can be studied while others are kept constant (something that is often hard to achieve in reality) and in that way they can illuminate potential outcomes. For instance, Fooks et al (2015) note that the complexity of PES auctions over multiple rounds makes it difficult to develop a realistic theoretical model of them and instead favours the use computational or experimental economic approaches.

Agent based modelling (ABM) is a type of computational modelling where the model starts from an individual representation of the actors in a system and simulate how the sum of their actions and interactions create macroscopic patterns. ABMs make it possible to study systems that are not in equilibrium, as well as the formation of equilibria. Modelling actors individually means that heterogeneity can be incorporated, but it also means that non-rational behaviour and learning among the actors can be included and accounted for, which is highly relevant when modelling how land-owners decisions are affected by the introduction of PES.

In agent-based modelling of PES systems the agents are likely to represent land owners, which exhibit certain characteristics of their land and behaviour. The agents can make decisions on whether to join a conservation program or not and on what bids to place in reverse auctions for conservation contracts. Potentially, they could also decide on whether to comply with the program standards without joining the program and on whether to fulfil the contract or not once they have joined the program (though this is not explored in this paper).

Agent-based models have previously been used to study multi-unit, reverse auctions in Hailu & Schilizzi (2004) and Hailu and Thoyer (2007; 2010), but not a specific orientation towards PES systems.

Program	Country	Years	Setting	Auction type	Ranking of bids	Activity payed	Repeated	Results and lessons	Reference
Conservation Reserve Program (CRP)	USA	1985-present	Governmental program	Discriminatory auction	Yes by Environmental Benefit Index	Asset building	Yes	High additionality (only 15% of participants would have done land changes without the program). Cost-effective, but decreasing efficiency over time due to bidder learning.	Claassen, et al (2008) Reichelderfer and Boggess (1988).
Environmental Quality Incentives Program (EQIP)	USA	*1996 – present* Auction: 1997-2001	Governmental program	Discriminatory auction (?)	Yes.	Asset building	Yes	During the auction period bids were low. This could be due to low funding of the program that led to high rejection rates. There were also private benefits to the practises promoted in the program. The number of applicants declined every year.	Claassen, et al (2008)
BushTender Trial	Australia	2001-2003	Governmental field trials to increase biodiversity	Discriminatory auction	Yes, by Biodiversity Benefits Index	Asset building	Yes, 2 rounds	High compliance among participants. Improved cost-effectiveness compared to a fixed-price scheme. Was accompanied by several more auction programs for ecosystem services in Australia.	Latacz-Lohmann and Schilizzi (2005)
Challenge Funds	Scotland, UK	1997-2002	Governmental programs to plant new forest	Discriminatory auction	Yes. Bids were given a score based on several criteria.	Asset building		High additionality. Cost-effective. Complaints about uncertainty from participants. Scheme was replaced by new fixed price scheme 2003, where the price level was set using information from the auction.	CJC Consultants, (2004). Latacz-Lohmann and Schilizzi (2005)
Grassland Conservation Pilot Tender	Germany	2003-2005	Conservation agency, maintaining low-intensity grazing systems	Discriminatory auction	No	Asset building	Yes, 3 rounds	Initially a fixed-rate payment scheme, but with very low sign-up rates. The auction was run to determine the necessary price to increase participation. The auction, however, also had low participation rates. Low signup was probably due partly to land scarcity in the area.	Latacz-Lohmann and Schilizzi (2005)
Northeim model project	Germany	2004-2006	Field study with governmental funding aimed at increasing biodiverse grassland	Discriminatory auction	No individual ranking, but 3 "pools", with different levels of environmental quality.	Asset building	Yes, 2 rounds	The average bids varied for the three pools and they were higher for the higher environmental service pools. The lowest quality pool was compared to a fixed price scheme and the cost in the fixed payment scheme was 53% higher. The auction was popular with participants.	Klimek, et al (2008)
Sumberjaya AF conservation auction	Indonesia	2007	Experimental field study, mitigating erosion to decrease water degradation.	Uniform auction, one occasion but repeated (8) rounds	No	Asset building	No	55% of participants fulfilled the contracts.	Leimona, Beria, et al (2009)
Tree planting in Malawi	Malawi	2008-2011	Experimental field study. Tree planting and tending.	Uniform auction and a control group with fixed payment (given the cut-off price from uniform auction)	No	Asset building	No	Participants in the auction had a higher tree survival rate compared to the ones given the fixed payment. The auction was estimated to provide a 30% cost saving per surviving tree.	Jack, (2013) Ajayi, et al (2012)
Reforestation conservation auction	Kenya	2009	Experimental field study. Tree planting and tending.	Discriminatory auction, one occasion but repeated (7) rounds	No	Asset building	No	The PES auction was compared to a control group and it was more cost-efficient and had a higher tree survival rate (up to 87% compared to 55% in baseline).	Khalumba, et al (2014)
Landrace conserv payments	Bolivia & Peru	2010	Experimental field study. Farming communities payed to plant threatened crops.	Discriminatory auction	Yes (3 different categories)	Asset building	No	The bids differed significantly between Bolivia and Peru and depending on the chosen criteria the auction yielded different results. Emphasis is put on multi-criteria targeting approaches and trade-offs between different conservation goals.	Narloch, et al (2011)

Table 1. *PES programs using auction mechanisms*

3. Model description

Here we present an agent based model developed to study the efficiency of auctions in PES programs. The model is spatial, with each agent being placed on a grid where each grid cell representing a land parcel of equal size. The agents are heterogeneous with respect to the provision of ecosystem services (ES) and opportunity cost (OC) of participation in the PES program. The opportunity cost is assumed to include all aspects related to joining the PES program and complying with program conditions (e.g., forgone profits from conserving the land or the costs of alternative management practices, as well as risk premiums and transaction costs). Opportunity costs are perfectly known by land-owners, while ecosystems service provision is unknown and estimated by the ES buyer. OC and ES are assumed to be normally distributed in the population and the correlation between the two distributions can be varied. In every time step each agent submits a bid for conserving its land that is equal to, or higher than, its opportunity cost. If accepted, the agent enrols in the program and conserves its land for this time step.

For the results presented in this paper, the model has been run with 10 000 agents. If nothing else is specified, the mean value of the opportunity cost distribution is set to 20 USD/ha of land and the standard deviation is 5. The default values for the ES distribution is also 20 units/ha as a mean and 5 units as standard deviation. Importantly, these values will not affect the final results, and shall be treated as numeraire. In the baseline the correlation between the two distributions is 0.

As mentioned in the introduction, a key source of inefficiency in PES programs is adverse selection, with actors that would have complied with the program condition regardless apply and get payed for something that they would have done anyway. We therefore assess the impact of payments by measuring the additionality of the PES program, defined here as the sum of the ES provision of the agents enrolled in the program multiplied by their probability of non-compliance (i.e., the higher risk of non-compliance for an agent, the higher expected environmental benefit from enrolling the agent in the program). We normalize this by the total expected ES provision across all agents, according to the following equation:

$$(1) \qquad Expected\ environmental\ benefit\ (\%) = \frac{\sum_{i\epsilon\, S_{program}} p_i * ES_i}{\sum_{i\epsilon\, S_{all}} p_i * ES_i}$$

We explore two extreme cases of baseline compliance. In the first case, baseline compliance without the program is zero ($p_i=1$ for all agents), which is often the case for asset building activities, such as reforestation, that would be unprofitable without subsidies. In the second case, baseline compliance is assumed to be high (about 97.5%), which is more common for activity restricting programs, such as programs for forest conservation in areas with baseline deforestation rates of one or a few percent per year. In the latter case, the probability of non-compliance for agents not enrolled in the PES program, p_i, is given by the following equation:

$$(2) \qquad p_i = \alpha \frac{OC_i}{OC_{max}}$$

Here, the probability for non-compliance depends on the agent's opportunity cost, OC_i, compared to the highest opportunity cost all actors in the model, OC_{max}, (i.e., a higher opportunity cost entail a higher risk of deforestation). The parameter α scales the risk of non-compliance so to achieve a given average risk in the full population.

We assume that there is a fixed annual budget for the program, in the base case set so that it is possible to pay approximately 40% of all agents given their opportunity cost. We analyse the expected environmental benefits under four auction designs: uniform auction and discriminatory auction, each without and with benefit targeting (ranking of agents by their ES provision). The performance of the auctions is compared with fixed payment schemes with and without benefit targeting (selection to the program based on ES provision). These different program designs, explained below, are summarized in Table 2.

In the base case of the fixed payment scheme without targeting, participants are randomly chosen among the applicants (e.g., first-come, first-serve). In the uniform auction, agents are assumed to submit bids equal to their OC, as there is no incentive for strategic behaviour. Bids are then sorted with the lowest bid first and an algorithm calculates: if we give this agent's bid, to all previously accepted agents, will the budget cover it? If the answer is yes, the agent is enrolled in the program and the model goes on to the next agent on the list. When the budget is exhausted, the bid of the last agent accepted will be given to all agents enrolled in the program.

For the uniform auction with benefit targeting bidders are ranked by bids/ES. Starting with the lowest bid/ES an algorithm calculates, in every step, if that agents bid/ES multiplied by the sum of ES for the already accepted agents is less than the program budget. If it is, the procedure is repeated for the next agent in the list, until a bid multiplied by total accepted ES is equal to or higher than the budget. Then, the previous agent is the last one accepted and all agents are paid that bid/ES multiplied by their ES.

In the discriminatory auction, agents are also sorted after their submitted bid, with the lowest bid first. Here all agents are enrolled and paid their bid price (in the order of the list) until the budget runs out. In the discriminatory auction with benefit targeting the list is sorted after bid/ES provision starting with the lowest value. Apart from that the procedure is the same as in the normal discriminatory auction.

As mentioned in section 2.1 in a discriminatory auction, where agents are only payed their submitted bid, there are incentives for strategic behaviour such as bid shading. Therefore, we introduce learning through neighbour interaction to the model. In the first round of the auction, all agents bid their opportunity cost. Thereafter we assume that each agent knows the bids of its eight closest neighbours from the previous round, and whether they were successful or not. If any of the neighbours have a higher, and successful bid, the agent will copy this bid for the next auction round (if several neighbours have higher successful bids the highest one will be chosen). If the agent already has the highest bid in the neighbourhood, it will stick to its bid. If there are no successful bids among the agent or its neighbours the agent will bid its opportunity cost.

Program design:	Agent decision	Rule for selecting contracts… …without benefit targeting	…with benefit targeting
Fixed-price	An agent will apply for PES if the set fixed-price is equal to or higher than their opportunity cost of participation.	If the number of applicants exceed the number of available contracts, participants are chosen randomly.	If the number of applicants exceed the number of available contracts, applicants are ranked by their ES (highest payed).
Uniform auction	Agents will place bids equal to their opportunity cost of participation.	Bidders are ranked by bids. All agents are paid the same price, with the price given by the agent with the highest accepted price.	Bidders are ranked by bids/ES. All agents are paid the same price per ES, with the price given by the agent with the highest accepted price per ES.
Discriminatory auction	In the first round, agents will place bids as in the uniform auction. In following rounds, they will change the bid to the highest accepted bid among their neighbour's.	Bidders are ranked by bids and paid their bid from lowest to highest, until the budget is exhausted.	Bidders are ranked by bids/ES and paid their bid from lowest to highest, until the budget is exhausted.

Table 2: *Summary of the decision rules used by agents for accepting payments (fixed-price scheme) or place bids (uniform and discriminatory auctions) and the rules used by the environmental service buyers for selecting program participants, when participants are ranked by their ES provision or not.*

4.Results

4.1 PES schemes with uniform payments per land-owner

In this section we compare PES schemes that gives the same payment per unit of land to all applicants. The schemes that do this are: uniform auctions, fixed payments where applicants accepted into the program are chosen at random and fixed payments where all of the applicants are ranked after their ES provisions and then the ones with the highest rank are chosen, as long as they are willing to accept the offered payment (in our case, if $OC_i <$ payment), and until money runs out (benefit targeting).

We start by recognizing that PES programs using fixed payments not based on auctions can sometimes be close to the correct price or far from it. Figs.2 and 3 show the expected environmental benefit for different price levels in a fixed payment scheme with a given budget. The price levels on the x-axes of the figures are given as multiples of the price level that would be found in a uniform auction.

In Fig.2 the standard deviation of the opportunity cost distribution is varied between 5%, 25% and 50% of the mean value of the distribution, when baseline compliance is zero, with and without benefit targeting (dashed versus solid lines in the figure). The dotted straight lines in the figure is the environmental benefit obtained in a uniform auction under the corresponding assumption regarding the standard deviation.

If the standard deviation is low (corresponding to a low heterogeneity in opportunity cost among the actors) setting a too low price in the PES scheme will be highly ineffective, since no actors will have an interest in taking part of the program. We see that with a standard deviation of 5% of the mean, a price that is just 10% lower than the optimal price is enough to lose almost all potential participants. Setting a price that is higher than the optimal level is less damaging.

As theoretically predicted, compared to fixed payments schemes without benefit targeting, the uniform auction always gives a higher (or equal) environmental benefit. With higher standard deviation there is more to gain from using the fixed payment scheme with benefit targeting, and for both the standard deviation of 25% and 50% it can give a higher expected environmental benefit than the standard uniform auction. A uniform auction disregards the ES provision of the potential participants and only maximizes the number of participants for a given budget, thus, a fixed scheme with a higher price and benefit targeting can produce significantly better results since it enables actors with higher opportunity cost (and thus also higher ES provision) to take part of the program.

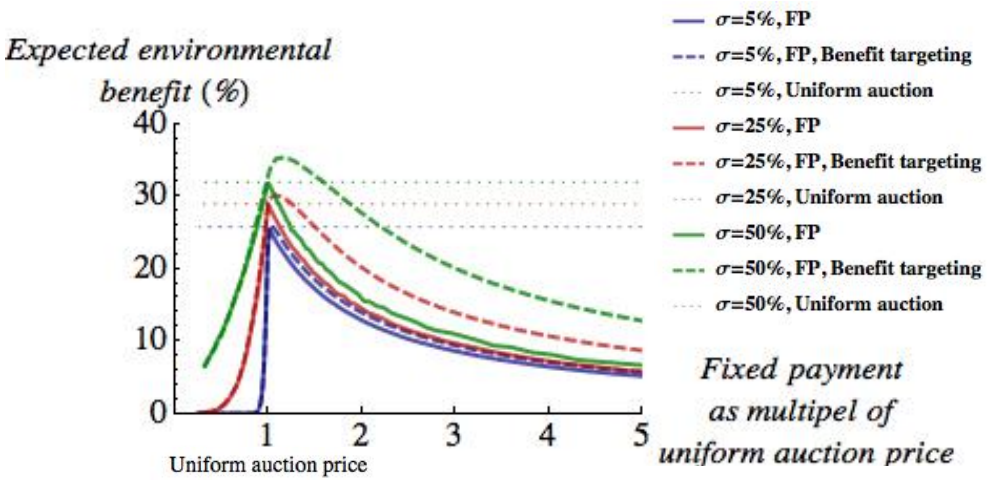


Figure 2. Expected environmental benefit conserved in the PES program as a function of the level of fixed payment. The fixed payment in the figure is measured as a multiple of the optimal price level. The data series represents scenarios with varied standard deviations for the opportunity cost distribution in the model. In all of the scenarios the mean of the opportunity cost is the same and the standard deviation is measured in percentage of the mean. The dotted straight lines in the figure is the environmental benefit obtained in a uniform auction under the corresponding assumption regarding the standard deviation.

Fig. 3a shows the expected environmental benefit for the program, when baseline compliance is zero, with and without the benefit targeting (dashed versus solid lines in the figure) and with different correlations. The case with a fixed price scheme with benefit targeting and a high price produces a better result with regards to environmental benefit when the correlation is zero or higher.

a) Zero baseline compliance **b) High baseline compliance**

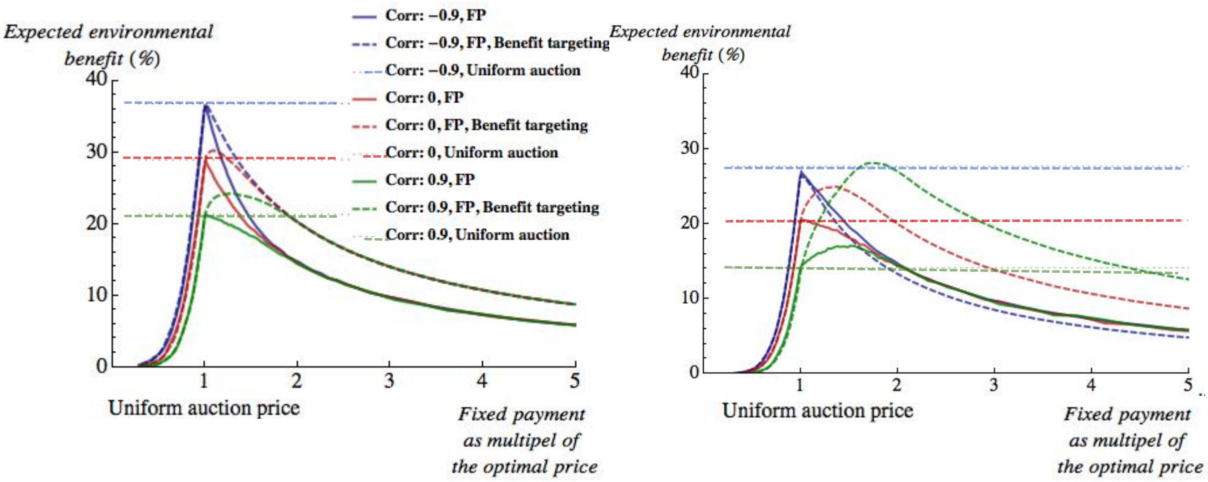


Figure 3. Expected environmental benefit conserved in the PES program as a function of the level of fixed payment. The fixed payment in the figure is measured as a multiple of the optimal price level. The data series represents scenarios with varied correlations between opportunity cost and environmental benefit. In Fig.2a) the baseline compliance without the program is zero. In Fig2.b) the baseline compliance without the program is high (ca 97.5%).

Fig.3b shows the results from the same PES designs in a context where baseline compliance is high. As can be seen, there are large variations in the additionality between the different payment schemes, depending on correlation and the level of the fixed payment. If the correlation is strongly negative, there is no extra gains from ranking bids after environmental benefit in the fixed payment scheme and in this case the uniform auction gives the highest additionality. However, if the correlation is zero or strongly positive the ranked fixed payment scheme outperforms the uniform auction when payments are 1-2 (for correlation 0) or 1-4 (for correlation 0.9) times higher than the uniform auction payment. If the correlation is 1, the fixed payment scheme with benefit targeting can give almost twice as high expected environmental benefit as the uniform auction.

As noted previously, agents with higher opportunity cost can be included in a fixed payment scheme with a higher price. If there is a positive correlation between opportunity cost and ES provision this also means that those agents will have a high ES provision. With a high baseline compliance, the probability of non-compliance with program conditions is higher for agents with high opportunity costs (see Eq.2). Thus, high opportunity cost agents included in the program by a ranked fixed price scheme, have higher ES provision and higher risk of non-compliance. Both these factors increase the expected environmental benefit.

To conclude, if uniform payments across land-owners are preferred and the objective is to maximize environmental benefit, a fixed payment scheme might in some cases be a better option than uniform auction format, though this will depend on the landscape where PES is introduced and on how well ES buyers will be able to estimate land-owners true cost of participation.

4.2 PES schemes with differentiated payments

As described in section 2.1, PES schemes with differentiated payments can leave room to include more participants for the same budget when the auction is one-shot (so there is no opportunity for agents to learn how to optimize their bids). The extent to which this increase PES effectiveness do however depend on how heterogeneous the landscape is (in terms of opportunity cost and ES provision) and on the correlation between opportunity cost and ES provision. In Fig.4 we show the expected environmental benefit for the different auction types with varied correlation for the case where baseline compliance without the program is zero and for the case where it is high.

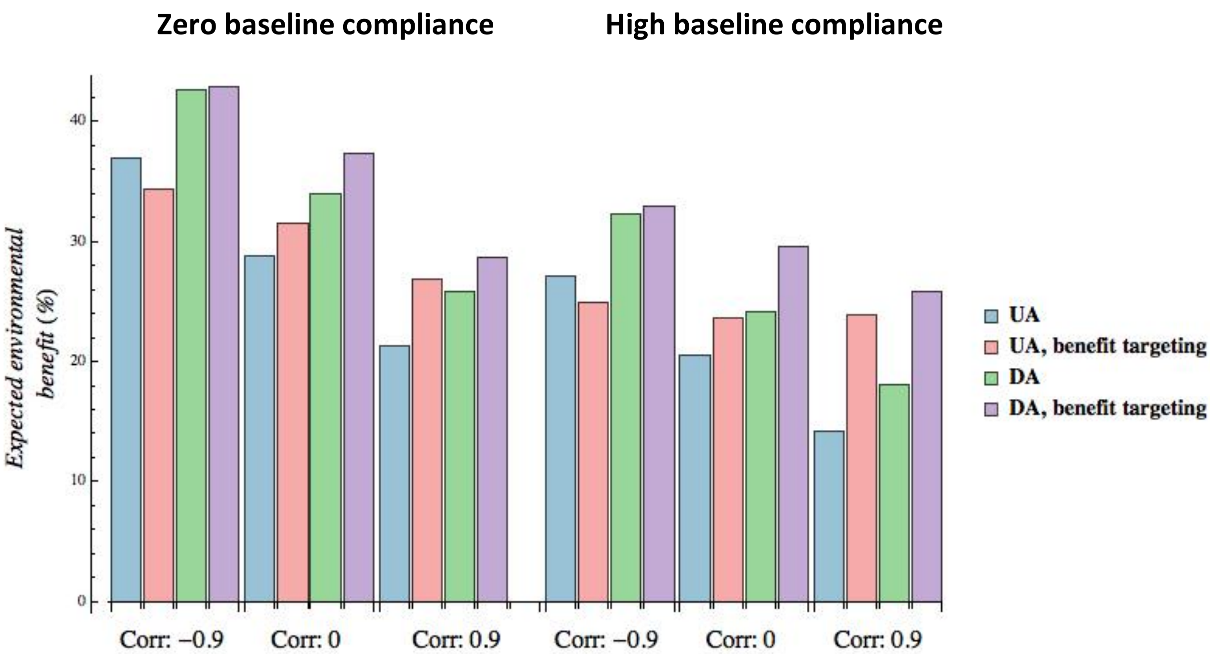


Figure 4. Expected environmental benefit for Uniform Auction (UA), Uniform Auction with benefit targeting, Discriminatory Auction (DA) and Discriminatory Auction with benefit targeting for correlation -0.9, 0 and 0.9 in the zero baseline compliance case (to the left) and the high baseline compliance case (to the right).

When the correlation is zero, and the baseline compliance is zero, the expected environmental benefit obtained under the different auction formats is as one might expect from the theoretical literature, with uniform auction providing the lowest expected environmental benefit, and discriminatory auction with benefit targeting providing the highest.

When the correlation is strongly negative (-0.9), it means that the lower the opportunity cost, the higher the ES provision, across the actors. In this setting uniform auctions and discriminatory auctions maximizes environmental benefit by enrolling the agents with the lowest opportunity cost and no benefit targeting is necessary to increase performance (though discriminatory auctions can still enrol more agents and thus get a higher expected environmental benefit). In this case the uniform auction with benefit targeting even performs worse than the uniform auction without benefit targeting. This is because in the uniform auction without benefit targeting the agents with the highest ES provision will be included in the program since they have very low opportunity costs and you get ES provision “cheap”. In the uniform auction with benefit targeting, however, agents are instead paid per unit of ES provision, so including those agents with low opportunity costs suddenly becomes very costly, and thus fewer agents can be included in the program.

If the correlation is 0.9, the opportunity cost per unit of ES provision is the same for all agents and thus the uniform auction with benefit targeting (where all actors are paid the same price per unit of ES provision) and the discriminatory auction with and without benefit targeting are equally good, while the uniform auction without benefit targeting gives a lower expected environmental benefit since all agents are paid a uniform payment.

For negative correlations, the expected environmental benefit for the different auctions, in the case with high baseline compliance is only scaled compared to the case with zero baseline compliance. When the correlation is strongly positive, the auctions with benefit targeting performs significantly better than the other ones, which is not the case for the zero baseline compliance case. With the positive correlation, agents with high ES provision also have high opportunity costs. The agents with high opportunity cost and ES provision will not be included in the auctions without benefit targeting due to their high bids, but they might be included in auctions with benefit targeting (since they get a high value of ES provision per bid). As stated in Eq.2 agents with high opportunity costs have a higher risk of non-compliance and thus provides higher expected environmental benefit to the program when included. This explains why the ranked auctions are the most efficient in the case with high baseline compliance and strong positive correlation. Comparing the auctions in this setting with the ranked fixed price from the previous section, the highest expected environmental benefit for the fixed payment scheme with benefit targeting is close to 28% (see Fig.3) which is significantly higher than both the uniform and discriminatory auction without benefit targeting (see Fig.4).

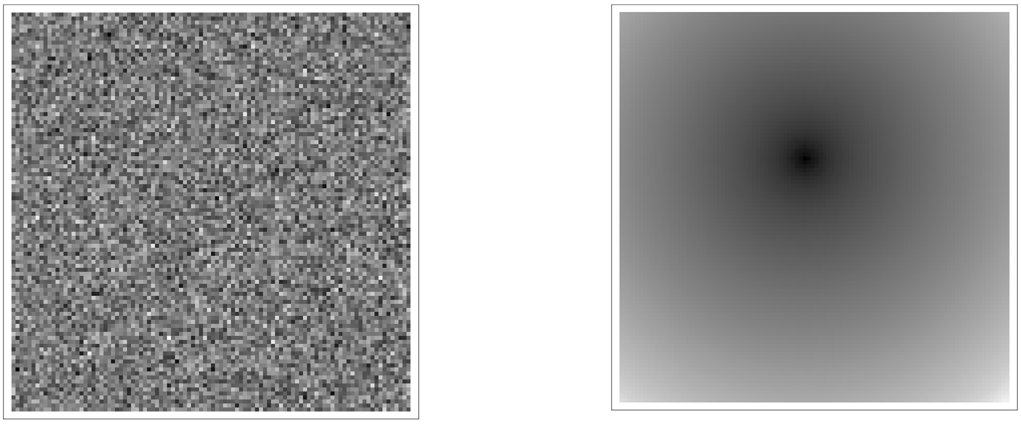
It is worth noting, however, that maximizing environmental benefit through benefit targeting by ES provision, may reduce the number of actors that can be enrolled in the program for a fixed budget. This may of course have implications in terms of equity and poverty alleviation.

4.3 Discriminatory auctions and learning

So far, agents in the model have submit their true opportunity cost to the auction. In a uniform auction, this is a reasonable assumption, since the dominant strategy for the agents is to disclose their true opportunity cost. However, in a discriminatory auction, where agents are only payed their submitted bid, there are incentives for strategic behaviour such as learning to optimize ones bid over time by looking at successful neighbours and copying their bids.

Introducing this mechanism, the benefits of discriminatory auctions start to deteriorate and the conservation outcome quickly converges to a level close to the uniform auction. How fast the environmental benefit deteriorates is dependent on how the opportunity cost is distributed in the landscape. If opportunity costs is randomly distributed across the landscape (see Fig. 6), all agents are close to another agent with a higher successful opportunity cost that it can copy, thus quickly driving up the price for conservation, which in turn deteriorates the total environmental benefit. However, if the opportunity cost is assumed to have a high spatial autocorrelation (see Fig. 6), agents mainly have neighbours with opportunity costs similar to themselves. Thus, it takes longer time for high prices to spread in the population and drive down the total environmental benefit.

The pace at which high prices spread in the population also depends on how large share of agents that are accepted into the program, which in turn depends on the size of the PES budget. Since the agents learn successful bids from their neighbour they are more likely to do so, and raise their own bid, if many of the neighbours placed successful bids in the last round. If the budget is set at a level that allows 70% of the agents to be paid in a uniform auction, in a discriminatory auction with learning the expected environmental benefit for landscape 1 drops even below the level in the uniform auction and stays there. In the case with a low budget the expected environmental benefit for landscape 1 drops as quickly but instead stabilizes slightly above the uniform auction level. This is illustrated in Fig.7 for the case with zero baseline compliance. Learning can also be assumed to take place in discriminatory auctions with benefit targeting and results from this is similar (but slightly scaled) to the ones in Fig.7. The case with high baseline compliance also results in the same patterns of eroded expected environmental benefit over time, with different pace for the two landscapes as in Fig.7.



Landscape 1 Landscape 2

Figure 6 Distribution of opportunity cost. The darker the colour the higher the opportunity cost. In Landscape 1 the opportunity cost is randomly distributed, while in Landscape 2 there is a spatial autocorrelation and a concentration of high opportunity cost land in a certain region.

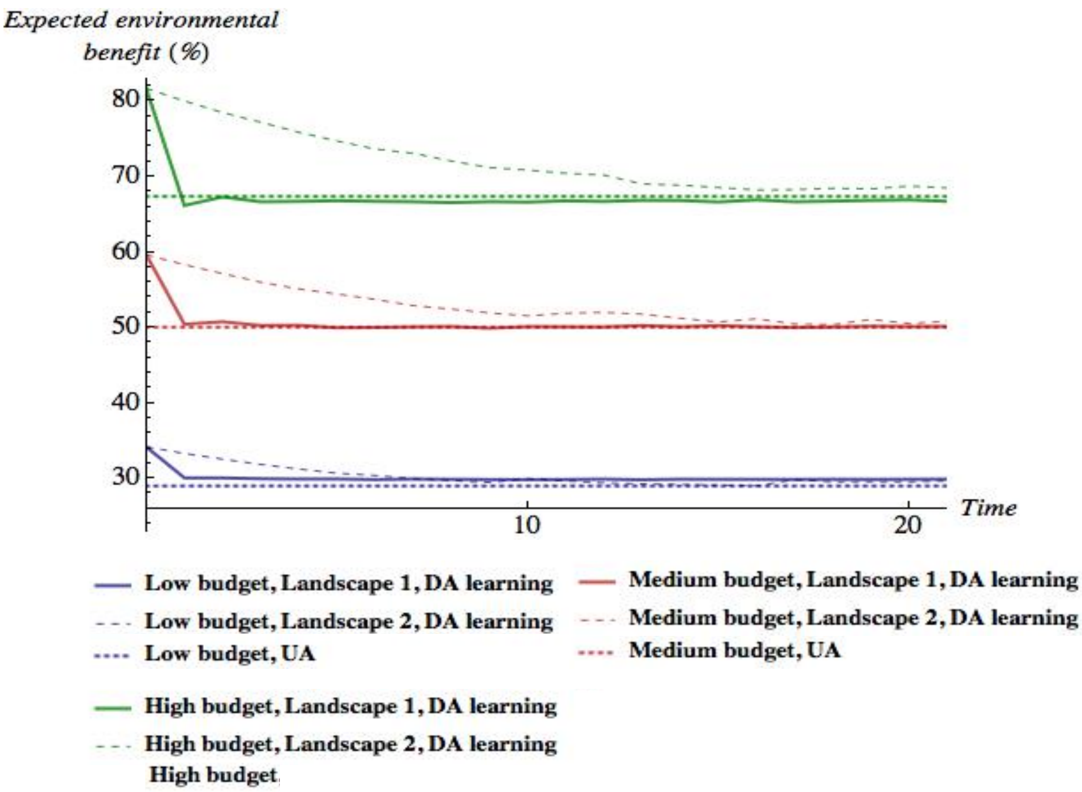


Figure 7 Expected environmental benefit conserved in the PES program as a function of time, for discriminatory auctions in different landscapes and for different sizes of the PES program budget. In the low budget approximately 30% of the agents can be paid in a uniform auction, in the medium budget 50% can be payed and in the high budget 70%.

5. Discussion and Conclusions

In the available empirical literature few auction based PES programs are analyzed. The characteristics of the programs, that exists, vary in everything from geographical location to auction type. The evaluation and reporting of their outcomes is as diverse, in quality and scope. Several studies report significant increases in additionality and/or effectiveness from the use of auctions, but the lack of empirical studies and comparable results impedes statistical analyzes. In this paper we use a stylized agent-based model that explicitly accounts for the risk of adverse selection and non-additionality, to systematically explore how landscape characteristics, such as the distribution and correlation between opportunity costs and ES provision across land-owners affect the effectiveness of auctions. Our results suggest that the efficiency of different PES program schemes is highly dependent on the characteristics of the landscape in which they are implemented, as well as on the baseline compliance with PES conditions.

We see that in fixed payment schemes, high payment levels are preferable to too low levels, since low payment levels easily will erode the number of applicants. Using a uniform auction makes the applicants reveal their opportunity cost and thus helps set the "optimal" payment level. This was applied in the Grassland Conservation Pilot Tender in Germany, where an originally fixed payment scheme that had too few applicants was turned into an auction to find the right payment level (even though also this attempt failed to attract enough participants, probably due to land scarcity). In the Scottish Challenge Funds information obtained from the bids in an auction was used to set appropriate levels of payment in a fixed payment scheme that followed (Latacz-Lohmann and Schilizzi, 2005).

All of the auction based PES programs in the empirical literature are targeted towards asset building activities (such as tree planting) where the baseline compliance normally is very low. When baseline compliance is high, as it often is in programs for forest conservation, and the correlation between opportunity cost and ES provision is positive, PES schemes with benefit targeting, provide significantly higher efficiency in the model. This effect is so strong that under these circumstances a fixed price with targeting is better than a discriminatory auction without targeting, and it can give twice the environmental benefit provided by a uniform auction without targeting.

The majority of the auction based PES programs in the empirical literature use discriminatory auctions, which is not so surprising since, theoretically, discriminatory auctions are the most efficient when baseline compliance is low. However, as is found both for the Conservation Reserve Program in the US (Claassen, et al, 2008 and Reichelderfer and Boggess, 1988) and in our model, cost-effectiveness decrease over time when participants learn to optimize their bids during repeated auction rounds.

We compare the effects of agents learning to optimize their bids by copying successful neighbours' bids in two different landscapes. One where opportunity cost is randomly distributed so that actors have neighbours of very varying opportunity costs, and one where there is a spatial autocorrelation and high opportunity cost land is concentrated to a certain region so that actors only have neighbours with opportunity costs similar to themselves. In the second landscape it takes longer time for high prices to spread in the population and deteriorate the efficiency of the discriminatory auction. In reality, conditions similar to the first landscape could potentially be found when PES programs are implemented in places where actors easily can get information from other actors with very different opportunity costs (for instance in geographically small but heterogeneous landscapes). Conditions in the second landscape are more similar to implementing a program in a large geographical area where information sharing between different parts is uncommon. A way to decrease heterogeneity of opportunity cost in auctions, and potential future work, is to introduce bid-pools, where different parts of the landscape can have separate prices in the auction.

The effects of spatial autocorrelation and neighbour learning are examples of landscape and behaviour characteristics, important to PES program efficiency, that are hard to capture with conventional economic models, but that can be studied with agent based models. There are also other factors such as non-rational behaviour and other types of learning, not covered in this paper, that could be included in future work, to further the understanding of auction based PES programs in different landscapes and settings.

As shown in this paper, there are several landscape characteristics and pre-settings that are important determinants of which policy design that will provide the best conservation outcome for a limited budget. Some of these factors are previously known, while for others, there is a lack of explicit studies. In the theoretical literature it is easy to rank the effectiveness of the auction designs that we have studied in this paper, but using explicit modelling we show that there are circumstances when this ordering does not hold. Thus, when choosing a policy design for a PES program, if effectiveness is a concern, one should consider how well the opportunity costs of the participants is known, what the correlation between opportunity cost and ES provision across the land might be and how high the baseline compliance with program conditions is.

References

Ajayi, Oluyede C., B. Kelsey Jack, and Beria Leimona. (2012). Auction design for the private provision of public goods in developing countries: lessons from payments for environmental services in Malawi and Indonesia. *World development* 40.6: 1213-1223.

Baylis, Kathy, Jordi Honey-Rosés, Jan Börner, Esteve Corbera, Driss Ezzine-de-Blas, Paul J Ferraro, Renaud Lapeyre, U Martin Persson, Alex Pfaff, and Sven Wunder. (2015). Mainstreaming impact evaluation in nature conservation, *Conservation Letters*.

Börner, J., K. Baylis, E. Corbera, D. Ezzine de Blas, P.J. Ferraro, J. Honey-Rosés, R. Lapeyre, U.M. Persson, and S. Wunder. (2016). Emerging evidence on the effectiveness of tropical forest conservation, *PLoS ONE*.

Cason, T. N., Gangadharan, L., & Duke, C. (2003). A laboratory study of auctions for reducing non-point source pollution. *Journal of Environmental Economics and Management,* 46(3), 446-471.

Cason, Timothy N., and Lata Gangadharan. (2004). Auction Design for Voluntary Conservation Programs, *American Journal of Agricultural Economics*, 86: 1211-17.

CJC Consulting. (2004). Economic Evaluation of the Central Scotland Forest and Grampian Challenge Funds. Final report for Forestry Commission Scotland.

Claassen, Roger, Andrea Cattaneo, and Robert Johansson. (2008). Cost-effective design of agri-environmental payment programs: US experience in theory and practice. *Ecological Economics* 65.4: 737-752.

Ezzine-de-Blas, D., Wunder, S., Ruiz-Pérez, M., & del Pilar Moreno-Sanchez, R. (2016). Global patterns in the implementation of payments for environmental services. *PloS one*, *11*(3), e0149847

Ferraro, Paul J. (2008). Asymmetric information and contract design for payments for environmental services, *Ecological Economics*, 65: 810-21.

Ferraro, Paul J., and Agnes Kiss. (2002). Direct payments to conserve biodiversity, *Science*, 298: 1718-19.

Ferraro, Paul J., and Subhrendu K. Pattanayak. (2006). Money for Nothing? A Call for Empirical Evaluation of Biodiversity Conservation Investments, *PLoS Biol*, 4: e105.

Ferraro, Paul J., and R. David Simpson. (2002). The Cost-Effectiveness of Conservation Payments, *Land Economics*, 78: 339-53.

Fisher, Brendan, Andrew Balmford, Paul J Ferraro, Louise Glew, Michael Mascia, Robin Naidoo, and Taylor H Ricketts. (2014). Moving Rio forward and avoiding 10 more years with little evidence for effective conservation policy, *Conserv. Biol*, 28: 880-82.

Fooks, Jacob R., Kent D. Messer, and Joshua M. Duke. (2015). Dynamic Entry, Reverse Auctions, and the Purchase of Environmental Services. *Land Economics* 91.1: 57-75.

Hailu, Atakelty, and Steven Schilizzi. (2004). Are Auctions More Efficient Than Fixed Price Schemes When Bidders Learn?, *Australian Journal of Management*, 29: 147-68.

Hailu, Atakelty, and Sophie Thoyer. (2007). Designing Multi-unit Multiple Bid Auctions: An Agent-based Computational Model of Uniform, Discriminatory and Generalised Vickrey Auctions. *Economic Record* 83.s1: S57-S72.

Jack, B. Kelsey. (2013). Private information and the allocation of land use subsidies in Malawi. *American Economic Journal: Applied Economics* 5.3: 113-35.

Khalumba, Mercelyne, et al. (2014). Combining Auctions and Performance-Based Payments in a Forest Enrichment Field Trial in Western Kenya. *Conservation biology* 28.3: 861-866.

Klemperer, Paul. (1999). Auction Theory: A Guide to the Literature, *Journal of Economic Surveys*, 13: 227-86.

Klimek, S., Steinmann, H. H., Freese, J., & Isselstein, J. (2008). Rewarding farmers for delivering vascular plant diversity in managed grasslands: A transdisciplinary case-study approach. *Biological Conservation*, *141*(11), 2888-2897.

Latacz-Lohmann, Uwe, and Steven Schilizzi. (2005). Auctions for conservation contracts: a review of the theoretical and empirical literature. Report to the Scottish Executive Environment and Rural Affairs Department 15.

Latacz-Lohmann, Uwe, and Carel Van der Hamsvoort. (1997). Auctioning conservation contracts: a theoretical analysis and an application, *American Journal of Agricultural Economics*, 79: 407-18.

Leimona, B., Jack, B. K., Lusiana, B., & Pasha, R. (2009). Designing a procurement auction for reducing sedimentation: a field experiment in Indonesia. *EEPSEA Research Report*, (2009-RR10).

Narloch, Ulf, Unai Pascual, and Adam G. Drucker. (2011). Cost-effectiveness targeting under multiple conservation goals and equity considerations in the Andes. *Environmental Conservation* 38.04 (2011): 417-425.

Persson, U Martin, and Francisco Alpizar. (2013). Conditional cash transfers and payments for environmental services—a conceptual framework for explaining and judging differences in outcomes, *World Development*, 43: 124-37.

Samii, Cyrus, Matthew Lisiecki, Parashar Kulkarni, Laura Paler, and Larry Chavis. (2014). Effects of payment for environmental services (PES) on deforestation and poverty in low and middle income countries: a systematic review, *Campbell Systematic Reviews*, 10.

Reichelderfer and Boggess (1988). Government decision making and program performance: The case of the Conservation Reserve Program. *American Journal of Agricultural Economics*, 70: 1-11.

Wolfstetter, Elmar. (1996). Auctions: an introduction, *Journal of Economic Surveys*, 10: 367-420.

Wunder, Sven. (2015). Revisiting the concept of payments for environmental services, *Ecological Economics*, 117: 234-43.