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Agri-environmental auctions for phosphorus load reduction: experiences from a Finnish pilot*

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We examine environmental auctions on working agricultural lands. We organized a discriminatory auction where farmers were asked to make bids on spreading gypsum on their fields to reduce phosphorus loads to surface waters. The parcel-specific bids were ranked based on their load reduction–compensation ratios. To assess load reductions, we built an environmental benefit index (EBI) based on three factors: P-status of the soil (phosphorus available for crops), field slope and location with respect to waterways. As the per tonne price of gypsum delivery from the factory was higher for small quantities, the auction format allowed bundling of field parcels to reduce transportation costs. We evaluate auction's ability to target the environmental (or abatement) measures to field parcels with the highest load reduction potential and analyse the economic efficiency of the auction by comparing the pilot auction with simulated bidding behaviour and with hypothetical flat rate payment schemes. The pilot auction targeted the environmental measures effectively. It was also more efficient than a flat rate payment, even when the flat rate scheme was combined with an EBI eligibility criterion.

Key words: agri-environmental auction, environmental benefit index, information rent, phosphorus load, pilot.

1. Introduction

Environmental auctions, as green bidding systems, challenge the flat rate policy instruments traditionally used in voluntary agri-environmental programs. A flat rate policy tends to be generous to farms with low compliance costs and does not allocate environmental measures to field parcels providing the highest environmental benefits. Competitive bidding systems, in contrast, create competition between participating farmers, making them partly reveal their private conservation costs. The most often applied form is the multiunit discriminatory price auction. It does not lead to complete revelation of private costs, giving rise to information rents to auction participants. It, nevertheless allocates the conservation budget to field parcels with the highest environmental benefits in a cost-efficient way with low information rents and

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without a heavy information burden on regulatory authorities (Latacz-Lohmann and van der Hamsvoort 1997; Latacz-Lohmann and Schilizzi 2005).

Environmental auctions have been successfully applied to environmental protection, particularly in agriculture. For instance, in the US, the Conservation Reserve Program (CRP) has employed auctions to allocate environmental protection measures since 1985. As of March 2012, some 29.65 million acres were under CRP contracts, accounting for about 3 per cent of the total farmland (Farm Service Agency 2012). In Australia, conservation auctions have been piloted and implemented in several areas and for different environmental targets, examples being the Victorian Bush Tender program to promote nature conservation contracts (Stoneham *et al.* 2003), the Auction for Landscape Recovery to focus on biodiversity and other environmental benefits (Hajkowicz *et al.* 2007), and the Catchment Care auction to promote remnant vegetation conservation (Connor *et al.* 2008). The world's first application of an environmental auction to forestry was started in 2003 in Finland, where the METSO program for forest biodiversity conservation instituted contracts that were based on environmental benefits and landowners' compensation requests (Juutinen and Ollikainen 2010).

Several features distinguish environmental auctions from the benchmark auction model. Bids tend to have multiple dimensions as monetary compensations are weighted with estimated environmental benefits. A single farmer might bid for multiple parcels with potential synergies in conducting the conservation activities. Also, costly bidding might influence the farmer's willingness to pose a bid in the first place. Literature has used auction theory as a guide to construct and assess auction design beyond its actual scope. In particular, uniform price auctions generate no incentives for bid shading, but overcompensate bidders due to cost heterogeneity and multiple units being accepted. Discriminatory price auctions do not overcompensate, but may be inclined to bid shading. The extent to which there is bid shading and, hence, information rents is an empirical question (Latacz-Lohmann and van der Hamsvoort 1997). Efficiency of discriminatory auctions depends crucially on the amount of information rents. Some recent laboratory experiments focus on the issue (Cason and Gangadharan 2004), but not much in general can be said: rents tend to increase with the environmental index, if known by the bidder.

There are even fewer studies reporting and analysing actual pilots. To our knowledge, only Kirwan *et al.* (2005), Juutinen and Ollikainen (2010) and Juutinen *et al.* (2013) have assessed information rents from actual pilot programs. These studies focus on policy cases that incentivise farmers to remove land from ordinary production. A greater challenge is to apply environmental auctions to working lands, that is, agricultural fields or forestry plots under active production. The literature lacks studies on information rents and performance of programs designed for working lands.

We present and examine experiences from a discriminatory price multiunit pilot auction on working agricultural lands conducted in Nurmijärvi, Southern Finland in September 2010. The auction contained two special features. First, the aim was to reduce phosphorus loads to waterways – a challenging task given the dynamic nature of soil phosphorus and consequent phosphorus runoff. Second, the auction was based on a simple but effective environmental benefit index (EBI) describing the benefits of reducing phosphorus loads and designed to ensure that the budget is allocated in a cost-efficient way.

Farmers were asked to submit bids for buying gypsum and spreading it on field parcels of their choice to reduce phosphorus loads. Application of gypsum to arable soils is a new, promising measure to reduce phosphorus runoff swiftly; abatement through gradually depleting the soil phosphorus takes much longer. Gypsum application reduces losses of both particulate and dissolved phosphorus, particularly in clay soils (Ekholm *et al.* 2012). Gypsum has no known effects on crop yields, but may improve the soil structure.

The EBI was based on three environmental characteristics of a parcel: soil phosphorus content (P-status), parcel slope, and proximity to surface waters. Farmers were asked to submit bids consisting of the compensation payment they requested and a description of the target parcel(s) in terms of size, slope, proximity to surface waters and soil P-status. This information was used to construct the EBI, which together with the compensation payment determined the bid rank of the bids. As environmental indices can be used to improve the performance of traditional flat rate policies as well as auctions, we are interested in examining how the EBI performed and how it was understood by farmers.

The pilot auction allowed farmers to bundle many of their own parcels into a single bid. This feature resembles combinatorial auctions used in a variety of applications such as in airlines bidding for airport runway access, transportation service procurements or spectrum right auctions (Cramton *et al.* 2006). The pilot auction differed from a combinatorial auction mainly in its computational requirements. Computing the EBIs for bundles was straightforward, and the cost savings from bundling was due to freight costs which were also readily available.

We describe the auction format and the bidding behaviour, and provide descriptive statistics on the participating and non-participating farmers. We focus particularly on the auction's ability to direct the abatement measures to parcels with the highest nutrient runoff risk when compared to alternative policy measures and the general performance of the pilot auction. To assess the performance of the auction, we compare the results from the actual pilot to two alternative auction simulation models and two alternative flat rate payment schemes that draw on the same bid data and the actual outlays farmers paid for the gypsum.

The rest of the paper is organised as follows. Section 2 is devoted to a description of the pilot and Section 3 provides descriptive data on its outcomes. Section 4 assesses the environmental performance of the pilot and Section 5 its economic efficiency. A concluding Section 6 assesses main lessons learned.

2. Description of the Nurmijärvi pilot auction

The auction was conducted in Nurmijärvi, Southern Finland, in September 2010. It was a discriminatory price (pay-as-bid) multiunit auction, where local farmers were asked to submit bids to spread gypsum (a fixed amount of four tonnes per hectare) on parcels of their choice and to suggest a payment providing adequate compensation for carrying out the measure.[1] The bids were two-dimensional. The compensation requirement was weighted with the estimated reduction in phosphorus loading after undertaking the measure on the associated parcel. The ratio of required compensation and the EBI was used to rank the bids.

The farmers were provided with information necessary to enable them to estimate the desired compensation. Gypsum was stated to have no effect on crop yields; unit and hauling costs of gypsum were given, as well as various contractors' contact information to ask for application costs. Farmers were carefully advised how to compute the environmental index and the overall bid score and how to submit bids on individual parcels and on bundles of individual parcels.

2.1. Environmental benefit index

The EBI used in the pilot was designed to estimate the parcel-specific reductions in algal-available phosphorus load from applying gypsum. That is, the index measures the environmental benefits provided by the farmer. The initial algal-available phosphorus load from a given parcel was estimated. This is defined as a sum of dissolved reactive phosphorus (DRP) and a fraction of soil-bound particulate phosphorus (PP). The load of DRP is linearly dependent on the plant-available phosphorus in the soil, or P-status (Uusitalo and Jansson 2002). In Finland, P-status is regularly measured by analysing soil samples and estimating the amount of phosphorus (mg/L) available in them (Vuorinen and Mäkitie 1955). The load of PP is assumed to depend on the field slope (Puustinen *et al.* 2010). PP is defined as contributing to algal-available phosphorus with a weight of 0.16 (Ekholm *et al.* 2005), meaning that 6.25 kg of PP in runoff water is equivalent to a kilogram of

[1] Spreading gypsum suited the pilot well, as it is not included as an environmental measure in the current Finnish agri-environmental program. Furthermore, gypsum had been recently tested in Nurmijärvi in a project analysing its abatement effects, so there was prior knowledge about it in the area.

Table 1 Environmental benefit index by P-status and parcel type

P-status	Slope <1.5%, bordering			Slope 1.5–6%, bordering			Slope >6%, bordering		
	Land	Ditch	Surface water	Land	Ditch	Surface water	Land	Ditch	Surface water
<8	8	17	19	14	30	34	29	66	73
8–14	13	28	31	18	42	46	34	77	85
>14	18	41	46	24	55	61	40	90	100

DRP. Using algal-available phosphorus as a measure accurately relates the physical event (the passage of nutrients into surface waters) to the eventual environmental damage (algal growth in surface waters).

The second step was to assess the effect of gypsum application on the initial phosphorus load. Gypsum increases the electrical conductivity of the soil solution and improves the structure of soil aggregates. This reduces the loads of both forms of phosphorus (Ekholm *et al*. 2012). By the time of the pilot, initial results from a project examining the long-term load reductions achieved by applying gypsum indicated that spreading four tonnes of gypsum on clay soils reduced both forms of phosphorus by as much as 50 per cent.[2] Accordingly, we can directly use the estimated loss of algal-available phosphorus per hectare to form the index.

Finally, we took into account the effect of retention of phosphorus by classifying three location types for parcels. As there are no reliable empirical estimates on retention of phosphorus in different water bodies, we determined the retention percentages based on expert judgement. For parcels bordering receiving waters (rivers, lakes and ponds), retention was assumed to be zero; for those bordering a ditch, 10 per cent; and for the rare cases of land-locked parcels, 60 per cent.

Due to the linearity of gypsum's abatement effects, we were able to derive the index values directly by scaling the potential nutrient loads between 0 and 100. The greater the potential load from a given field parcel, the greater the load reduction from gypsum application. Hence, fields with high potential loads obtain high EBIs. Potential loads were determined for a total of 75 parcel types. To make the index more tractable for potential bidders, certain slope and all production technology classes were combined to form 27 different parcel types (Table 1).

Table 1 illustrates the EBI in the format as it was presented in a brochure posted to local farmers. The highest values were obtained on parcels with a P-status above 14 mg/L that bordered surface waters and had a slope steeper than 6 per cent. For example, a parcel bordering a ditch, with a slope between 1.5 and 6 per cent and a P-status between 8 and 14 mg/L received an EBI value of 42.

[2] The final results specified the abatement of dissolved phosphorus as 29 per cent and of PP as 57 per cent (Ekholm *et al*. 2012). Using these would have changed the EBI slightly.

2.2. Bundling of field parcels in bids

Bundling of parcels was included in the auction format to account for economies of scale. Farmers are familiar with purchases with high relative freight costs (such as lime), where full loads are essential. We assumed that farmers would feel more comfortable when given the chance to block the possibility of winning a bid that required a half-empty truck delivery; full loads were less costly per tonne, and hence gave an opportunity to improve the bid score by lowering compliance costs and thereby the required compensation.[3] Indeed, it turned out that 7 out of 10 accepted bids were for bundles.

2.3. Other features of the pilot

An introductory letter was posted to all farmers in Nurmijärvi on 24 June 2010 announcing the upcoming pilot auction in the area. The letter presented the main idea and timing of the pilot, but did not contain any detailed information. A two-hour meeting with farmers was organised on 10 August and again on 18 August. After the first meeting, the material on the pilot was posted to all farmers in the area. It included a brochure containing a detailed explanation of the auction rules (defining the environmental index and the bid ranking); the important dates; contact information for ordering gypsum at a predetermined per tonne price; contact information of three local custom operators for spreading gypsum; the actual bid sheet; and a stamped envelope for returning the sheet. The bids were due on 25 August, that is, 15 days after the first farmers' meeting.

The pilot also received media attention, being featured as front page news in the main national rural newspaper (*Maaseudun tulevaisuus*, 9 August), given coverage in the local newspaper (*Nurmijärven uutiset*, 8 August) and made the subject of a report on a national TV channel (MTV3 news August 10). In each of these media, the auction budget of €25,000 was made public.

3. Overview of the outcome of the pilot

Table 2 presents an overview of the outcome of the pilot. For all bids, accepted or rejected, we describe the range, components and EBI values, the type of bid, the land area involved and the number of participants. The range of bids, presented as min–max–mean values, is fairly small, and the range of all offers and accepted offers is almost the same. The rejected offers have a smaller range, indicating lower EBI values. Half of the field parcels for which bids were submitted were ultimately enrolled.

[3] Yara set the price of gypsum at 18.15 €/tonne and the freight costs depending on the size of the order at €546 for 4–14 tonnes, €809 for 15–30 tonnes, and €1024 for 31–38 tonnes (full trailer truck load).

Table 2 Overview of bids, environmental benefit scores and participants

	All bids	Accepted bids	Rejected bids
Bid (€/ha)	199–277 (224)	201–277 (221)	199–260 (229)
Environmental benefit index (EBI) Components			
Slope (%)	1–10 (2.5)	1–6 (2.5)	1–10 (2.5)
P-status (mg/L)	3.5–155 (23.7)	6.6–155 (32.4)	3.5–15 (7.2)
Bordering land (*n*)	8 parcels	0 parcels	8 parcels
Bordering water/ditch (*n*)	30 parcels	24 parcels	6 parcels
EBI	8–78 (34.5)	28–78 (43.8)	8–34 (22.5)
Bid type			
Individual P parcels	6	3	3
Bundled parcels	32 in 10 bundles	21 in 7 bundles	11 in 3 bundles
Acreage (ha)	182 (227 ha if doubles included)	112	70 (115 ha if doubles included)
Bids (*n*)	21	10 (+2)	9
Participants (*n*)†	9	5	5

†One participant submitted both accepted and rejected bids.

The key conclusion to be drawn from Table 2 is that the auction enrolled parcels most sensitive to phosphorus loads. Looking at the individual components of the EBI, there are no differences in the slopes of the parcels between the accepted and rejected bids. All accepted parcels bordered either ditches or surface waters.

The most striking difference can be found in P-status: the mean value of P-status for the accepted parcels is about 32 mg/L, which is very high compared with the 7 mg/L for the rejected bids. This result is particularly interesting for three reasons. First, the link between P-status and losses of DRP is well established. Hence, the pilot auction managed to allocate environmental measures to parcels actually important for water quality. Second, information on P-status is not public but readily available to farmers: it is a standard measure for all farms participating in the Finnish Agri-environmental Program, which covers over 95 per cent of the arable area in the country. Third, the auction rules applied did not generate any incentive to over-report the P-status as being above 14 mg/L (Table 1); that is, the effect of a P-status of 14 and 140 mg/L had exactly the same effect on the EBI. Therefore, we find the reported P-statuses reliable. Overall, the phosphorus losses were substantially higher from the accepted parcels than from the rejected ones. Moreover, because the EBI was not sensitive to P-statuses above 14 mg/L and the actual average P-status of accepted parcels was significantly higher, the environmental benefit of targeting was substantially higher than that suggested by the difference in EBIs.

The bids per hectare varied between €199 and €277. The rejected bids contained on average a slightly higher compensation requirement than accepted bids. There are, however, no statistically significant differences in the means (or the variances) of the accepted and rejected bids. If we use values not weighted by acreage, the mean of accepted bids is higher (€221) than the mean of rejected bids (€118). There was no statistically significant correlation between the EBI and the bids (bid = 0.67 × EBI + 197; R^2: 0.35). We can, however, rather safely conclude that the bids did not decrease with EBI, which is intuitive.

Finally, as Table 2 reveals, the majority of the bids were bundles. Only seven parcels were offered individually; the rest were part of bundles of various sizes. The largest bundle was 31.6 ha, the smallest 7.5 ha; both were accepted. One accepted bundle included two parcels that were also offered as individual parcels and would have been accepted as such. The designation 10 (+2) in Table 2 refers to these parcels.

Considering that the budget was made public, the pilot auction did succeed in attracting enough bidders to create competition. In the following sections, we analyse in more detail the effectiveness and efficiency of the auction.

4. Assessing the environmental effectiveness of the pilot

The pilot succeeded in enrolling the most important parcels among the submitted ones. This does not, however, indicate how successful the auction mechanism was in attracting the most environmentally sensitive parcels to join the pilot program. This can be determined by comparing the outcomes of the pilot to the relevant features of all field parcels in the area.

Recall that the slopes of the farms in the accepted and rejected bids were similar and on average 2.5 per cent, although the steepest were 10 per cent. The average slope of Finnish fields is estimated by Puustinen *et al.* (1994) to be about 1.6 per cent (median 0.8 per cent). Hence, the pilot did not direct the load-reducing measures very strongly to the steeply sloped fields. There are many possible explanations for this outcome. For instance, farmers may not have had steep fields that they considered suitable for the pilot program. More likely, however, they found that ascertaining the P-status is substantially easier than determining the slope of the field. A farmer whose land had a high P-status may have been more likely to participate in the auction than a farmer whose land had steeply sloped fields, even though these two characteristics played an equal role in determining the EBI. The estimation of field slope always involves uncertainty, as the slope profile may vary.

How well did the program succeed in enrolling high P-status parcels? Uusitalo *et al.* (2007) collected data on P-status for various Finnish farming regions, including Uusimaa of which Nurmijärvi comprises 5 per cent. The median *P*-value for the Uusimaa region is 9 mg/L, the mean 11.7 mg/L and the highest quartile 13 mg/L. Using the original data set for the Uusimaa region, we fitted a gamma distribution of P-status in the region and obtained the parameters $k = 5.4$ and $\theta = 2.2$. Figure 1 depicts the distribution.

Assuming that Nurmijärvi has the same distribution of P-status as the rest of the Uusimaa, we can assess how well the pilot auction succeeded in enrolling the most suitable parcels into the program. The average P-status of accepted bids was 32.4 mg/L. In Uusimaa, only about 0.1 per cent of the

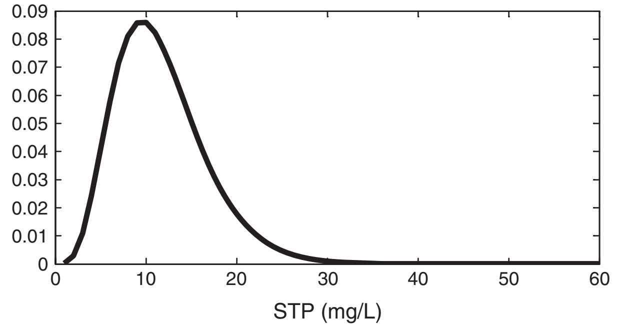

Figure 1 The gamma distribution of the P-status in Uusimaa region.

farmland has a P-status above 32.4 mg/L. This suggests that our auction mechanism succeeded in enrolling the parcels with highest initial phosphorus loads. This result holds only for phosphorus, though; and while it may generalise to larger regions, it has no implications for auctions targeting other nutrients, such as nitrogen.

Another approach for ascertaining the ability of an auction format to enrol the most sensitive parcels is to compare it to other targeting methods. An opportunity to do so presented itself through TEHO, a water protection project in Southwest Finland, in which specialists (soil scientists and leaching researchers) identified field parcels with the highest P-status and these parcels were later treated with gypsum. The process involved no costs for the farmers, who only had to give information on their parcels' P-status if asked and to accept that gypsum would be applied to their fields. For treatment, the project identified 31 ha with average P-status 53 mg/L.

The fields in South West Finland have a higher average P-status than those in the Uusimaa region. Using the data on P-status tests summarised in Uusitalo *et al*. (2007), we obtained parameter estimates $k = 4.2$ and $\theta = 4.1$, for a gamma distribution for *P*-values in Southwest Finland. Using this distribution we estimate that about 0.1 per cent of the fields in Southwest Finland have a P-status at or above 53 mg/L, coincidentally the same amount, to the second decimal, as in the Nurmijärvi pilot. This indicates the effectiveness of enrolment in the two approaches was identical. While the samples are too small to verify this finding statistically, identical enrolment serves as anecdotal evidence of the auction program's ability to attract farmers to submit bids on high P-status parcels.

5. Assessing the efficiency of the pilot auction

To further assess the pilot mechanism's efficiency, we compare the actual bidding behaviour with two alternatives: an auction simulation model, and a flat rate payment scheme. Because we focus on the impact of EBI on the bidding outcome, we provide two versions of both approaches: the auction and flat rate scheme with and without the EBI as an eligibility criterion. Both approaches require using compliance cost information. Thus, we start our discussion on costs and information rent in the context of the pilot.

5.1. Costs and information rents in actual bids

For efficiency assessments we would need data on actual compliance costs to which we, unfortunately, do not have access. For all bidders we do know the product price and freight costs. We are able to estimate the application costs from contractors' prices for applying lime. While these items represent the major part of costs, other costs as well, perceived or real, may be present; and there might also be unobserved benefits. Farmers might have different perceptions of gypsum's effect on soil structure or even on crop yields and these may be expressed in bids. They might also be willing to share some costs of environmental protection. In the absence of this information we employ expected compliance costs only. This means that farmers' compliance costs were driven solely by the acreage treated. The cost components are the freight (*ex post* known) and application costs. It also presents EBI values, bids and their rank on the basis of their benefit–cost ratio (B/C). The offers are numbered according to their B/C ratio. The reported land areas, EBI values, bids and ranks are from the pilot data. The expected compliance costs and information rents are our estimates.

Table 3 shows that in the pilot, the EBI value alone would have been a good selection criterion: only in two cases does accounting for the costs change the ranking based on EBI value alone. This kind of outcome is not, however, typical of green auctions. Our finding is explained by the fact that

Table 3 Data from the accepted bids in the pilot auction and assessment of information rents

Bid no.	Data from the pilot					
	Cumulative area (ha)	EBI-value (B)	Bid (€/ha) (C)	Rank (B/C)	Compliance cost (€/ha)	Information rent, maximum (€/ha)
1	9.66	64	212	1	211.2	0.8
2	17.97	78	277	2	222.6	54.4
3	27.12	61	219	3	211.4	7.6
4	34.60	53	238	4	203.3	34.7
5	66.17	39	215	5	203.3	11.7
6	82.05	41	236	6	211.2	24.8
7	89.13	31	205	7	204.4	0.6
8	99.83	28	201	8	211.2	−10.2
9	106.40	28	202	9	204.4	−2.4
10	111.73	28	206	10	204.9	1.6
Mean	11.73	—	221	—	208.8	12.4

EBI, environmental benefit index.

the spreading of gypsum on field parcels entails fairly identical costs across farms. The second interesting result is that information rents for farmers are low but, as stated above, this finding is conditional on compliance cost uncertainty. Bids number 8 and 9 have zero or slightly negative rents. This may be due to unforeseen costs during the submission of bids. Finally, a casual inspection suggests that the bids are slightly correlated with EBI values. In the next section, we provide a theoretical basis for this finding.

5.2. Bids and expectations: insights from an auction simulation model

An auction simulation model is used to further assess the results of the pilot: we generate bids of profits maximizing farmers, determine the information rents and compare the outcomes of the two variants of the model. Furthermore, we examine what assumptions on the expectations yield outcomes close to the actual bid; this allows us to estimate how farmers perceived differences in compliance costs and EBI values. We follow Latacz-Lohmann and van der Hamsvoort (1997) in the simulation but, unlike them, we include EBI in the bidding process. Recall, EBI depends on factors that the farmer cannot impact in the short run. Despite this fact, farmers must make expectations on bid/EBI ratios to participate in bidding. We denote EBI values by e and the upper limit of the bidder's expectation about the maximum expected bid/EBI by $\bar{\beta} = b''/e''$. The bidders' expectations about this implicit bid cap are uniformly distributed in the range $\left[\underline{\beta}, \overline{\beta}\right]$, where the lower bar represents the minimum ($\underline{\beta} = b'/e'$) and upper bar the maximum expected bid cap. The probability that the bid is accepted is given by

$$P(\theta \leq \bar{\beta}) = \int_{\theta}^{\bar{\beta}} f(\theta)\mathrm{d}\theta = 1 - F(\theta). \tag{1}$$

The expected net payoff of the risk-neutral farmer from bidding is a product of the revenue from winning the bid and the acceptance probability:

$$(\pi_1 + b - \pi_0)(1 - F(\theta)), \tag{2}$$

where π_0 denotes the profit under no participation and π_1 is profit under the secured conservation contract. The farmer chooses the bid, b, and thereby the ratio b/EBI, according to:

$$b^* = \pi_0 - \pi_1 + \frac{(1 - F(\theta))e}{f(\theta)}, \tag{3}$$

where $f(\theta)$ is the probability density function associated with $F(\theta)$ and e is the parcel's EBI-value.

The difference $\pi_0 - \pi_1$ in Equation (3) represents the costs of complying with phosphorus load reductions and the additional term, $(1 - F(\theta))e/f(\theta)$, is the information rent.

We next make use of the properties of the uniform distribution in Equation (3) to determine the closed form solution of the optimal bid. We focus just on an interior solution – the case where $\underline{\beta} \leq \theta \leq \overline{\beta}$. The optimal bid in the presence of EBI is determined by

$$b^* = \frac{\pi_0 - \pi_1 + e\overline{\beta}}{2}. \tag{4}$$

Hence, when EBI matters for participation in an auction, the optimal bid depends on the conservation costs and the expected cap multiplied by the bidder's own EBI value ($e\overline{\beta} = e(b''/e'')$). Clearly, we have

$$\frac{\mathrm{d}b}{\mathrm{d}e} = \frac{\bar{\beta}}{2} > 0. \tag{5}$$

Thus, the higher the EBI of the submitted field parcel, the higher the bid. In a recent article, Glebe (2013) obtains a similar result.

When farmers expect that environmental performance is about the same across the farmers, the optimal bid is the same as under an auction without EBI:

$$\lim_{e \to e''} b^* = \frac{\pi_0 - \pi_1 + e(b''/e'')}{2} = \frac{\pi_0 - \pi_1 + b''}{2}. \tag{6}$$

We next simulate an auction model with and without EBI to further examine how EBI impacts the auction simulation outcomes. For the sake of comparison, we employ the same expectations in both models. We start with the case reflecting Equation (6) where individual EBIs are assumed equal to e''. Table 4 provides the simulation results drawing on the pilot study data and assuming that farmers have identical beliefs regarding variation in costs (variation by 40 per cent around the mean).

Table 4 shows that with approximately €25,000 budget the nine best B/C ratio offers can be selected, and the simulation leads to higher bids than in the

Table 4 Simulated auction: expectations formed on the basis of compliance cost (40% cost variation)

Bid no.	Cumulative area (ha)	Bid (€/ha)	Rank (B/C)	Cumulative budget (€)	Information rent (€/ha)	Information rent (%/bid)
2	8.3	257.4	1	2139	34.8	13.5
1	18.0	251.7	2	4571	40.6	16.1
3	27.1	251.8	3	6875	40.4	16.1
4	34.6	247.8	4	8729	44.5	17.9
6	50.5	251.7	5	12,726	40.6	16.1
5	82.1	247.8	6	20,550	44.5	17.9
7	89.1	248.3	7	22,308	44.0	17.7
9	95.7	248.3	8	23,939	44.0	17.7
10	101.0	248.6	9	25,264	43.7	17.6
8	111.7	251.7	10	27,958	40.6	16.1
Mean	—	250.1	—	—	42.2	16.9

Table 5 Simulated auction: expectations formed on the basis of bid/EBI (40% variation)

Bid no.	Cumulative area (ha)	Bid (€/ha)	Rank (B/C)	Cumulative budget (€)	Information rent (€/ha)	Information rent (%/bid)
2	8.3	397.8	1	3306	175.2	44
1	18.0	342.5	2	6615	131.4	38
3	27.1	328.9	3	9624	117.5	36
4	34.6	296.9	4	11,845	93.6	32
6	50.5	256.2	5	15,913	45.0	18
5	82.1	244.1	6	23,618	40.7	17
7	89.1	216.4	7	25,150	12.0	6
9	95.7	205.3	8	26,499	1.0	0
10	101.0	205.3	9	27,593	1.0	0
8	111.7	208.7	10	29,827	−2.4	−1
Mean	—	282.2	—	—	73.9	26

EBI, environmental benefit index.

pilot: the average bid is now €250/ha, whereas in the pilot it was €221/ha. The rank of accepted offers changes too, but only slightly. Information rents are also higher in the simulation, although they still remain reasonably low on average (€42/ha), representing about 17 per cent of the value of a bid. Strict comparison to the actual pilot is not valid though, as outcomes in Table 4 depend on our assumptions on farmers' expectations. Lowering expectations to below 10 per cent around the mean would result in an outcome close to the actual pilot. Thus, farmers in the pilot generally expected a rather homogeneous cost structure.

Table 5 presents the results for a case where farmers form expectations about the ratio of bid to EBI, and shows the main result relative to Table 4. Accounting for EBIs in the simulation increases information rents relative to the case where EBIs are not included in the auction mechanism or are identical. Thus, now only seven offers can be selected with a €25,000 budget. This confirms what we found in theory. Information rents decrease with the rank and increase with the value of EBI. The rank of offers differs from that of the actual pilot but remains the same as in Table 4. Impact on the conservation budget is slightly higher than in the previous case. Finally, expectations on bid/EBI variation must be reduced below 10 per cent to yield the same information rents as in the actual pilot. This finding can be interpreted as follows. As theory and simulations show, using the same expectations for both auctions leads to higher information rents under bid/EBI. Therefore, when we explain observed information rents in Table 3, we need to use lower expectations than in the auction simulation without EBI.

5.3. Bids and expectations: insights from flat rate payment policy

We next compare the outcomes of the auction with hypothetical flat rate payments and flat rate payments with EBI eligibility criterion. The flat rate assigns gypsum treatments for parcels with compliance costs below the uniform payment level. The flat rate payment with eligibility criterion further sets a minimum EBI level for any parcel to be compensated by the program.

We conduct the analysis in the following manner. For the simple flat rate payment, we order the bids according to the upper and lower bounds of their compliance costs as defined in Section 5.1. Parcels will be included in the program in this order until the budget is as close to the budget of the actual auction as possible. The uniform compensation is then equal to the highest compliance cost.

Flat rate payment with EBI eligibility criterion is two dimensional: it includes the payment and the EBI threshold. The optimal flat rate scheme is found by comparing alternative EBI – flat rate combinations and choosing the one satisfying the budget constraint and generating the highest value for the budget.

We calculate the weighted average EBI per hectare and the weighted average P-status per hectare for the enrolled parcels for the four cases. We also report the total acreage and the budget. The results are given for each policy and for both assumptions regarding information rents in Table 6.

The first column denotes the area weighted average EBI which corresponds directly to environmental benefits in our model. The areas and budgets differ slightly as different policies enrol different parcels combinations. The EBI per (hundred) € offers a clear cut efficiency criterion for each policy.

The case 'Maximum information rent' assumes that the costs of making a bid as well as all other transaction costs are zero. Hence, the compliance costs comprise of gypsum price, freight and the application costs only. The amount exceeding these in the bid is information rent. The 'Minimum information rent' represents the opposite pole: there is no information rent. Variations in bids reflect differences in unobservable underlying costs. The higher the information rent, the less efficient the auction format as shown in Table 6. Both flat rate policies are less inefficient relative to the auction pilot under the maximum information rent.

Table 6 Flat rate payment schemes with alternative assumptions on information rents

Policy	Maximum information rent				Minimum information rent			
	EBI (criterion)	Area	Budget (flat rate)	EBI/100€	EBI (criterion)	Area	Budget (flat rate)	EBI/100€
Flat rate	31.7	121	25,051 (207)	15.3	29.5	127	27,430 (215)	13.9
Flat rate w. criterion	40.6 (27)	118	25,033 (211)	19.2	41.5 (28)	103	24,614 (238)	17.4
Pilot auction	44.2	112	24,717	20.0	44.2	112	24,717	20.0

EBI, environmental benefit index.

Table 7 Comparing the pilot auction, flat rate payments and simulations

Policy	EBI	Area (ha)	Budget (€)	Flat rate or average bid (€/ha)	EBI/100€
Flat rate	31.7	121	25,051	207	15.3
Flat rate (EBI criterion)	40.6 (27)	118	25,033	211	19.2
Auction simulation (compliance cost)	45.9	101	25,264	250	18.4
Auction simulation (bid/EBI)	48.3	89	25,150	282	17.1
Auction pilot	44.2	112	24,717	221	20.0

EBI, environmental benefit index.

5.4. Comparing the auction, flat rate payments and simulations

Table 7 collects the key outcomes of the four alternative schemes presented in previous sections. Due to the discrete nature of bids, budgets and program acreages vary. For each scheme, we present the acreage, budget, mean EBI per € ratio (divided by 100 for ease of interpretation), flat rate payments and the optimal EBI threshold for the flat rate scheme with EBI criterion.

The flat rate payment picks up the cheapest parcels, but is less effective in targeting the measures to most suitable parcels. The flat rate payment includes by chance the highest EBI parcel, which improves its performance markedly. Nevertheless, the efficiency of the auction – as measured by the EBI per € – is 31 per cent higher than with the flat rate payment.

A flat rate with EBI eligibility criterion and an auction with an EBI lead to higher EBI values relative to the flat rate scheme and an auction without an EBI. The flat rate payment with eligibility criterion is only 4 per cent less efficient than the auction. Intuitively, targeting is more effective when parcels are chosen on the basis of an EBI only. The differences are rather small, however. The flat rate schemes perform quite well, thanks to rather small cost differences.

6. Conclusions

We examined experiences from a pilot auction on working agricultural lands in Southern Finland whose aim was to reduce phosphorus loads to waterways. We focused on how suitable the auction format is for phosphorus load reduction and how cost-efficiently an EBI describing the benefits of phosphorus reduction allocates the conservation budget. A novel measure, spreading gypsum, was used to reduce phosphorus loads. Farmers were asked to make bids on spreading gypsum on their fields. As the per tonne costs of delivering the gypsum were higher for small quantities, the auction format allowed bundling of field parcels as a means of reducing these freight costs.

Our main conclusion is that the auction format performed well. The pilot enrolled the parcels providing the highest environmental benefits – reductions in dissolved and PP runoff – from among the parcels for which bids were submitted. The key factor that separated the enrolled targets from rejected ones was P-status: it was four times higher for accepted bids. Moreover, the auction format attracted some of the most environmentally sensitive parcels in the area. This was shown by a comparison to data on P-status in the study area and to an expert allocation of gypsum in another region. Finally, our simulations demonstrated that information rents remained low, but also suggest that stewardship attitudes may have been present in the pilot. Factors prompting this finding are the low number of participants in the pilot and the possibility that the bids were submitted by the environmentally most active farmers.

The auction format relied on the developed EBI and the possibility of bundling parcels which farmers used extensively. Seven of the ten bids were for bundled field parcels. Farmers used bundling to adapt to indivisible transportation costs showing a sound understanding of the economics inherent in the bidding. Bundling is a natural response to many kinds of economies of scale the farmers may face, worth studying in more detail in future research.

The EBI designed for this research had a dual role: It helped the farmers assess the importance of their fields relative to environmental targets and assisted the organisers in ranking and enrolling the targets. Our phosphorus runoff EBI can be used as part of any environmental policy. Of the three environmental criteria making up the EBI – field slope, proximity to ditches or surface waters and P-status – slope did not separate the accepted and rejected bids and location did so only in some cases. The most important criterion was the P-status of the soil, which was four times higher for accepted than rejected bids. This suggests that a simpler EBI, one with just two defining criteria (P-status and location), may work well in policies to reduce phosphorus runoff. Naturally, what is suitable in the case of phosphorus does not apply to nitrogen, as it exhibits very different dynamics in agricultural soils. An EBI for nitrogen would have to be defined differently.

We compared the pilot auction to simulated auctions and flat rate payment schemes with and without an EBI. The flat rate scheme picks up the cheapest parcels, but is less effective in targeting the measures to most suitable parcels. The auction pilot was much more efficient than the flat rate payment. Combining an EBI with flat rate and auction schemes increased their efficiency. The flat rate payment with eligibility criterion was only 4 per cent less efficient than the auction, suggesting that flat rate schemes perform quite well when cost differences are small.

Auctions are an interesting and promising policy tool. With the exception of applications to retirement lands, we know too little of the performance of auctions in the case of working lands. Future research is needed in particular work that would make it possible to deal with biodiversity as well as the complexities of nitrogen use and nitrogen runoff. Mitigation of climate change, a topical issue, is an area where auctions could play an important role in reducing agricultural greenhouse gas emissions.

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References

Cason, T. and Gangadharan, L. (2004). Auction design for voluntary conservation programs, *American Journal of Agricultural Economics* 86 (5), 1211–1217.

Connor, J.D., Ward, J.R. and Bryan, B. (2008). Exploring the cost effectiveness of Land conservation auctions and payment policies, *The Australian Journal of Agricultural and Resource Economics* 51 (3), 303–319.

Cramton, P., Shoham, Y. and Steinberg, R. (2006). *Combinatorial Auctions*. MIT Press, Cambridge, MA.

Ekholm, P., Turtola, E., Grönroos, J., Seuri, P. and Ylivainio, K. (2005). Phosphorus loss from different farming systems estimated from soil surface phosphorus balance, *Agriculture, Ecosystems and Environment* 110, 266–278.

Ekholm, P., Valkama, P., Jaakkola, E., Kiirikki, M., Lahti, K. and Pietola, L. (2012). Gypsum amendment of soils reduces phosphorus losses in an agricultural catchment, *Agricultural and Food Science* 21 (3), 279–291.

Farm Service Agency. (2012). Conservation reserve program status – end of march. Available from URL http://www.fsa.usda.gov/Internet/FSA_File/mar2012onepager.pdf [accessed 25 April 2012].

Glebe, T. (2013). Conservation auctions: should information about environmental benefit be made public?, *American Journal of Agricultural Economics* 95 (3), 590–605.

Hajkowicz, S., Higgins, A., Williams, K., Faith, D.P. and Burton, M. (2007). Optimisation and the selection of conservation contracts, *The Australian Journal of Agricultural and Resource Economics* 51, 39–56.

Juutinen, A. and Ollikainen, M. (2010). Trading in Nature Values as a means of biodiversity conservation in boreal forests: theory and experience from Finland, *Forest Science* 56, 201–211.

Juutinen, A., Mäntymaa, E. and Ollikainen, M. (2013). Landowners' conservation motives and the size of information rents in environmental bidding systems, *Journal of Forest Economics* 19 (2), 128–148.

Kirwan, B., Lubowski, R.N. and Roberts, M.J. (2005). How cost-effective are land retirement auctions? Estimating the difference between payments and willingness to accept in the Conservation Reserve Program, *American Journal of Agricultural Economics* 87 (5), 1239–1247.

Latacz-Lohmann, U. and Schilizzi, S. (2005). *Auctions for conservation contracts: a review of the theoretical and empirical literature*. Report to the Scottish Executive Environmental and Rural Affairs Department.

Latacz-Lohmann, U. and van der Hamsvoort, C. (1997). Auctioning conservation contracts: a theoretical analysis and an application, *American Journal of Agricultural Economics* 79, 407–418.

Puustinen, M., Merilä, E., Palko, J. and Seuna, P. (1994). *Drainage Level, Cultivation Practices and Factors Affecting Load on Waterways in Finnish Farmland*. Publications of the National Board of Waters and the Environment, Series A(198). National Board of Waters and the Environment, Finland (in Finnish).

Puustinen, M., Turtola, E., Kukkonen, M., Koskiaho, J., Linjama, J., Niinioja, R. and Tattari, S. (2010). VIHMA-A tool for allocation of measures to control erosion and nutrient loading from Finnish agricultural catchments, *Agriculture, Ecosystems and Environment* 138, 306–317.

Stoneham, G., Chaudri, V., Ha, A. and Strappazzon, L. (2003). Auctions for conservation contracts: an empirical examination of Victoria's BushTender trial, *The Australian Journal of Agricultural and Resource Economics* 47, 477–500.

Uusitalo, R. and Jansson, H. (2002). Dissolved reactive phosphorus in runoff assessed by soil extraction with an acetate buffer, *Agricultural and Food Science in Finland* 11, 343–353.

Uusitalo, R., Turtola, E., Grönroos, J., Kivistö, J., Mäntylahti, V., Turtola, A., Lemola, R. and Salo, T. (2007). Finnish trends in phosphorus balances and soil test phosphorus, *Agricultural and Food Science* 16, 301–316.

Vuorinen, J. and Mäkitie, O. (1955). The method of soil testing in use in finland, *Agrogeological Publications* 63, 1–14.