Conservation Biology

Contributed Paper

A Revealed Preference Approach to Estimating Supply Curves for Ecosystem Services: Use of Auctions to Set Payments for Soil Erosion Control in Indonesia

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Abstract: *To supply ecosystem services, private landholders incur costs. Knowledge of these costs is critical for the design of conservation-payment programs. Estimating these costs accurately is difficult because the minimum acceptable payment to a potential supplier is private information. We describe how an auction of payment contracts can be designed to elicit this information during the design phase of a conservation-payment program. With an estimate of the ecosystem-service supply curve from a pilot auction, conservation planners can explore the financial, ecological, and socioeconomic consequences of alternative scaled-up programs. We demonstrate the potential of our approach in Indonesia, where soil erosion on coffee farms generates downstream ecological and economic costs. Bid data from a small-scale, uniform-price auction for soil-conservation contracts allowed estimates of the costs of a scaled-up program, the gain from integrating biophysical and economic data to target contracts, and the trade-offs between poverty alleviation and supply of ecosystem services. Our study illustrates an auction-based approach to revealing private information about the costs of supplying ecosystem services. Such information can improve the design of programs devised to protect and enhance ecosystem services.*

Keywords: conservation auction, conservation planning, payments for ecosystem services, poverty alleviation, program design, revealed preferences, supply curves

Un Método de Preferencia Revelada para la Estimación de Curvas de Suministro de Servicios del Ecosistema: Uso de Subastas para Fijar Pagos por la Erosión de Suelos en Indonesia

Resumen: *Para proporcionar servicios del ecosistema, los propietarios de tierras incurren en costos. El conocimiento de estos costos es crítico para el diseño de programas de pago por conservar. La estimación precisa de estos costos es difícil porque el pago mínimo aceptable a un proveedor potencial es información privada. Describimos cómo se puede diseñar una subasta de contratos de pago para recabar esta información durante la fase de diseño de un programa de pago por conservar. Con una estimación de la curva de suministro de servicios del ecosistema, los planificadores pueden explorar las consecuencias financieras, ecológicas y socioeconómicas de programas alternativos. Demostramos el potencial de nuestro método en Indonesia, donde la erosión de suelo en fincas cafetaleras genera costos ecológicos y económicos aguas abajo. Datos de oferta de una subasta, de precio uniforme y pequeña escala, de contratos de conservación permitieron estimar los costos de un programa ampliado, la ganancia por integrar datos biofísicos y económicos a los contratos y los pros y contras entre la disminución de pobreza y el suministro de servicios del ecosistema. Nuestro estudio ilustra un método basado en subasta para revelar información privada sobre los costos del suministro de*

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Paper submitted March 13, 2008; revised manuscript accepted July 7, 2008.

Conservation Biology, Volume 23, No. 2, 359–367

DOI: 10.1111/j.1523-1739.2008.01086.x

servicios del ecosistema. Tal información puede mejorar el diseño de programas diseñados para proteger e incrementar los servicios del ecosistema.

Palabras Clave: curvas de suministro, diseño de programa, disminución de pobreza, pagos por servicios del ecosistema, planificación de la conservación, preferencias reveladas, subasta de conservación

Introduction

Performance payments for ecosystem services are alternative to command-and-control or indirect-incentive approaches to conservation (e.g., Ferraro 2001; Ferraro & Kiss 2002; Jack et al. 2008). Compensating landholders for the costs they incur in their conservation efforts helps align the private and public benefits from conservation. To affect land-use practices, the payment approach requires accurate estimates of private costs, specifically landowners' willingness to accept (WTA) a conservation contract (i.e., the minimum price they require for the contract activities). If payments undercompensate landowners, the approach will not induce behavioral change because of poor enrollment or high noncompliance rates. If payments overcompensate landowners, the approach will not maximize conservation benefits from a given budget.

The cost-effectiveness of a payment for ecosystem services program can thus be enhanced if program designers reliably estimate a supply curve of ecosystem services obtained per dollar spent. We demonstrate how procurement auctions can be used to reveal this private information during the design phase of a program. This information can then be used to generate an estimate of the supply curve for ecosystem services for the targeted program population. We implemented an experimental auction as part of a payment for ecosystem services project on the island of Sumatra, where coffee farmers bid for payment contracts to implement erosion control. We show how knowledge of the shape of the supply curve allows for simple modeling exercises that explore efficiency gains from targeting payments to specific types of landholders and other variations in program design.

The existing literature in environmental economics and conservation biology recognizes the gains in conservation benefits obtained for a fixed budget when cost measures are integrated into the conservation-planning process (Naidoo et al. 2006). Nevertheless, landholders' opportunity costs of conservation are unknown to the conservation planner. To estimate these costs, a variety of methods have been proposed.

Cost-flow or bioeconomic models rely on observable plot or farm characteristics to generate cost estimates (Richards et al. 1993; Antle & Valdivia 2006; Naidoo & Adamowicz 2006). Where heterogeneities in private cost are present and difficult to observe, these types of estimates may be inaccurate (Ferraro 2008). Rural areas in the developing world often exhibit market imperfections or significant subsistence components in the farm portfolio, making accurate estimates from observable characteristics difficult. Although such approaches typically model opportunity costs as foregone expected profits from alternative uses of the land, landowners' WTA a conservation contract is determined by more than foregone profits. Unobservable risk preferences, time preferences, option values, cultural values, and subjective beliefs are also important (e.g., Parks 1995).

In principle, stated preference methods, such as contingent valuation, capture these hard-to-measure components of a landowner's WTA value. Such methods rely on hypothetical questions to elicit valuations (Carson & Hanemann 2005), which may result in bias because respondents have no incentive to tell the truth or to invest cognitive effort into estimating their true private values (Harrison 2006).

In contrast, revealed preference approaches to economic valuation use data on observed market decisions to capture all components of decision makers' preferences (Adamowicz et al. 1997). Like cost-flow modeling approaches, revealed preference estimates are derived from real decisions rather than hypothetical ones. At the same time, they incorporate hard-to-measure aspects of landowners' subjective values, such as a farmer's own discount rate. To accurately measure these values, revealed preference approaches rely on related competitive-market transactions, which do not typically exist for ecosystem services.

Auctions reveal preferences by creating a temporary competitive market. An appropriately designed auction provides an incentive for all bidders to reveal private information about their true valuation of a good or service. Auctions for nonmarket valuation are most commonly used in laboratory settings (surveyed in Kagel 1995; Harrison 2006). In the context of conservation payments, auctions are primarily used to allocate contracts cost effectively within a predetermined budget or quantity goal (i.e., to select the lowest cost landholders for enrollment in the program; Latacz-Lohmann & Schilizzi 2005). We used an auction to estimate supply curves for integration into program design. To the best of our knowledge, this is the first exposition of the potential uses of auctions for cost revelation during the design phase of a conservation payments program, as well as the first use of a conservation auction in a developing country context. Specifically, we conducted the following 3 exercises: examined the effect of different budgets on conservation outcomes; incorporated a plot-level erosion index into selection of land parcels; and explored the socioeconomic impacts of alternative targeting strategies.

Methods

As part of a project for payment for ecosystem services on the island of Sumatra led by the World Agroforestry Centre (ICRAF), we implemented a procurement auction to elicit private information on landowners' WTA payments in return for soil-conservation investments on private coffee farms. The Sumberjaya subdistrict, where the auction took place, is dominated by coffee crops in erosion-prone uplands. Erosion transports sediment loads to sensitive aquatic ecosystems and has negative effects on the resident flora and fauna. Moreover, a gradual reduction in soil organic carbon due to erosion can lead to a reduction in ecosystem carbon storage (van Noordwijk et al. 1997). Finally, soil erosion in Sumberjaya contributes to the siltation of a downstream hydropower reservoir that provides electricity for 3 provinces in Sumatra.

Erosion control generates private and public benefits. By ignoring the public benefits in their private decisions, farmers tend to underinvest in soil conservation. Several on-farm techniques effectively reduce soil erosion from smallholder coffee farms in the Sumberjaya watershed (Agus et al. 2002; Agus & Van Noordwijk 2005). Four focus-group discussions involving 76 farmers led to the selection of 3 scalable and verifiable techniques: soil infiltration pits, vegetation strips, and ridging between coffee trees (Leimona et al. 2008). These techniques constituted the requirements of the contracts allocated through the pilot auction. We measured performance on the basis of land-use activities, rather than actual services supplied, because of monitoring difficulties and the risk burden for landholders (Wunder 2007). As a result, the units supplied are hectares under soil erosion control, rather than tons of soil erosion avoided. We also assumed that each parcel independently contributed to the overall benefit score. Thresholds, or other ecological complementarities, may alter the shape of the supply curve (Naidoo et al. 2006).

The contracted soil-conservation techniques reduce erosion without decreasing coffee production, incur few fixed costs, and require primarily labor investment (farmers already owned needed tools). Components of landowners' WTA values were anticipated to include observable characteristics, such as plot slope, and unobservable characteristics, such as the opportunity cost of labor. Bids in an appropriately designed auction capture all of these factors, including private information that cannot be determined by program designers, and thus reveal the distribution of WTA values within the sample.

To provide an incentive for truthful cost revelation, we used a uniform-price rule in which the final contract price equaled the lowest rejected-offer price. Under this price rule, bidders who bid above their true values risked losing the contract at a price they would have been willing to accept. Bidders who bid below their true value risked winning a contract at a price below their minimum acceptable price. Thus, all bidders' best (weakly dominant) strategy was to bid their true WTA value. In contrast, in discriminative-price procurement auctions, where winning bidders receive a contract price equal to their own bid (e.g., Stoneham et al. 2003), bidders have strategic incentives to inflate their bids above their true WTA value. Full details of the auction rules, including pricing and enrollment rules, were provided to participants at the start of the auction.

The conservation auction was carried out on consecutive days in 2 villages in a single subwatershed. The villages were selected on the basis of hydrological studies that showed their contribution to sediment loads. A random sample of participants from the subdistrict population would have provided more representative results, but the interests and preferences of the partner organization precluded this approach.

The primary occupation in the study villages is coffee farming, most of which takes place on small, individually owned plots. The auction was limited to owners of private coffee plots and excluded plots on state forest lands, which are subject to other regulations. One village consisted of 55 households, 53 of which owned private agricultural land. Of these, 5 rented or sharecropped their land, leaving 48 eligible households, all of which participated in the auction. In the other village, 55 of the 87 households owned private agricultural land. Of these, 20 rented or sharecropped their land. Thus, 35 households were eligible, and 34 participated in the auction. To ensure that participants understood the contract requirements, the implementing organization offered training on implementation of the conservation techniques prior to the auction. Details of the contracts were not revealed in advance, to reduce the risk of collusion.

Farmers submitted sealed bids representing their per-hectare price for accepting a conservation contract with payments in 3 installments, the second and third payments conditional on verification of compliance. The multiinstallment payment plan provided incentives for compliance for the duration of the contract, which mitigated valuation problems associated with moral hazard (i.e., lowering bids because of the expectation of lax enforcement). Plots were treated as discrete: all or none of the plots were contracted (thus the budget was not exhausted in one village).

In each of the 2 villages, the auction lasted 2–3 h, during which the participants heard the contract described, received auction instructions, and placed bids. Following Cummings et al. (2004), the auction consisted of several rounds preceding the final allocation round. After each provisional round, the bidder-identification numbers of provisional winners were announced. No price information was provided between rounds, and participant communication was minimized through the seating arrangements. Bids were revised and resubmitted for each round, a process designed to increase familiarity with the mechanism and provide an opportunity for learning. Participants were told the number of provisional rounds in advance to ensure that they based their final-round bids solely on their WTA values and not on expectations about the number of rounds. Table 1 describes the design characteristics of the auction (first column adapted from Cummings et al. 2004; Hailu & Schilizzi 2004) and key statistics associated with bidding and contracting outcomes.

Cost-flow or bioeconomic models rely on observable plot or farm characteristics to generate cost estimates. In situations where observable characteristics yield accurate predictions of bids, policy makers can benefit from a regression-based pricing scheme that allows for plot-specific estimates of WTA on the basis of sample auction results (e.g., Athey et al. 2002). To test the viability of this approach in our sample, we used an OLS regression to examine whether observable characteristics yield reasonably precise and consistent predictions of cost. Spatial interactions were ignored because they should not affect accurate cost elicitation. We regressed the logarithm of observed bid prices for all auction participants ($n = 82$) on all observable plot and landholder characteristics for which we had data and expected would explain opportunity cost. We assumed the model was additive and included slope, position on the hillside, soil color and texture, distance to the nearest tarmac road, current and past soil-conservation investment, plot size, and village: $\ln(\text{bid}) = \alpha + \beta_1{}^*\text{slope} + \beta_2{}^*\text{position} + \beta_3{}^*\text{color} + \beta_4{}^*\text{texture} + \beta_5{}^*\text{distance} + \beta_6{}^*\text{current} + \beta_7{}^*\text{past} + \beta_8{}^*\text{village} + \epsilon$. We included all explanatory variables with a hypothesized effect on opportunity cost in the regression to give the model the best chance to explain the outcome data.

To further test the ability of observable characteristics to capture the drivers of WTA values, labor-cost information was elicited prior to the auction with 2 approaches. First, during focus groups, farmers estimated the labor requirements of the contract on the basis of wages, number of hired workers, and number of work days. Second, cost information was gathered during a household survey that asked about investments for past soil conservation activities.

Table 1. Design characteristics and summary statistics of soil-conservation auction in Sumberjaya, Indonesia, used to estimate contract supply curve.

Auction characteristic	*Auction outcome statistic*
Auction type: one-sided, sealed bid procurement auction	Participants: 82
Bidding units: per hectare willingness to accept the contract	Contracts awarded: 34
Budget limit: predetermined, concealed	Eligible hectares: 70
Number of rounds: 7 provisional, 1 binding	Hectares contracted: 25
Announcement of provisional winners: by identification number	Mean contract price per hectare: $171.70
Pricing rule: uniform, lowest rejected price	Mean bid per hectare: $263.14
Tie rule: random	Minimum bid per hectare: $66.67
Bidder number: known, fixed	Maximum bid per hectare: $2,777.78
Activities contracted: determined in advance	Bid standard deviation: $344.91

Results

Just under half of the 82 auction participants received contracts for soil conservation activities. The total budget of around US$4450 was combined with the uniform pricing rule to determine the contract price of US$177.78/ha in the first village and US$166.67/ha in the second village ($1 = 9000 Indonesian rupiah). Just over one additional hectare of conservation investment would have been purchased if participants were paid their own bid (i.e., discriminative-price auction). Nevertheless, as explained earlier, bid inflation under a discriminative-price rule would reduce these gains. In the following discussion, we did not consider a single high-outlier bid.

The aggregate supply curve from the 2 villages, which describes the number of hectares enrolled in the program

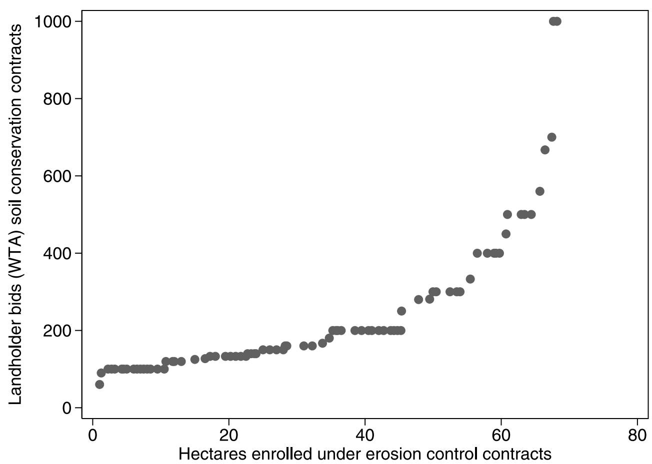

Figure 1. Supply curve for hectares under soil-erosion control measures, estimated from auction bids for payment contracts in Sumberjaya, Indonesia.

for any given price, followed an exponential distribution with increasing marginal costs (Fig. 1). This supply curve represents short-run costs for conservation investments as estimated by the participants, which may change as participants learn more about the contract or the contractor. Other approaches to predicting contracting costs, including regression analysis and labor-cost estimates, failed to accurately approximate the values elicited from the auction.

Observable landholder characteristics provided low explanatory power for the costs revealed by the bids. The adjusted R^2 value from the regression analysis was only 0.0783, and the regression was not significant ($F = 1.46$; $p > F = 0.1474$). Although a subset of the variables may perform equally well, the overall fit of the observable characteristics demonstrated the poor predictive power of the set of observable characteristics for which we had data. Low variability of elicited costs and observable characteristics in our sample contributed to the low explanatory power of the model. Unobservable components may have significantly affected differences in WTA values in our sample.

Labor-cost approximations overestimated the cost of purchasing soil-conservation investments. The estimate from focus-group discussions was US$300/ha, including foregone wages from the farmer's own labor investment. The estimates based on retrospective calculations during the household survey were slightly lower, around $225. The cost estimates based on labor investments were 30–75% higher than the average auction price of $171.70/ha and 24–65% higher than the median bid. On the basis of estimated labor costs, 14.8–19.8 ha could be enrolled under the available budget, as opposed to the 25 ha actually purchased (26–69% more). On the other hand, the mean bid price was between the 2 labor-cost estimates, which suggests that these methods may accurately estimate mean values. Labor-cost estimates were not necessarily inaccurate; they simply provided incomplete measures of WTA values.

Modeling Exercises

An accurate estimate of the supply curve from a representative sample of the population can greatly enhance program design by allowing simulation of alternative designs prior to full implementation. With data from the Sumberjaya auction, we developed 3 models to illustrate use of the auction data in program design. First, we examined outcomes under different potential budgets. Second, we showed how bids can be combined with measures of erosion per hectare to target plots with certain characteristics such as high erosion-control benefits. This cost-efficiency targeting may be achieved through a scoring rule in a scaled-up auction or through a coarser approach of benefit targeting under an eligibility rule that excludes, ex ante, the land parcels that are of least priority for erosion control. Third, we explored the relationship between design alternatives and distributional impacts. This latter exercise is particularly important in low-income nations where "pro-poor" payment programs are a policy priority (Pagiola et al. 2005; Wunder 2008).

We focused on these 3 models because they had the greatest potential to affect scaling-up decisions. With an estimated supply curve, other useful modeling exercises, such as cost–benefit analysis, are possible. The 3 exercises are developed generally and then applied to the data from Sumberjaya. Recall that our sample was not a random sample from the Sumberjaya population and thus may not be fully representative of the watershed. Even in the case of a random sample, scaling extensions are limited to the population from which the sample is drawn and do not directly inform program design outside of the sampling setting or time frame. Furthermore, our soil-erosion control values represented crude estimates obtained primarily through household survey measures and did not allow for spatial targeting simulations. These models were intended to illustrate the methodology, rather than provide a foundation for designing a scaled-up program in Sumberjaya. Transaction costs for the implementing agency were not considered in the analysis, but may substantially affect the cost-effectiveness of alternative designs (Jack et al. 2008). Such costs can be incorporated easily into the analyses we conducted (Ferraro 2003, 2004).

Budget Scenarios

Under an assumption that the auction participants provided a representative sample of households in the Sumberjaya watershed that would be eligible to participate in a soil-conservation contracting program, the supply curve in Fig. 1 can be scaled to represent the supply curve for Sumberjaya. In the case of soil conservation, the watershed is the relevant project scale. The information embodied in Fig. 1 produces estimates of the costs of scaling-up our contracting program or, equivalently, estimates of the number of contracted hectares possible under a given budget. For example, assume 8000 households, or around 12% of the total population in Sumberjaya, are eligible for payments (e.g., upland coffee farmers with private landholdings) and that the conservation buyer (e.g., hydroelectric company) has an annual budget of US$0.43 million for payments. If the buyer wants to pay each household the same fixed take-it-or-leave-it price, one would predict that the buyer could contract on about 2500 ha. If, however, on the basis of hydrological models, the buyer determines that contracts on a minimum of 5000 ha are needed to prevent economically relevant siltation from taking place, the data predict program costs of US$1.67 million. Estimates of the monetary value of the benefits from reducing soil erosion would further allow cost–benefit analyses to decide the optimal number of contracted hectares.

Cost-Efficiency Targeting

A conservation payment program faces many design choices, including whether to target investments on the basis of costs, benefits, or some combination of both. The gains from integrating cost and benefit information depend on the distribution of and correlation between costs and benefits (Babcock et al. 1997). Where relative benefit heterogeneity is greater than relative cost heterogeneity or where costs and benefits are positively correlated, targeting on the basis of the ratio of benefits to costs is likely to improve cost-efficiency. We estimated erosion control benefits in Sumberjaya from an erosion index that captures the relative erosion contribution from each plot in the sample (in contrast to a cost-efficiency analysis, a cost–benefit analysis assigns a dollar value to each parcel).

Any of the myriad targeting models in the conservation-planning literature (Margules & Pressey 2000) could have been used in conjunction with data from the auction. We developed a simple model to demonstrate cost-efficiency targeting with the Sumberjaya auction data. The cost efficiency of a contracted hectare was assumed to be a ratio of erosion potential to costs: $v_i = \varphi(\mathbf{Q}_i)/p_i$, where $\mathbf{Q}_i$ is a vector of plot characteristics that approximate the erosion contribution of plot i, φ is a simple linear-weighting function of the characteristics, and p_i is the bid per hectare on plot i. Ignoring the erosion potential of plots and accounting only for costs implicitly sets $\varphi(\mathbf{Q}_i)$ to 1, making the value per hectare equal to $1/p_i$. In our uniform price auction, such a targeting rule implies setting a price per hectare equal to the first rejected offer, r, and accepting all N_{r-1} plots with per hectare bids lower than p_r.

Introducing erosion potential into the targeting assigns variables and weights to $\mathbf{Q}_i$. Soil and hydrology experts from ICRAF identified the plot characteristics that contributed most to erosion in Sumberjaya and ranked them in order of importance: $\mathbf{Q}_i = \{$slope, position, soil color, soil texture$\}$. Each of the erosion-related characteristics is a categorical variable with 3 levels. As is often done in the conservation literature (see Ferraro 2004 for references), we used a linear scoring function to measure erosion potential: $\varphi(\mathbf{Q}_i) = w_1{}^*\text{slope} + w_2{}^*\text{position} + w_3{}^*\text{soil color} + w_4{}^*\text{soil texture}$, where $\varphi = \{4, 3, 2, 1\}$ on the basis of expert opinion (e.g., soil color makes twice score contribution of soil texture). We assumed that enrolling more erosion-prone land generates greater conservation benefits. Thus, the higher the value of $v_i = \varphi(\mathbf{Q}_i)/p_i$, the more desirable the land parcel for enrollment in the program. A more sophisticated approach would estimate soil erosion with and without a contract on the basis of biophysical models and data of finer resolution.

To maximize the erosion control potential per dollar spent in this design scenario, we ranked plots highest to lowest by v_i and awarded contracts until the budget was exhausted. Scoring bids in an auction creates strategic incentives to inflate bids. To make the cost-efficiency targeting results directly comparable to cost-only results, we ignored such incentives. Thus the cost-efficiency analysis overestimates conservation gains from targeting through a scored auction. In Sumberjaya relative cost heterogeneity dominated relative benefit heterogeneity, due in part to the coarseness of the erosion measure: the coefficient of variation on participant bids, p_i, was 0.78 (SD 185.3), whereas the coefficient of variation on erosion potential, $\varphi(\mathbf{Q}_i)$, was 0.14 (SD 3.07). Furthermore, the correlation obtained from a correlation matrix of erosion potential and costs was negative (−0.17). Greater relative cost variability and negative cost–benefit correlation imply limited gains from cost-efficiency targeting over cost-only targeting.

There are gains from integrating benefit and cost information, as evidenced by the higher benefits per dollar spent (Table 2). As predicted, however, these gains are small (7.5%).

Several scaled-up targeting approaches are available for cases where cost-efficiency targeting substantially increases conservation benefit per dollar spent. One option uses a scored auction that ranks bids in a process very similar to the modeling exercise described above. In a scored auction, such as Australia's BushTender auction (Stoneham et al. 2003), the auctioneer assigns each bidder's plot a score (usually including nonmonetary measures of benefits) that may or may not be known to the bidder. The plots are then ranked by score and bid cost (e.g., v_i) and enrolled, starting with the highest cost efficiency, until

Table 2. Soil-conservation contract enrollment outcomes from modeled targeting scenarios.

Targeting scenario	*No. of households*	*No. of hectares*	*Price per hectare (US$)*	*Average erosion potential index per enrolled hectare*	*Erosion potential per dollar*
Cost only	34	25.00	172	22.24	0.129
Cost- efficiency	31	24.00	167	23.14	0.139
Eligibility rule	31	24.00	167	23.10	0.138
Pro-poor	13	4.75	1111	22.69	0.020

the budget is exhausted. Although scored auctions may offer gains in theory, empirical evidence from both laboratory and field studies shows that when bidders have information about the scoring rule, they bid strategically to increase their profits from the auction (Athey & Levin 2001; Cason et al. 2003). In the presence of strategic bidding, the predicted efficiency gains from targeting on the basis of pilot supply-curve data will not generalize to a scaled-up scored auction. Measures to reduce strategic bidding under a scored auction are frequently adopted in practice, and discussed for the conservation contracting case by Latacz-Lohmann and Schilizzi (2005).

As an alternative to a scored auction, conservation buyers can use an eligibility rule in a scaled-up auction or fixed-price (take-it-or-leave-it) payment system. An eligibility rule would exclude land plots with $\varphi(\mathbf{Q}_i)$ below some threshold and thus direct payments away from low-erosion plots. Such a rule reduces administrative costs. We modeled 1 potential eligibility rule on the basis of our coarse measure of erosion potential (third row, Table 2). Focusing on the slope variable, which contributes most to erosion, we excluded all parcels with plot slope in the least erosion-prone category. This eligibility rule eliminated 11 participants with a mean bid of US$455.56/ha. In terms of total benefits generated, the rule outperformed the cost-only targeting and was only slightly less efficient than the cost-efficiency approach.

Payment in ecosystem-service programs in developing countries are often expected to benefit poorer members of a population (Pagiola et al. 2005; Wunder 2007). Eliciting the distribution of costs through a pilot auction provided an opportunity to predict whether a scaled-up program would benefit the poor. The relative wealth levels of the participants with and without contracts can be assessed under potential scoring or eligibility rules. We used the Sumberjaya auction data to select the least well-off households on the basis of our household-survey data. Under "pro-poor" targeting, enrollment declined to 4.75 ha owned by 13 households at a price of US$1111/ha (fourth row, Table 2). Total benefits per U.S. dollar invested were much lower under the pro-poor targeting, which suggests trade-offs between conservation and poverty-alleviation objectives in the study setting. In an alternative investigation of trade-offs, we compared socioeconomic indicators for those who would have received contracts under different targeting rules in the pilot auction.

On average, households selected for contracts under the "pro-environment" rules (rows 2 through 4) were at least as wealthy as the average bidder (median values), and substantially wealthier than households selected under the pro-poor rule (Table 3). The pro-poor rule also selected households with smaller-than-average land holdings and lower-than-average education levels. Because participation in the program was only open to households with private land tenure, the program itself may have selected for relatively wealthier households (24% of the villagers had no private land).

Table 3. Mean characteristics of auction participants receiving soil-conservation contracts under modeled targeting scenarios (median values in parentheses).

Targeting Scenario	*Asset (US$)*	*Area (ha)*	*Education (years)*
Cost-only targeting	11,190 (3,945)	0.74 (0.75)	5.8 (6.0)
Cost-efficiency targeting	12,753 (3,955)	0.80 (0.75)	5.7 (6.0)
Eligibility rule	12,156 (4,133)	0.81 (0.75)	6.2 (6.0)
Pro-poor targeting	1,183 (1,167)	0.37 (0.25)	4.4 (4.0)
Sample average	8,667 (3,978)	0.83 (0.75)	5.7 (6.0)

Discussion

Publication of the Millennium Ecosystem Assessment (2005) and associated articles (e.g., Armsworth et al. 2007) shows that conservation biologists are increasingly focused on the supply of ecosystem services. Securing these ecosystem services through performance payments has been touted as an important conservation tool. Payment programs range from international compensation schemes, such as Reductions in Emissions from Deforestation in Developing Countries (REDD) (UNFCCC 2007), to smaller-scale watershed schemes. Effective design of such programs, and conservation planning in general, requires accurate information on the supply curves for ecosystem services.

We showed how an incentive-compatible procurement auction could be used as a research tool to estimate these supply curves. The auction approach overcomes many of the weaknesses of existing valuation methodologies and is viable even in the absence of well-functioning markets. We implemented the auction in the context of reducing soil erosion in coffee-growing region in Indonesia. We then demonstrated how the resulting supply curve could be used to estimate the cost of a scaled-up payment program, to ascertain the gains from integrating biophysical and economic data to target contracts, and to explore the trade-offs between poverty alleviation and ecosystem service supply. Evaluating the potential distributional impacts of different targeting rules ex ante provides the opportunity to plan explicitly around both ecological and socioeconomic impacts.

Our implementation of the approach contains several limitations. First, our data presented were collected on a nonrepresentative sample of landowners from the watershed population, whereas modeling exercises rely on the assumption of a representative sample. Future studies would benefit from a sampling scheme that allows for more generalizable findings. Second, the elicited cost information pertained to land-management outcomes that were correlated with the provision of ecosystem services rather than the outcomes themselves. These cost estimates are ex ante and may not directly equate with contract compliance; we intend to investigate contract compliance and implications of noncompliance for cost valuation. Third, biophysical measures used in the modeling exercises came primarily from rough survey measures. More sophisticated ecological modeling may offer different perspectives on the gains from integrating ecological and economic information to target contracts. For example, hydrological models of the watershed may suggest targeting that explicitly accounts for the spatial coordination of contracts, either for contiguity or key locations in the watershed.

The value of the auction methodology extends beyond local scaling-up considerations. The extensions most likely to improve conservation planning and program design require further data collection. First, completing similar auctions at multiple sites and for multiple services around the world will provide conservation scientists, practitioners, and policy makers with a better picture of the necessary budget to pay for ecosystem services on a global scale. Second, our experimental auction design can help conservation scientists test hypotheses about reducing opportunity costs of conservation. For example, a field auction could be used to test whether educating suppliers about private benefits of ecosystem services can lower perceived opportunity costs, as many conservation education programs implicitly assume. Thus, we believe continued experimentation with procurement auctions as a revealed preference mechanism for conservation-contract program design is warranted and will improve the success of ecosystem conservation efforts.

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