Testing the Design Variables of ECOSEL: A Market Mechanism for Forest Ecosystem Services

Abstract: ECOSEL is a voluntary market framework for private provision of forest ecosystem services. Multi-objective optimization is used in conjunction with a unique funding mechanism to generate and market forest management alternatives that are projected to lead to efficient bundles of ecosystem services on a piece of forestland. ECOSEL allows the public to bid on the competing alternatives. Whichever option attracts the highest combined value of bids over the associated costs is implemented by the landowner. We conduct a series of experiments to test and inform the design of the mechanism in an attempt to maximize social surplus and seller revenues. We find that allowing the participants to communicate with each other during bidding increases the likelihood of an outcome that maximizes social surplus. We also find that a lower number of alternatives presented for bidding increases seller profit. Lastly, threshold cost disclosure, whether to disclose the amount of money to the bidders that would have to be raised for a particular alternative, has a mixed impact depending on the perceived value of the services. We identify a range of public good values where cost disclosure is always the best policy with respect to both social surplus and seller profit.

Keywords: Experimental economics, mechanism design, multi-objective optimization, ecosystem service market, subscription game

Introduction

The objective of this paper is to use experimental economics to inform the design of ECOSEL, a voluntary market framework (Tóth et al. 2010) for forest ecosystem services. We show that some of the design variables of the mechanism can be streamlined to maximize social surplus or forest landowner revenues, or both. In conducting the economic experiments to test the design of the market mechanism, we guided by the real-world context of ECOSEL. In other words, we try to preserve as much realism about the design parameters of ECOSEL as possible without compromising the experimental control. As a consequence, the experimental results are clearly applicable to ECOSEL, but they can also be used more generally in the context of voluntary provision of public goods. This study is the first experimental analysis of a voluntary funding mechanism for public goods where multiple, competing bundles of goods are offered and the bidders hold different private values with respect to these bundles.

Forests provide a suite of ecosystem services to the public, and the goal of ECOSEL is to efficiently increase their provision. Clean air, water, carbon sequestration, recreational opportunities, wildlife habitat or even a place for spiritual recharge are some of the many benefits of forests. It is difficult to capture the monetary value of these benefits as they are often characterized by various degrees of *non-excludability* and *non-rivalry* (e.g., Pagiola et al. 2004, p 10). The owner of a forest that provides an expansive forest view would have difficulties in excluding someone else from enjoying the scenery even if the individual did not pay for the privilege; hence the non-excludability. Similarly, enjoying a forest's scenery doesn't reduce its supply. Others can still enjoy the benefits regardless of how many enjoyed these benefits before; hence the non-rivalry. A well-known consequence of these properties of public goods is their under-provision in conventional markets (Pagiola et al. 2002). The inability to monetize the value of ecosystem services from forestlands can drive premature timber extraction or the conversion of land to real estate development.

Markets provide an incentive for forest landowners to maximize return on their investments. Land conversions often compromise ecosystem functions thereby diminishing public goods. In the Pacific Coast Region of the United States alone, 15,000-20,000 ha of non-federal forestland have been lost to urban development each year over the last two decades (Alig et al. 2010, p. 59). Many landowners who do not sell their land for development, manage their forests for maximum timber revenues — the greatest return on investment aside from selling the land. Intensive timber production can also lead to decreased provision of non-timber services. Regulatory responses that seek to minimize harvest intensity might be counterproductive as they often give an incentive for private landowners to abandon forestry and convert to a *higher-and-better-use* to avoid regulations (Bradley et al. 2009). Timber regulations can also adversely affect rural, forest-dependent communities. The development of a functioning market for forest ecosystem services would be beneficial to both rural and urban communities. Rural communities could generate extra revenues while protecting the health and integrity of their resources, whereas people in urban centers who often express concern over intensive timber management would enjoy additional ecosystem services.

While publicly-funded, voluntary conservation programs such as the Environmental Quality Incentives (EQIP), the Forest Land Enhancement, the Conservation Reserve (CRP), or the U.S. Forest Service's Forest Stewardship Programs can be quite effective (Kilgore et al. 2007) in complementing regulatory frameworks, they are often underfunded. Federal and state budget uncertainties suggest that improved funding for these programs is unlikely. Certification standards such as those administered by the Forest Stewardship Council (FSC) or the Sustainable Forest Initiative (SFI) can also encourage the production of ecosystem services on forestlands that participate in these programs. However, the costs of compliance are typically borne by the landowner without guaranteed immediate payoffs. Other voluntary mechanisms that don't rely on taxpayer dollars or political support can be critical complements to these efforts. The volume of private contributions that have been raised to support conservation programs in the United States such as those of the Nature Conservancy provides evidence for the effectiveness of voluntary contributions (The Nature Conservancy 2009). ECOSEL (Tóth et al. 2010) is one such mechanism with the unique capability of identifying minimum-cost management alternatives that lead to different combinations of ecosystem services, which are then offered to the public for competitive bidding via a web-based platform (University of Washington 2011). First we give a brief formal description of ECOSEL and then put the mechanism in the context of existing literature regarding the theoretical and empirical properties of similar instruments. For a more comprehensive, technical introduction to ECOSEL, and its ability to bypass the problem of *additionality*, the reader is referred to Tóth et al. (2010). We conclude by justifying why it is critically important to test the efficiency and profit-generating capability of the proposed mechanism in laboratory settings before it can be implemented on the ground.

The ECOSEL Mechanism and Terminology:

ECOSEL is a voluntary market mechanism that attempts to match willing sellers (e.g., forest landowners) with willing buyers of ecosystem services via a web-based platform where, for select forestlands, competing *minimum-cost* management plans are offered for public bidding. In ECOSEL, the management plan with a combined value of bids that most exceeds the corresponding threshold cost (i.e., a profit-maximizing plan) is implemented by the landowner. Should the bids fall short of the reserve price, they are returned to the participants and the game concludes without management commitments. This makes the bidding phase of ECOSEL a variant of a *subscription game* and allows us to capitalize on existing theoretical and empirical literature on subscription games in order to further study how ECOSEL should be structured. Subscription games (Admati and Perry, 1991) are voluntary mechanisms for the provision of public goods that are provided only if the total of contributions exceeds the predetermined costs. Should the contributions fall short of these costs, they are refunded to the donors. The players or participants of the ECOSEL game "subscribe" or contribute money to management plans that they want the landowner to implement. In the experiments that follow, we call the players *subjects*. Minimum cost plans are found via *multi-objective optimization* (Tóth et al. 2006, Tóth and McDill 2009) using the concept of *Pareto-efficiency*. A management alternative is Pareto-efficient if none of the environmental outputs or costs that are projected to come with the alternative can be improved (i.e., increased for environmental outputs, or decreased for costs) without compromising another output. Presenting minimum cost alternatives is important for two reasons. First, minimum cost of provision of forest ecosystem services is a necessary condition for economic efficiency in their provision and, second, from the bidding perspective, one wishes to make *reserve prices* (a.k.a., *threshold costs* or *provision points*), i.e., the costs that would have to be met for an alternative to be economically acceptable for the landowner, to be as low as possible. Lower prices are more likely to attract bidders.

In the initial phase of an ECOSEL game, a multi-objective mathematical programming model of form $p = \underset{x}{Max}\{ f_1(x), f_2(x),... f_n(x) : g(x) \le 0, x \in \{0,1\}\}$ is formulated, where x is a vector of binary decision variables that represent the management activities that can potentially take place as part of the different alternatives. Functions $f_i(x)\ \forall i \in \{1,2,...n\}$ denote the set of objectives that define the ecosystem services and commodity outputs that would result from a sequence of management decisions. Lastly, $g(x) \le 0$ is a set of inequalities that impose logical, operational and regulatory constraints on the decision variables. The regulatory constraints, such as maximum harvest opening size restrictions (Goycoolea et al. 2009), are crucial parts of an ECOSEL model as they determine what services and at what amounts are already being provided by regulation. It is also important to emphasize that the decision variables in program p are discrete and refer to the timing of 0-1 management decisions such as whether to cut a stand or not, or whether to decommission a road or not. The discrete nature of these decisions makes the monitoring of the production of ecosystem services fairly straightforward and inexpensive. While we note that ECOSEL can be used to capture more subtle changes in forest management such as thinning intensity or controlling species composition, there is plenty of evidence in the literature (Barbieri and Malueg 2008, Menezes et al. 2001) that public goods of only the *discrete type* have a reasonable chance to lead to efficient provision in subscription games. In practical terms, offering continuous public goods such as incremental changes in management in a game like ECOSEL might increase the modeling and monitoring expenses, which are parts of what is collectively called *transaction costs*, to an extent that would render the game unattractive to sellers or buyers, or both. The reader is referred to Tóth et al. (2006), Tóth and McDill (2009) or to Tóth et al. (2010) for examples on how exactly specific ecosystem services, such as carbon sequestration or wildlife habitat, can be captured in model p.

The solution to program p in the *objective space* is a finite set of Pareto-efficient bundles of ecosystem and commodity services. In the corresponding *decision space*, the solution is a set of management plans defined by the optimal values of vector x. For convenience, we refer to a specific management plan that is used in an ECOSEL game as an *alternative* or *option*. The projected combination of ecosystem services associated with an alternative is called a *bundle*. Since there is a one-on-one correspondence between alternatives and bundles, we use these terms interchangeably. Figure 1 depicts an actual set of Pareto-efficient management plans that were derived for Pack Forest, Washington as an example. Here, the ecosystem services to be sold are old-forest habitat area and carbon sequestration. The opportunity costs are defined as forgone timber revenues. Foregone timber revenue provides the appropriate measure of opportunity costs of a management plan for a forest which is managed primarily for timber revenues. For non-industrial forest landowners who have other ownership objectives (Butler 2008, Lin 2010), the opportunity costs could be defined differently; for example as the minimum compensation to forego development revenues. In general, given the voluntary nature of ECOSEL, the definition of opportunity cost will depend on the landowner who is putting their forest management up for bidding.

We note that since problem p is a discrete optimization problem, solutions can only be found using specialized algorithms due to the lack of convexity. To derive the Pareto set in Figure 1, Tóth et al. (2010) used the Alpha-Delta Algorithm introduced in Tóth et al. (2006) and in Tóth and McDill (2009). Other techniques such as some variants of the Weighted Objective Function (Geoffrion 1968) or the ε-Constraining Method (Haimes et al. 1971) could also be used. Assuming that one of the objectives in problem p is an opportunity cost function, each solution (or equivalently: a management plan) has an associated cost in ECOSEL. In the proposed bidding process these costs serve as the basis for the threshold costs. The bidding process is open to the public whose bids are aggregated by the mechanism based on the notion of non-rivalry.

To formalize the ECOSEL game, we let *I* denote the set of bundles of public goods, i.e., ecosystem services, that are available for bidding, and we let *K* denote the set of potential bidders. Subscripts *i* and *j* index set *I* and *k* indexes set *K*. Each potential bidder $k \in K$ is assumed to have a value, v_i^k associated with each bundle $i \in I$. This value is known to the individual but is not known by the other bidders. Finally, let b_i^k denote the final bid that bidder *k* places on bundle *i* and let r_i denote the threshold cost of bundle *i*. Bundle *i* wins in the ECOSEL game if the total bids associated with this bundle exceed the threshold cost, i.e., if $\sum_{k\in K} b_i^k - r \geq 0$, and if bundle *i* yields the maximum net revenue to the seller: $\sum_{k\in K} b_i^k - r_i = Max_{j\in I}\left(\sum_{k\in K} b_j^k - r_j\right)$. Then, if the subscription game is successful and bundle *i* wins, the *net social benefit* or *social surplus* associated with bundle *i* will be the sum of the resulting net benefits to the bidders and the net benefits to the seller : $SS_i = \sum_{k\in K}\left(v_i^k - b_i^k\right) + \sum_{k\in K} b_i^k - r_i$ $= \sum_{k\in K} v_i^k - r_i$. Note that social surplus only depends on the values that the players assign to the winning scenario and on the associated threshold cost but not on the value of the bids. We regard bundle *i* efficient if, of all the bundles that are available for bidding, it is bundle *i* that maximizes SS_i: $\sum_{k\in K} v_i^k - r_i = Max_{j\in I}\left(\sum_{k\in K} v_j^k - r_j\right)$. An outcome of ECOSEL is *efficient* if the bundle that wins in the game is also the one that maximizes social surplus.

Classification of ECOSEL and Literature Review:

ECOSEL can be viewed as a competitive, multidimensional, multi-good voluntary public goods subscription game with incomplete information, a predefined set of *provision points* (threshold costs) and refundable contributions (Admati and Perry 1991). Unlike most previously considered subscription games, ECOSEL can be competitive in that the players might have very different values with respect to the management plans offered and the resulting public goods (*preference heterogeneity* or *asymmetry*). Thus, a particular outcome of the game might be preferred by some, but not necessarily by all players. For example, a winning management plan that significantly reduces timber production in a forest might be a great outcome for a conservation organization or for recreational users, and these groups may even cooperatively bid to assure the outcome. In contrast, a local sawmill whose operational viability depends on the raw materials that would come out of the forest will unlikely favor this outcome. The competitive nature of the ECOSEL game, as well as the fact that the mechanism is intended to generate revenues implies that the mechanism is also akin to *auctions*. For that reason, we refer to specific instances of the ECOSEL game as auctions. While private goods from forests such as timber are routinely sold in auctions and such auctions have been studied extensively (e.g., Athey et al., 2011, Stone and Rideout 1997), we propose an auction mechanism for forest public goods. Unlike conventional auctions, however, ECOSEL is a multi-good auction because multiple, mutually-exclusive alternatives are offered for simultaneous bidding, and multiple bidders can win if the sum of their bids most exceeds the reserve price. The alternatives are also multidimensional in that they lead to bundles of different outputs rather than single products. In the forest management context, one plan could lead to more carbon sequestration and more old-forest habitat production but to less timber revenues than another plan. Depending on their preferences, bidders weigh the tradeoffs as they bid. ECOSEL is a game of incomplete information because, at the outset, the players don't know about each other's preferences with respect to the goods offered. Lastly, ECOSEL is intended to attract the sellers of ecosystem services by promising the possibility of a profit when the sum of bids exceeds the threshold costs.

While the theoretical properties of complete-information subscription games have been studied (e.g., Bagnoli and Lipman 1989, Admati and Perry 1991, Marx and Matthews 2000), and encouraging properties regarding the possibility of voluntary provision of public goods have been established, games of incomplete information have proven to be much less tractable. Even static, two-player problems generate a profusion of equilibria and more exact characterizations require strong simplifying assumptions (Alboth et al. 2001, Barbieri and Malueg 2008, 2010, Laussel and Palfrey, 2003, Menezes et al. 2001). The general consensus in the theoretical literature suggests that, under incomplete information, subscription games are not efficient (Menezes et al. 2001, Laussel and Palfrey 2003, Barbieri and Malueg 2010) due to the increased complexity of the coordination problem. In other words, there is a positive probability that a good is not provided in cases when it is efficient. However, Menezes et al. (2001) established that subscription games, where contributions are refunded if a threshold is not met, are superior in efficiency to games where no refunds are allowed. Also, Barbieri and Malueg (2008) showed that subscription games can act as profit-maximizing selling mechanisms over all incentive-compatible selling mechanisms, which is a very important result for ECOSEL (and reinforces the auction interpretation of an ECOSEL process).

Lastly, evidence from public economics suggests that allowing the players to voluntarily disclose or conceal their identity in subscription games increases the likelihood of a successful outcome. "Warm-glow" effects (Andreoni 1990), moral motivation (Brekke et al. 2002), social norms (Levy-Garboua et al. 2009) and confidentiality (Andreoni and Petrie 2004) can all play a role and thus ECOSEL allows the players to decide how they want to manage their identity.

Experimental research on the performance of public good subscription games started with Bagnoli and McKee (1991) setting out to test Bagnoli and Lipman's (1989) theoretical findings of good efficiency properties of such games. While Bagnoli and McKee (1991) found strong evidence that the subscription games result in efficient public good provisions, their results were challenged by Mysker et al. (1996). Uncertainty regarding subject pool effects (Cadsby and Maynes 1999), incomplete information about valuations (Marks and Croson 1999), the number of subjects in the contributors' pool (Rondeau et al. 1999), and the effect of challenge and matching gifts both in the field and the laboratory (Rondeau and List 2008) make generalizations regarding the efficiency of the mechanism we aim to study difficult. The preponderance of evidence suggests that certain design features of these games are clearly conducive to more bidding. These include the presence of discrete thresholds in contributions (Isaac et al. 1989, Suleiman and Rapoport 1992, Dawes et al. 1986, Poe et al. 2002), a full refund in case the contributions don't exceed the threshold (Isaac et al. 1989, Rapoport and Eshed-Levy 1989, Cadsby and Maynes 1999, Marks and Croson 1998), and allowing for multiple rounds as opposed to a single round of contributions (Schelling 1960, Marx and Matthews 2000). Other features of the mechanism are not as clear, and demand further investigation.

Objectives and Justification:

Two very important, but conceptually different questions arise in the context of ECOSEL. First, what kinds of bundles of ecosystem services should be offered for sale? And second, in what market context should these bundles be presented and under what market rules? While actual preferences for ecosystem services are critical for answering the first, this paper focuses exclusively on the second question. We seek to find a design for the ECOSEL game which has the best potential to increase social welfare in terms of increased provision of forest ecosystem services to society. We want ECOSEL to be successful in selecting and funding management plans that are projected to yield as much net social benefits as possible. A second, not necessarily conflicting, goal is to select a design that maximizes seller profit. Using experimental economics methods, we consider the effects of bidder communication, the number of alternatives presented, and threshold cost disclosure. We chose these factors because neither economic theory nor experimental economics provide sufficient guidance for the context of a multi-unit public good subscription game of incomplete information.

The number of bundles of ecosystem services presented for bidding might affect the performance of the mechanism. Fewer alternatives might limit flexibility so that players are unsatisfied with the choices offered. A large number of bundles on the other hand may prove to be too difficult for the subjects to analyze and might also result in scattered bids preventing convergence towards a potentially successful outcome (cf., Bagnoli et al. 1992).

Second, it is not clear if threshold costs should be disclosed to the bidders, or if it should be kept hidden and the players notified only if a particular threshold cost has been met. A coordinated group of bidders would have no difficulty closely bracketing the true threshold cost with repeated contribution rounds however such coordination is not guaranteed *ex ante*. We expect the *coordination problem*, a situation in which the players must make mutually consistent decisions to realize mutually beneficial outcomes, to be stronger if threshold costs are not disclosed as some bidding might be spent on threshold cost discovery rather than on tacit or explicit bidder cooperation. Previous theoretical (Nitzan and Romano 1990; Suleiman 1997) and experimental investigations indicate the efficiency properties of the mechanism may be hampered (Wit and Wilke 1998, Au 2004, Gustaffson et al. 2000) if the threshold costs are hidden. On the other hand, a recent theoretical analysis by McBride (2006) suggests that the contributions under threshold uncertainty may be higher if the value of the public good that is presented for bidding is sufficiently high. The reasoning behind this result is that an individual bidder is likely to contribute if they feel that they are a pivotal contributor. McBride (2006) shows that there exists a positive relationship between threshold uncertainty and the probability that one's contribution is pivotal when the value of the public good is sufficiently high, with the direction of the relationship reversed when the value of the public good is low. In a recent experimental test of his prediction, McBride (2010) finds some support for the hypothesis, although his results are based on a game with no refund and with a single public good project financed by all-or-nothing contributions.

Finally, we wish to explore the impact of subject communication on the auction's efficiency and on seller profit. On one hand, subject communication may help reduce free riding and the extent of the coordination problem (Baliga and Morris 2002, Farrell and Rabin 1996, Aumann and Hart 2003). Sometimes called "cheap talk" due to its nonbinding nature, subject communication has been demonstrated to positively affect the performance of a voluntary contribution mechanism both in theoretical (Agastya et al. 2007) and experimental settings (Vossler et al. 2006, Krishnamurthy 2001). On the other hand, subject communication may act to erode seller profits as bidders coordinate to just exceed the threshold cost, thereby undermining one incentive for sellers to participate in the market.

It is important to point out that laboratory tests are just one of the many procedures needed before a mechanism like ECOSEL can be implemented. A legal framework is currently under development to ensure that both the bidders and the sellers would enter into a binding contract. A third-party organization, e.g., a land trust, would monitor seller actions and ensure compliance with the winning management plan in cases where the services are being provided. Insurance arrangements might also be necessary for the landowner to hedge against unforeseen natural calamities and market uncertainties. Finally, stated preference surveys and qualitative focus group analyses may inform both the design of the mechanism and identify the set of ecosystem services that are of greatest interest to potential bidders in particular locations. While some of these investigations have been completed and others are underway, these analyses are beyond the scope of this paper. The laboratory tests informing the design of the ECOSEL mechanism are the focus of this study. In this paper, we describe the experimental procedures and the empirical results used to derive the design recommendations.

Methods

Experimental procedures are described in four steps. We start with an account of the motivation behind and the generation of the five alternative forest management plans that were used to create the public goods bundles presented in the experimental auctions. Second, we define the hypotheses about the three design variables that were tested: threshold cost disclosure, bidder communication and the number of alternatives offered. Experimental design is third, followed by a description of the econometric model that was used to test the hypotheses.

Management Plans:

For our laboratory tests, we selected five 45-year management plants for the University of Washington's 1,700 ha Pack Forest (Fig. 1 and 2). The five plans, A-E, differ in their projected outcomes with respect to ecosystem services and the associated opportunity costs and represent a diverse range of contrasting but Pareto-efficient combinations of discounted net timber revenues, carbon sequestration, and old forest habitat production. The latter two services, as well as the timber revenue objective, were chosen based on stakeholder input. All three outputs were imbedded in a mathematical program as functions of binary harvesting decisions that were to be applied to each of the 186 stands of the forest over nine 5-year long planning periods. The detailed formulation of the mathematical model is given in Tóth et al (2010). The model was solved using Tóth and McDill's (2009) Alpha-Delta Algorithm yielding a frontier of Pareto-efficient management plans, of which we chose five, A-E, for the laboratory tests (Fig. 1). Bundle A is the management plan that maximizes timber revenues given current regulations, timber prices, cost estimates, growth & yield estimates and the willingness of the University of Washington to maintain old-growth set-asides beyond what is required by law (i.e., seed capital). Bundles B-E are increasingly conservation oriented; they are projected to lead to increasing amounts of old forest habitat or carbon sequestration, or both at the expense of timber revenues. If a real auction was to take place at Pack Forest and none of the 5 bundles succeeded, Bundle A would be the most likely but not a certain outcome. For example, changes in prices, market demand and other factors may in the future make other options that are not necessarily known at the time of the auction, more profitable for the landowner. The uncertainty of future conditions suggests the threshold cost of Bundle A would be greater than zero in a real auction because there is an opportunity cost associated with giving up flexibility to depart from Bundle A as needed to maximize revenues. The threshold cost of Bundle A can be viewed as a "handcuff" fee for the landowner.

Each of the five plans represents one silvicultural pathway comprising of a sequence of nine yes-or-no harvest decisions for each stand. They all meet the minimum standards of sustainability (Ettl 2010): the minimum, area-weighted average age of the forest at the end of the planning horizon exceeds the average initial age, the maximum harvest opening size never exceeds 40.47 ha in any of the nine planning periods (Washington State regulations dictate a 48.56 ha limit), and harvest volume fluctuations between adjacent periods are bounded between 90 and 120%. The five management plans were presented in the experimental auctions as abstract trade-offs (not forest management scenarios) with relative, rescaled threshold costs so that the bidding process would not be affected by the preferences of bidders for actual ecosystem services. We emphasize that this study is about mechanism design and not about people's preferences with respect to ecosystem services. By choosing a realistic set of management alternatives to build the abstract public goods, we preserve the general nature of tradeoffs between costs and the various dimensions of ecosystem services.

Hypotheses:

We explore the properties of our subscription game with varying numbers of subjects in each auction and under heterogeneous subject endowments and heterogeneous subject preferences with the preferences being private information (i.e. known only to the bidder). These "nuisance" parameters intend to mimic real ECOSEL games where player pools, player preferences and purchasing power are beyond the auctioneer's control (although we control for their impact in our econometric analysis). On the basis of existing theoretical and experimental literature, we formulate the following hypotheses regarding the impact of the three design variables on auction efficiency and seller profit.

1. <u>Number of bundles presented:</u>

   H1E: Under preference heterogeneity, we expect coordination problems to be present, and, therefore, we *hypothesize that the higher the number of bundles offered, the greater the coordination problem, and, in turn, the lower the economic efficiency of the auction.*

   H1R: For similar reasons, we expect that *higher number of bundles leads to lower seller revenues.*

2. <u>Threshold cost disclosure:</u>

H2E: We expect that the impact of threshold cost disclosure depends on the perceived value of the public good presented to the bidders. In particular, we expect threshold uncertainty to lead to lower economic efficiency when the value of public goods is low but to higher efficiency when it is high.

H2R: Uncertainty over the threshold cost of a bundle may lead to over-contributions when the bundle ends up winning the auction. McBride (2006) calls these "redundant contributions". *Conditional on a bundle winning, we expect higher seller profit in auctions with undisclosed threshold costs.*

3. <u>Subject communication:</u>

H3E: Recognizing that moral motivation, social norms, confidentiality, or "warm-glow" effects can induce success in subscription games like ECOSEL (Brekke et al. 2002, Levy-Garboua et al. 2009, Andreoni and Petrie 2004, Andreoni 1990), *we expect that auctions with subject communication would lead to higher net social benefits.*

H3R: We expect subject communication to reduce the overall surplus being lost to the seller leading to lower seller profit.

Experimental design:

To test the above hypotheses, we assigned binary treatment variables to the three design features. The number of bundles was set to be either "high", where the abstract versions of all the 5 bundles from Pack Forests were used for bidding (Bundles A-E) or "low", where only 3, Bundles B, C, and E were used (Fig. 1). We let the binary variable that represents the number of bundles to take the value of 1 if three bundles are offered and 0 otherwise. We treated the threshold cost disclosure and subject communication policies also as yes-or-no design strategies. The threshold cost disclosure variable was set to 1 when the cost was disclosed, 0 otherwise, and the communication variable was set to 1 when communication among the subjects was allowed and 0 otherwise. This implies 8 auction types to be tested in a full factorial design. We used the following orthogonal fractional factorial design with 4 auction types: T1

(No communication, 3 bundles offered, threshold costs disclosed), T2 (No communication, 5 bundles offered, threshold costs not disclosed), T3 (Communication allowed, 3 bundles, threshold costs not disclosed), and T4 (Communication allowed, 5 bundles, threshold costs disclosed). Eight replications were carried out for each of the four auction types, each with a different subject pool. Orthogonal fractional factorial design, a standard choice in natural and social science fields (e.g., Fannin et al. 1981), allows the number of auction types that need to be tested to be cut by half without compromising the experimenter's ability to estimate the effects of the three factors on social surplus and seller revenues. The four auction types (T1, T2, T3 and T4) were assigned to four physical locations (classrooms) in a Latin squares design (Table 1), where each cell represents a single experimental auction. Economic efficiency (ranging from 0 in the case of no public good provided to 1 if the efficient bundle of public goods is provided) and seller profit associated in those auctions are the outcomes of interest.

As a next step, we created groups of bidders (subjects) to participate in the experimental auctions. We assigned predefined preferences for public goods and experimental monetary endowments to the subjects to use for bidding. We explored the properties of our subscription game with varying numbers of subjects in each auction and under heterogeneous subject endowments and heterogeneous subject preferences with the preferences being private information (i.e. known only to the bidder). By allowing these parameters to vary across the experimental auctions, we mimicked real ECOSEL games where player pools, player preferences and purchasing power are beyond the operator's control. Our goal was to make the results as robust as possible with respect to these anticipated heterogeneities. Our choice of experimental design followed Friedman and Sunder (1994) and Croson (2005) to directly control for the treatment (design) variables and to randomly control for the "nuisance" variables.

To mirror the heterogeneous preferences that people might hold with respect to ecosystem services such as tons of carbon sequestered over a period time in a given forestland if alternative i is implemented (X_i), and hectares of old-forest habitat that would develop over the same period of time and given the same management alternative (Y_i), we created the following *induced payoff function* for each player k:

$$v_i^k = \begin{cases} \alpha_k X_i + \beta_k Y_i + \omega_k - b_i^k & \text{if } \sum_{k\in K} b_i^k - r_i = Max_{j\in I}\left(\sum_{k\in K} b_j^k - r_j\right) \geq 0 \\ \omega_k & \text{otherwise} \end{cases} \quad [1]$$

where, in addition to using the same notation, v_i^k, b_i^k and r_i, as in the Introduction, we let ω_k to denote subject k's endowment in Experimental Monetary Units (EMUs, where 1 EMU = US$0.25) and $\alpha_k, \beta_k \in \{0,1,2\}$ to denote subject k's induced preferences with respect to X_i and Y_i. The values of X_i and Y_i were scaled based on the actual carbon sequestration potential and old-forest habitat area of the bundles developed for Pack Forest (Fig. 2). Preference parameters α_k and β_k were drawn randomly from set {0,1,2} for each of the 4 auction types each subject participated in with the restriction that $\alpha_k + \beta_k \geq 1$. This restriction was necessary to ensure that each subject had a positive value assigned to at least one public good in each bundle of two services. Table 2 summarizes the attributes of the bundles as they were presented to the subjects: we listed the assumed consequences for "carbon sequestration" and "old-forest habitat" (the values of X_i and Y_i), along with their threshold costs as shares of group endowments. The relative costs of the bundles follow the relative opportunity costs of changing management at Pack Forest. Given our definition of social surplus associated with a given bundle, that is the sum of valuations (v_i^k's) that the players assign to the bundles minus the threshold cost (r_i), the welfare maximizing bundle was Bundle E for all auctions. Due to the pre-assigned heterogeneous preferences, however, Bundle E was not unanimously preferred in all groups of bidders mirroring a possible lack of consensus on the best forest management plan in a real ECOSEL auction.

To introduce income heterogeneity, each subject was endowed with either 10 or 20 EMUs with a 50% chance each of getting either one for each auction. This allowed our findings to stand in the presence of some income heterogeneity, a likely factor in a real auction. An additional benefit of the randomization was to ensure that subjects would not be able to calculate the actual purchasing power available in the room by multiplying the value of their endowment with the number of subjects (although they could certainly get the minimum and a maximum estimate). This prevented coordination around simple cost-sharing rules, which could be observed in the lab but would not be applicable in a real-world ecosystem bidding situation.[1] While the EMUs did not carry over between auctions, those units that remained in the hands of the subjects and were not used for bidding could be redeemed for US$ at the end of both auction series.

Induced values, monetary endowments and subject group assignments were generated prior to the experiment. For each auction, each subject was given a different endowment and a set of induced values representing his or her payoffs in EMUs assuming that the associated bundle succeeds in the auction. Each subject participated in each of the four auction types (T1-T4). This involved random assignments of each subject to a row (room) in each of the columns (runs) in Table 1. No subject was assigned to the same auction type twice and by shuffling the subjects in each run of the experimental auctions we avoided the emergence of group-specific effects.

Subjects for the experimental auctions were recruited among University of Washington undergraduates across a variety of disciplines. To enable the experimenters to induce subject preferences that are not influenced by unobservable values that people might associate with "public goods", "forests", or "ecosystem services", no mention of these terms was made on recruitment flyers or during the experimental sessions (for detailed subject instructions, see the Appendix). Again, the purpose of this investigation was to shed light on the features of the auction itself, rather than on bidder preferences. To that end, we exerted experimental control over the subjects' preferences. As a result, our subject pools did not have to be representative of the population of actual bidders that we might expect to participate in real ECOSEL auctions.

We implemented two series of experimental auctions, 32 in total, using the design in Table 1. The first series was designed to have 60 subjects and the second to have 80 subjects. In reality, 54 subjects participated in the first, and 68 subjects in the second series of auctions. Subjects in the first series

[1] The degree of income heterogeneity used in our experiments may not be fully representative of a real situation where one or two large bidders (e.g., conservation groups) could have much more purchasing power than an individual bidder.

randomly drew an envelope coded 1-60 and subjects in the second series randomly drew one of the 80 envelopes. Each envelope contained 4 smaller envelopes directing the subject to one of the 4 rooms to participate in the 4 auction types in a predetermined sequence. The small envelopes also contained the subject's endowments in EMUs as well as the induced values representing their preferences for the public good bundles. Subjects arriving on time were paid a bonus of US$5 and were given an introductory presentation, as well as a quiz that tested their understanding of the experimental procedures (see Appendix for further details). The subjects then followed their specific auction sequence with the corresponding room assignments. Each auction started with a brief introduction to the auction rules. For example, subjects in a T2 auction were instructed not to communicate with each other, that 5 bundles were available for bidding, and that threshold costs were not disclosed. The introduction was followed by the 5 bidding rounds. The subjects were informed of the total bids and whether any bundle was winning after each round and they were told that Round 5 was the final round that determined the outcome of the auction. In each auction, subjects were given their induced values as determined by $\alpha X + \beta Y$ in Eq. [1]. This information was presented to the subjects highlighting the fact that payoffs were conditional on the success of the associated bundles in the auction. The subjects were told that they could bid on multiple bundles, provided that the sum of their bids for different bundles did not exceed their endowment. EMU bids that were placed on bundles that failed to win were refunded to the subjects in full. The seller (experimenter) kept any excess of the subjects' bids over the threshold costs. While there is some experimental evidence that the presence of various forms of rebates can enhance contributions towards a public good (cf., Croson and Marks 2000, Swallow et al. 2008, Spencer et al. 2009)[2], we chose not to pursue this treatment. In order for the ecosystem auction to be attractive to forest landowners, a chance of profit must be offered. This chance would be taken away by the presence of full rebates.

Both experimental sessions lasted for about 3.5 hours, including the introductory presentation, experimental auctions, debriefing session and the earnings payout session. Breaks and refreshments were

[2] Swallow and colleagues (2008) report on a small-scale field experiment where farmers were the sellers of ecosystem services (bird habitat) and the public could aggregate their contributions to reach the threshold cost. While this is similar to our concept in that a provision point game is used, any possibility of seller profit was precluded by design by offering full rebates of bids in excess of threshold costs.

provided. Across both sessions, the average earnings comprised $29.1, for approximately $8.3/hour. We did not receive reports of subject fatigue and no attrition was observed.

Econometric analysis:

As the hypotheses state, we wish to measure the impacts of design variables on the efficiency of the proposed mechanism as well as on the profit generated. Seller profit is simply the largest positive difference between total bids and the bundle threshold cost. Profit is only obtained if the auction is successful. We use relative efficiency, defined as the ratio of the social surplus of the winning bundle to the maximum possible social surplus as a parsimonious measure of auction efficiency (and success). If no bundle wins, the relative efficiency of the auction, along with seller profit, is zero. If the efficient bundle wins, the relative efficiency is 1, and values lower than 1 are obtained if a less efficient bundle wins the auction. Given that profits can only be observed in successful auctions where relative efficiency is greater than 0, we developed a *double-hurdle model* for relative efficiency and seller profit to test the impact of the design variables on the performance of the proposed mechanism. Double-hurdle models, first introduced by Cragg in 1971, have been used extensively in microeconomics to study consumer behavior in markets where the consumption of a good can be observed only for those individuals who have selected themselves as market participants. In our case, seller profit can only be observed for successful auctions, and analyzing factors influencing seller profit separately from auction efficiency may lead to selectivity bias. Furthermore, relative efficiency and seller profit are also censored in the auctions as relative efficiency must be between 0 and 1 and seller profit cannot be negative. To deal with the selection process and variable censoring we specify the double-hurdle in terms of unobserved, or *latent* relative efficiency and *latent* seller profit, which are modeled as a function of the design variables and other relevant auction-level variables:

$$w_i^* = a_i^w \gamma + \nu_i \qquad [2a]$$

$$z_i^* = a_i^z \eta + \varepsilon_i \qquad [2b].$$

Equation [2a] is the relative efficiency and [2b] is the (latent) seller profit equation. Both w_i^*, which denotes the latent relative efficiency, and z_i^*, which denotes the latent seller profit, are linear functions of a set of regressors a_i^w for relative efficiency and a_i^z for seller profit, with coefficients γ and η, respectively. Error terms, ν_i and ε_i are assumed to be bivariate normal, independently and identically distributed over the set of bundles with zero means and a variance-covariance matrix of $\Sigma = \begin{pmatrix} \sigma_\nu^2 & \rho\sigma_\nu\sigma_\varepsilon \\ \rho\sigma_\nu\sigma_\varepsilon & \sigma_\varepsilon^2 \end{pmatrix}$, where the diagonal elements denote the variances and the off-diagonals denote the co-variances between the two error terms. Regressor vectors a_i^w and a_i^z both comprise the three binary values of our design variables plus a set of other variables that have previously been shown to affect mechanism performance in subscription games (e.g., Croson and Marks 2000). After introducing the hurdle relationship between observed and latent profits and relative efficiency, we discuss these variables in detail.

In the relative efficiency equation, the latent relative efficiency, w_i^*, is unobservable. Instead, we observe w_i, which is related to the latent variable as follows:

$$w_i = \begin{cases} w_i^* & \text{if} \quad 0 < w_i^* < 1 \\ 0 & \text{if} \quad w_i^* \le 0 \\ 1 & \text{if} \quad w_i^* \ge 1 \end{cases} \qquad [3]$$

Since the latent variable is assumed to be normally distributed, it could take on negative values and values greater than 1. Thus, it is important to focus on the observable relative efficiency, using the normality of the latent variable for convenience in estimation. Observed seller profit is non-negative. Zero profit may arise as a result of a failed auction or if the sum of the contributions is exactly equal to the threshold cost of the bundle:

$$z_i = \begin{cases} z_i^* & \text{if } w_i^* > 0 \text{ and } z_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \qquad [4]$$

In addition to the design variables of threshold cost disclosure, the number of bundles, and subject communication, several other variables were introduced in the model specification. These additional variables were (1) the actual threshold cost of the bundle that maximized social surplus, (2) the actual maximum achievable net per person benefit (payoff or utility), (3) an interaction term between the cost disclosure variable and the maximum net benefit that was achievable in the auction, and (4) the variables capturing the subject learning effects[3]. We discuss these variables one by one.

As presented in Table 2, the original experimental design called for the threshold costs of the bundles that maximized social surplus to be set to one half of the total group endowment. Some variation was introduced in these values due to a few recruited participants not showing up for the experiment (Table 3 shows the actual threshold costs of the efficient bundle). We control for that variation in our model and expect that higher relative thresholds reduce the relative efficiency of the auction. We emphasize that this variable was not included in the profit equation (in vector a_i^z in Eq. 2b), as profit is realized only after a threshold has been cleared. Of note is that this is the only difference between the compositions of vectors a_i^w and a_i^z. The two sets of regressors are identical with respect to all the other variables.

The maximum achievable net benefit, averaged over the group participants, is expected to positively impact relative efficiency. Being a measure of how much an individual stands to gain, on average, from the success of the auction, it should have a positive impact on auction performance (Croson and Marks 2000). The expected impact on seller profit is ambiguous as it is not clear how the per person maximum benefit affects landowner profit once its impact on the success of the auction has been accounted for.

Importantly, including an interaction term between the cost disclosure variable and the maximum achievable net benefit in an auction provides a basis for an empirical test of McBride's (2006) result. As discussed earlier, we expect threshold cost uncertainty (non-disclosure) to lead to lower relative efficiency when the value of the auction, as measured by the maximum achievable net benefit, is low but to higher

[3] We also tested for group size and found that the number of bidders was not significant in either equation. This is an artifact of the way provision point was presented (as a fraction of the total group endowment), so a larger group with larger wealth would see a relatively more expensive public good. We were looking for the pure effect of group size. Similar to the existing literature (Isaac and Walker, 1988), we do not find such an effect. Based on our results discussed below, in the real setting, where threshold costs are fixed but group size can vary, increased group size would lead to relatively smaller threshold costs and would be beneficial for auction success.

efficiency when the value of public goods is high. Thus, we expect the coefficient on the cost disclosure variable to be positive, and we expect the coefficient on the interaction term to be negative, implying a critical value of a public good (i.e., the forest ecosystem services) which switches the impact of cost non-disclosure from negative to positive. Although McBride's (2006) model did not address the impact of the value of the public good on over-contributions (i.e., seller profit), we included the interaction term in the profit equation. We expect that a tradeoff exists between the bidders' desire to increase the share of the net benefit they get to enjoy in case the public good is provided (a case corresponding to lower seller profit) and the desire to see the high-value auction succeed. This suggests that the impacts of threshold disclosure and the interaction terms should be of opposite signs in the profit equation (in vector η in Eq. 2b).

We added two additional variables to vectors a_i^w and a_i^z in an attempt to account for subject learning effects and to see if these explain any of the variations in relative efficiency and seller profit. These extra variables were the auction run number (Table 1) and an interaction term between the communication variable and the run number. With the interaction term, we wished to capture the differential impact of subject communication as they gained more experience. It is important to note that the subjects were shuffled after each experimental auction to avoid group effects. Thus, the learning effects reflect only the impact of the subjects' familiarity and comfort with the design of the experiments.

Finally, although the subjects were carefully tutored and quizzed on their understanding of the experimental procedures before the actual auctions began (see Appendix), it is an accepted practice in experimental economics to treat the first rounds of the experiment as a practice or "burn-in" runs (e.g., Isaac and Walker 1988, McBride 2010). We followed this practice and excluded those auctions from the sample where the run number was 1 to ensure that the subjects were fully comfortable and familiar with the workings of the experiments.

The coefficients of the double-hurdle model (vectors γ and η) were estimated by a maximum likelihood procedure using the SAS ® software's Qualitative and Limited Dependent Variable Procedure (SAS Institute 2010). We discuss the estimation results and their interpretation in the next section.

Results and Discussion

We start our discussion with an overview of the overall success rate of the experimental auctions, the average relative efficiency and average profit margin. A detailed analysis of the estimated impacts of our design and nuisance variables on the mechanism's relative efficiency and seller profit margins follows. We conclude the section by discussing the implications of the results on designing a voluntary market mechanism for forest ecosystem services. We report all of the experimental data in Table 3 but shade the first run auctions with grey to signify their exclusion from the analysis.

Auction success, relative efficiency and seller profit:

The right hand side of Table 3 shows the outcomes of each experimental auction: the winning bundles, along with their threshold costs, the realized net benefits, the relative efficiencies and the seller's profit margins. Of the 24 experimental auctions (excluding the first auctions), the proposed mechanism succeeded, that is, a public good was provided in 16 trials. This corresponds to a success rate of 66.7%, which is quite high and is in line with findings from earlier research on similar provision point mechanisms (65% in Dawes et al. 1986; 33-63% in Croson and Marks 2000 and 50% in Swallow et al 2008).

As expected from theoretical analyses of subscription games of incomplete information, ECOSEL auctions were not fully efficient. Average relative efficiency, which was measured as the ratio of realized net benefits and the maximum possible net benefit, was observed to be 54.05% across the 24 experimental trials, and 81.07% in auctions ending with a public good being provided. Among the successful auctions, the theoretical welfare maximum, i.e., the maximum achievable net benefit, was obtained in 3 out of 16 trials (18.75%). With the exception of a single experimental auction, all auctions ending with the provision of a public good generated a positive profit for the seller, with an average 11.32% margin. This profit margin was 7.55% if all the experimental auctions, including the ones that were unsuccessful, are considered. This represents the *ex-ante*, unconditional, profit expectation for the potential seller of ecosystem services. This result is encouraging in the sense that ECOSEL needs to be able to offer a chance for significant profit to maximize forest landowner buy-in, thereby putting the mechanism in a distinct advantage over other voluntary instruments such as forest certification.

The impact of design and nuisance variables:

Table 4 presents the results of the estimation of the design and nuisance variable coefficients of the double-hurdle model [2-4]. Of the three design variables, communication and the threshold cost disclosure variables have a significant (<10% level of significance) impact on relative efficiency of the auction (Table 4). In terms of seller profit, the number of bundles and threshold cost disclosure variable had a significant impact. The former affected the profit positively, whereas the latter negatively. The auction run number was significant in the relative efficiency equation, and the interaction term between the run number and the communication variable failed to produce a significant effect on either efficiency or profit. This suggests that subject learning has a positive impact on the success of the auction, but that effect is not related to better communication among subjects. Next, we discuss whether our hypotheses can be corroborated or rejected based on the results of the econometric model.

Hypotheses H1E and H1R dealt with the impact of the number of bundles presented to the subjects. While no significant impact is observed in terms of relative efficiency, presenting three as opposed to five bundles was found to increase seller profit by 3.5 EMUs (12 percentage point increase in the profit margin), all other things being equal, and where the computation of the marginal impacts takes into account nonlinearities due to dependent variable censoring[4]. This impact, which is positive and statistically significant at the 5% level of significance, can be attributed to a smaller extent of the coordination problem.

Our hypotheses with respect to threshold cost disclosure (H2E, and H2R) are tested by observing the coefficients on the cost disclosure variable and the interaction term between cost disclosure and the maximum achievable net benefit from an auction. Our hypothesis H2E is corroborated: we observe a

[4] The details of the calculation of the marginal effects on a censored variable (relative efficiency) can be found in Greene (2003), p. 765. The estimated marginal effects in the profit equation needs to take into account two things: 1) censoring in the latent variable and 2) the selection process posited by the model. The marginal effects accounting for selection are computed using formulas presented in Greene (2003), pp. 782-783, and modified for censoring from below. The computations are carried out for each observation in the sample and averaged over the sample to arrive at the marginal effects presented.

positive and significant impact of cost disclosure dummy on relative efficiency, while McBride's (2006) result finds empirical support, as the coefficient on the interaction term is negative and significant. In our sample, the marginal impact of cost disclosure is a ~ 4.35% addition to relative efficiency. As discussed below, the model implies a critical value of the public good when non-disclosure becomes beneficial to relative efficiency. In designing a real auction, this implies that we ought to take into account the value of the ecosystem services being offered. If we expect the bundle to be valued highly by the potential bidders, then not disclosing the costs may be warranted on efficiency grounds.

Hypothesis H2R is corroborated as well: all things being equal, disclosing the threshold costs leads to lower seller profit. However, this effect is mitigated by the value of the auction to the bidders, and a high enough maximum net benefit from an auction could lead to a positive impact on seller profit from cost disclosure. On net, in our sample, the marginal impact of disclosure is 2.6 EMU (10 percentage point) reduction in seller profit.

The effect of non-binding communication is also consistent with our hypotheses (H3E and H3R): communication is estimated to have a persistent (non-diminishing with auction runs, as evidenced by the lack of significance of the communication/auction run interaction) positive impact on relative efficiency. We expected that the possibility of communication between subjects may reduce free-riding and reduce the coordination problem, as subjects were free to announce their preferred bundle of public goods or their intended bids (although the subjects were prohibited from disclosing their values or endowments or harassing other subjects in any fashion). Allowing subject communication has a large marginal impact of increasing relative efficiency of the experimental auction: 83%. The induced heterogeneity in subject valuations of the public goods bundles does not appear to undermine the effectiveness of communication. We do not disentangle the effect of communication on reducing free-riding from its impact on reducing the coordination problem, as our fractional factorial experimental design does not allow for separate estimation of the communication/number of bundles interaction. From the perspective of using the experimental results as a testbed for a forest ecosystem market, it is ultimately the net impact of communication that is of interest.

The effect of communication on seller profit is negative (as expected), but not significant. Our results are consistent with earlier studies (Krishnamurthy 2001), and provide empirical support to the positive postulated impact of communication on the efficiency of contribution games posited by Agastya et al. (2007).

As expected, the higher relative threshold of the efficient bundle, the lower the relative efficiency of the experimental auction. The maximum net benefit from the efficient bundle, averaged over the group participants, is found to positively impact the relative efficiency of the auction, and to have no significant impact on seller profit.

Finally, we note that the correlation in unobservables, ρ was not found to be significant under the two-sided test of the null hypothesis. That said, our expectation is that this correlation may be positive if the unobservable characteristics leading to a more efficient auction are positively related to unobservable characteristics influencing profit (e.g., some "bidding spirit" not captured by the model). We find some empirical support for this expectation: the one-sided hypothesis test of ρ being non-negative has a p-value of 0.099, allowing us to claim that ρ is non-negative at 10% level of significance[5]. This suggests that ignoring the selection process in unobservables would lead to biased estimates, and joint modeling of relative efficiency and seller profit is appropriate.

Design implications:

Given that our practical interest lies in using the experimental results for the design and administration of a real auction for forest ecosystem services, we analyze the predicted impact of the design variables in terms of both relative efficiency and seller profit. We explore whether some auction designs could be deemed to be superior or inferior along these two dimensions. In particular, we are looking for designs which would be Pareto-efficient (non-dominated) in efficiency-profit space. Conceptually, there can be several designs which would trade off the expected efficiency of the mechanism with the seller profit, conditional on the auction successfully providing a public good. Also, many designs could be discarded if they were shown to be inferior (dominated) by others. We do find a

[5] We thank the anonymous reviewer for this observation.

potential for such tradeoffs and for eliminating some auction designs in our experimental results. Of the three design variables, communication was found to be positively influencing relative efficiency without a significant impact on seller profit, and a low number of bundles was found to positively affect profit without a significant impact on relative efficiency. This immediately leads to auction designs involving communication and low number of bundles dominating other design options. Communication can be supported within the ECOSEL website by an internal messaging system where the bidders can contact each other with or without disclosing their identity. Links to social media can encourage players to build and nurture their causes towards forest services and establish larger coalitions for bidding. The result that a low number of bundles increase seller profit, highlights the importance of careful pre-auction planning for the forest landowner. The select management plans/bundles must be maximally representative of the dominant views of the known stakeholders. For auctions that involve large and valuable forest assets, this might mean that stated preference surveys might have to be done by the landowner prior to the auction.

Unlike communication and the number of bundles, the effect of cost disclosure on both efficiency and profit depends on the value of the public good available in an auction. Our experimental results allow us to identify a range of public good values where not disclosing the threshold costs is the preferred design from both the efficiency and profit standpoints. To see how this range can be derived, let $\Delta w^* = \sum_{i\in\{a_w\setminus\{d,m\}\}} \gamma_i a_{iw} + \gamma_d + M\gamma_m + \nu - \sum_{i\in\{a_w\setminus\{d,m\}\}} \gamma_i a_{iw} - \nu = \gamma_d + M\gamma_m$ be the difference between the latent relative efficiency of an auction which includes the threshold cost disclosure policy and an auction which does not. M denotes the maximum per bidder value of the public good that can be attained from the auction, while a_{iw} is the i^{th} element of vector a_w, and γ_i is the i^{th} coefficient. Coefficient γ_d denotes the effect of the cost disclosure variable on relative efficiency, while γ_m denotes the impact of the interaction term between the cost disclosure and the maximum achievable net benefit variables. Similarly, let $\Delta z^* = \sum_{i\in\{a_z\setminus\{d,m\}\}} \eta_i a_{iz} + \eta_d + M\eta_m + \varepsilon - \sum_{i\in\{a_z\setminus\{d,m\}\}} \eta_i a_{iz} - \varepsilon = \eta_d + M\eta_m$ be the difference in latent seller profit between an auction that uses cost disclosure and one which does not.

Here, a_{iz} is the i^{th} element of vector a_z, and η_i is the i^{th} coefficient. Coefficient η_d denotes the effect of the cost disclosure variable on seller profit, while η_m denotes the impact of the interaction term.

Clearly, if $\Delta w^* > 0$ and $\Delta z^* > 0$, then disclosing the cost produces an auction which dominates non-disclosure at the net benefit level of M, and if $\Delta w^* \leq 0$ and $\Delta z^* \leq 0$ then non-disclosure dominates threshold cost disclosure along both criteria of efficiency and profit at M. Otherwise, a tradeoff between efficiency and profit exists and the auction designer has to make a decision according to their preferences.

Given the results from both theory (e.g. McBride 2006) and our laboratory tests, let us assume that $\gamma_d > 0,\ \gamma_m < 0,\ \eta_d < 0,$ and $\eta_m > 0$. Then, disclosure dominates non-disclosure whenever $-\eta_d/\eta_m < M < -\gamma_d/\gamma_m$ as long as $-\eta_d/\eta_m < -\gamma_d/\gamma_m$. Otherwise, i.e., if $-\eta_d/\eta_m > -\gamma_d/\gamma_m$, then non-disclosure dominates disclosure whenever $-\gamma_d/\gamma_m \leq M \leq -\eta_d/\eta_m$. Clearly, given one set of parameters, there are only three scenarios: (1) $-\eta_d/\eta_m < -\gamma_d/\gamma_m$, or (2) $-\eta_d/\eta_m > -\gamma_d/\gamma_m$, or (3) $-\eta_d/\eta_m = -\gamma_d/\gamma_m$. At $-\eta_d/\eta_m = -\gamma_d/\gamma_m$, neither cost disclosure or nor non-disclosure makes any difference in relative efficiency or seller profit. Otherwise, depending on the magnitude of the effect of disclosure on relative efficiency relative its effect on profit, there will be a range of auctions where either the threshold cost disclosure or the non-disclosure policy, but not both, will be unambiguously preferable. Specifically, at low values of M, cost disclosure will lead to lower profit but higher relative efficiency. Then, as M increases, there is a range of values where, if $-\eta_d/\eta_m < -\gamma_d/\gamma_m$, then disclosure, and if $-\eta_d/\eta_m > -\gamma_d/\gamma_m$, then non-disclosure dominates in relative efficiency-profit space. Finally, at sufficiently high values of M, threshold cost disclosure leads to lower efficiency but higher seller profit. In our experiments, $-\gamma_d/\gamma_m \approx 173$ EMUs and $-\eta_d/\eta_m \approx 204$ EMUs. Thus, the behavior of experimental subjects suggests that when they are presented with auctions with a maximum realizable net per person benefit between 173 and 204 EMUs, not disclosing the threshold costs is the preferred design choice from both the efficiency and profit standpoints. In the experiments we analyzed, the average maximum net benefit per bidder was 12.7 EMUs, which is well below the range identified. This suggests that, at least for the experimental auctions, a threshold cost disclosure policy leads to higher relative efficiency but to lower seller profit.

In sum, our analysis suggests that design decisions have to take into account information on the likely magnitude of the net benefit forthcoming from the success of the auction. If the value of public goods presented is likely to be high, then the auction administrator faces a tradeoff between profit and efficiency. If efficiency is deemed relatively more important, threshold costs should not be disclosed to the bidders. On the other hand, if the auctions do not offer public goods of substantial value, then disclosing the threshold costs is likely to lead to better efficiency. This suggests that valuation exercises might need to precede the ecosystem services auctions to estimate the per person values potential bidders place on different bundles of ecosystem services.

Of course, caveats are in order before these results can be applied to real ecosystem services auctions. First, in our experiments, subjects are committed to participating in some kind of an auction before they see the specific design. In the real world, potential bidders may find it objectionable to even sign up for an auction where the cost of the bundle of ecosystem services is not disclosed. In a sense, this is an extensive margin consideration, versus the impact of cost disclosure on the intensive margin once the auction is underway. Second, subjects in an experimental session had a limited number of bidding rounds to discover the approximate magnitude of the threshold costs. Depending on the design of the real auction, bidders could adjust their non-committal bids before the auction ends in order to bracket the threshold cost of one or several bundles quite closely. Preventing such behavior, by limiting the number of bids a participant can submit for example, could make the auction too complex.

Finally, we considered the effects of variables related to how affordable the public good is relative to the group budget, as well as the magnitude of the potential social surplus. We found that both of these variables positively impact the likelihood of public good provision and the relative efficiency of mechanism. In the real world, this clearly relates to the cost of providing forest ecosystem services and to the public's willingness to pay for such benefits. We hope that emphasizing the cost-efficiency of the presented bundles of ecosystem services, via multi-objective optimization, can improve the communication of costs to the public and make the bundles more attractive compared to contributions where the conservation investments may not be optimally spent.

Conclusions

In this article, we studied the design of a voluntary market mechanism for forest ecosystem services, called ECOSEL. ECOSEL is a subscription game that has been shown to have promising properties with respect to many of the critical issues that arise in the context of public good markets, such as additionality or free-riding (Tóth et al. 2010). Using analytical techniques from experimental economics, we tested the effects of select design variables in ECOSEL on the ability of the mechanism to both increase the provision of ecosystem services to society and to provide the landowners who produce these services with a profit. We restricted our analysis to three design choices: (1) whether or not communication among ECOSEL market participants should be allowed, (2) whether a lower or a higher number of alternative management plans should be offered for bidding, and (3) whether the reserve prices (or threshold costs) of these plans should be disclosed to the bidders. Our results indicate that subject communication positively affects the relative efficiency of the mechanism without significant impact on seller profit. Non-binding communication may alleviate the problem of free riding by creating an implicit social norm of contribution, as well as alleviating the coordination problem due to existence of multiple bundles of public goods. A practical implication of this finding is that the bidders should be given access to a variety of communication channels including messaging boards internal to the ECOSEL website and links to social media where causes for forest and biodiversity conservation can be built and nurtured in conjunction with specific auctions.

Presenting fewer public goods to the bidders has a positive impact on seller profit, perhaps due to a smaller extent of the coordination problem, and has no significant impact on auction efficiency. This result suggests that potential sellers of forest ecosystem services must be careful as they select alternative plans for an ECOSEL auction. They need to manage the tradeoff between the risk of losing bidders with too few options and the reward of converging bids by selecting a small set of solutions that are broadly representative of the potentials of the resource.

The impact of disclosing the threshold costs was found to be consistent with theoretical results (McBride 2006) and has important implications for the design of real-world voluntary forest ecosystem markets. In particular, our results imply that a critical value of the public good exists where the non-disclosure of threshold costs becomes beneficial to the mechanism's relative efficiency. This suggests that, in designing a real world application of a subscription game like ECOSEL, we ought to take into account the value of the bundle of ecosystem services that are being offered. If we expect the bundle to be valued highly by the potential bidders, then not disclosing the costs may be warranted on efficiency grounds. However, high-value auctions perform better in generating seller profit when threshold costs are disclosed. We also found that there was a range of net expected auction benefits, where threshold cost disclosure may dominate other auction designs in terms of both the efficiency and the profit criteria.

The three design variables that we tested in this study are not the only ones that should be considered. Other variables such as allowing for the presence of seed capital (List and Lucking-Reilly 2002), large leading bidders (Levy et al., 2011), auction duration and sequencing, the amount of information regarding other players' bids disclosed to the bidders, and the features of the auction interface are also likely to be relevant for the design of a voluntary market. We leave the study of these options for future work.

As a final note, we argue that by bringing some ideas from the theory of voluntary public good provision to the forefront of forest science, we encourage the community to take a serious look at voluntary mechanisms for funding forest ecosystem services. We believe that voluntary markets such as ECOSEL have the potential to play an important complementary role in promoting non-timber forest goods. This article shows how the design of such mechanisms can be studied in a rigorous manner. More generally, this work also contributes to the understanding of a class of public goods subscription games that is more general in structure than what have previously been studied in the literature.

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Figure Captions

Figure 1. Pareto-optimal forest management plans for Pack Forest, Washington. Each point on the 3-dimensional surface represents a management plan, or equivalently, an ecosystem services bundle. Only five of the bundles are labeled: A-E.

Figure 2. Real forest management plans serving as a basis for the bundles presented in the experimental auctions.

Table Titles

Table 1. Latin square-based experimental design. Vector *r* represents the scaled threshold costs that are associated with each of the three or five alternatives that are available in each experimental auction.

Table 2. Bundle attributes (X_i and Y_i) and threshold costs, as percentages of total group endowments, for each experimental auction type. Values of X_i ("tons of carbon sequestration") and Y_i ("hectares of old-forest habitat") are scaled based on the actual carbon sequestration potential and old-forest habitat area of the bundles developed for Pack Forest, and threshold costs (reserve prices) were based on foregone revenue and scaled to the total endowments that were assigned to each group.

Table 3. Experimental auction attributes and outcomes. The total endowments, the max total benefits and the max net benefits were adjusted to the number of subjects who participated in the tests. Relative efficiency was calculated as a ratio (%) of realized net benefit and the maximum attainable net benefit. In binary design vector (*c*, *b*, *d*), *c=1* if communication is allowed, 0 otherwise, *b=1* if 3 bundles are used, 0 otherwise and *d=1* if threshold cost is disclosed, 0 otherwise).

Table 4. Econometric estimates of impacts on auction relative efficiency and seller profit.

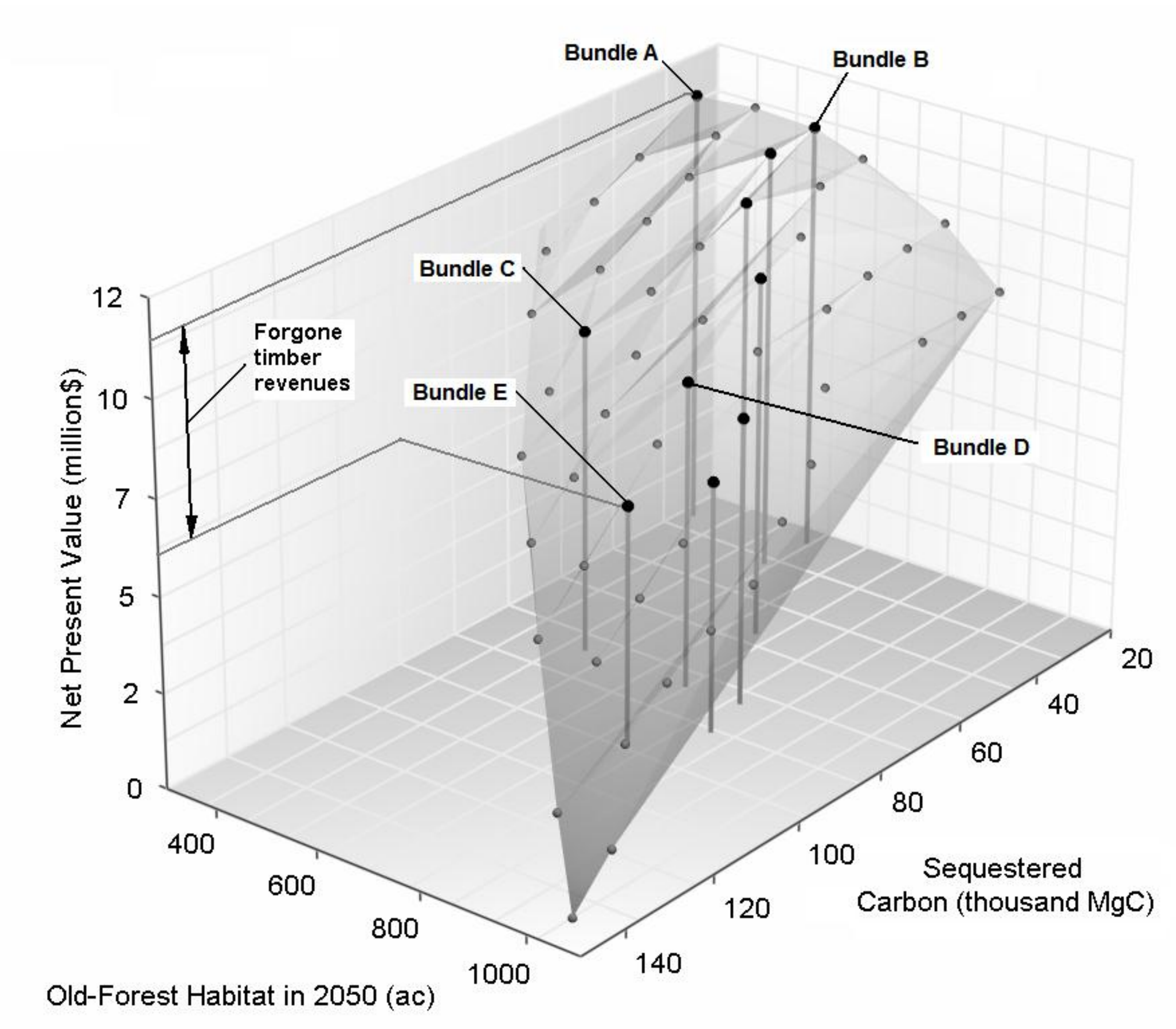
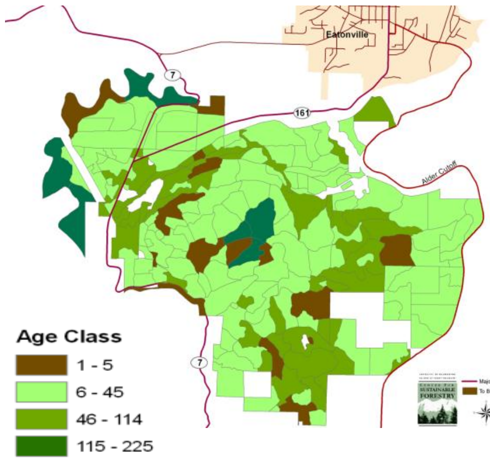
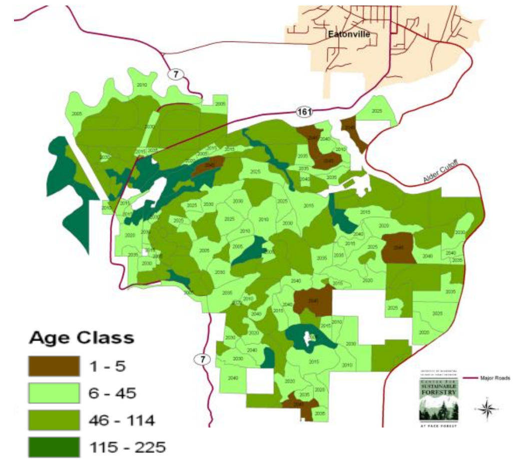

Bundle A
Bundle B
Bundle C
Bundle D
Bundle E
Forgone
timber
revenues
Net Present Value (million$)
12
10
7
5
2
0
400
600
800
1000
Old-Forest Habitat in 2050 (ac)
20
40
60
80
100
120
140
Sequestered
Carbon (thousand MgC)

Figure 1

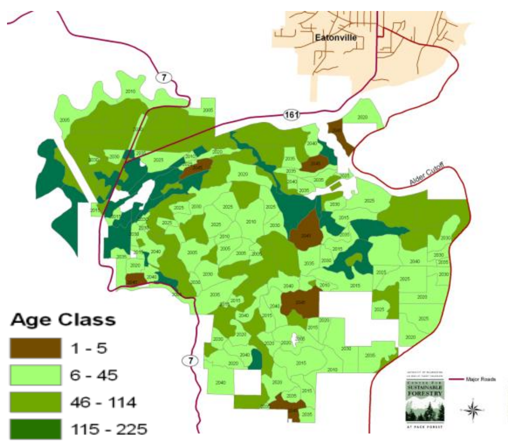
Baseline forest condition (2005)



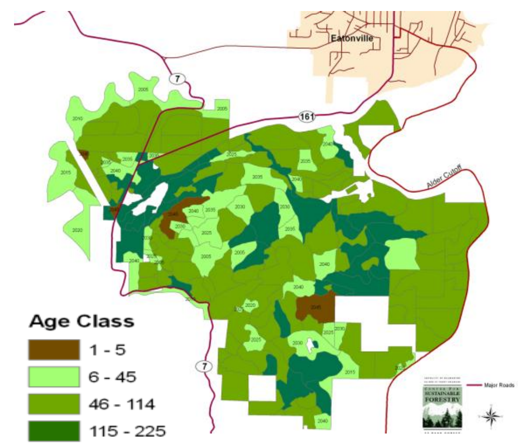
Basis for Bundle A (2050): Maximum net timber revenue, 28,338 t of carbon, 324 ac of old-forest habitat



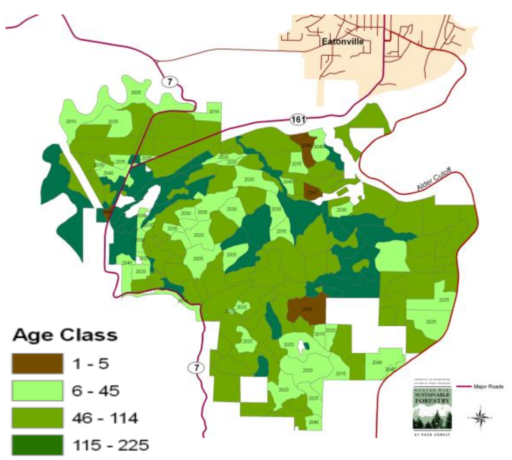
Basis for Bundle B (2050): 99% of maximum net timber revenue, 25,087 t of carbon, 534 ac of old-forest habitat



Basis for Bundle C (2050): 68% of maximum net timber revenue, 76,790 t of carbon, 498 ac of old-forest habitat



Basis for Bundle D (2050): 64% of maximum net timber revenue, 76,743 t of carbon, 699 ac of old-forest habitat



Basis for Bundle E (2050): 47% of maximum net timber revenue, 96,830 t of carbon, 747 ac of old-forest habitat

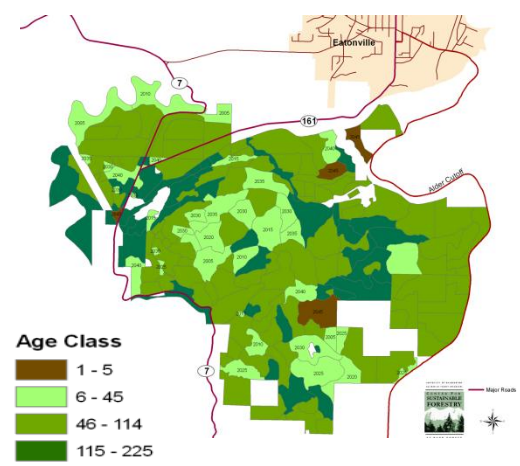


Figure 2

Table 1.

Rooms	Runs			
	1	2	3	4
R1	T1 *r* =(37,122,135)	T2 *r* =(22,24,79,86,120)	T3 *r* =(23,76,115)	T4 *r* =(15,17,56,61,85)
R2	T2 *r* =(23,26,86,94,130)	T3 *r* =(22,73,110)	T4 *r* =(21,23,76,83,115)	T1 *r* =(17,56,85)
R3	T3 *r* =(18,59,90)	T4 *r* =(27,30,99,108,150)	T1 *r* =(20,66,100)	T2 *r* =(24,27,89,97,135)
R4	T4 *r* =(14,15,50,54,75)	T1 *r* =(13,43,65)	T2 *r* =(16,18,59,65,90)	T3 *r* =(28,92,140)

Table 2.

Auction types	Bundle attributes	Bundles (i)				
		A	B	C	D	E
T1, T3	X_i	-	2.50	7.70	-	9.70
	Y_i	-	5.30	5.00	-	7.50
	Threshold costs (% group endowment)	-	10.00	33.33	-	50.00
T2, T4	X_i	2.80	2.50	7.70	7.70	9.70
	Y_i	3.20	5.30	5.00	7.00	7.50
	Threshold costs (% group endowment)	9.00	10.00	33.33	36.00	50.00

Note: Bundles B, C, and E were presented to subjects in auctions of type T1, T3 under labels "a", "B", and "C"

Table 3.

	Type(cbd)* /run#	Total endow-ments (EMU)	Max total benefit (EMU)	Threshold cost of welfare maximizing bundle (EMU)	(% of total endowment)	Max net benefit (EMU)	No. of players	Winning bundle ID	cost (EMU)	Realized net benefit (EMU)	Relative efficiency (%)	Profit (EMU)	(% margin)
1	T1(011)/1	320	476	185	57.81	291	20	-	-	-	0.00	-	-
2	T1(011)/2	110	187	65	59.09	122	7	B	13	76	62.30	2	15.38
3	T1(011)/3	100	208	100	100.00	108	9	-	-	-	0.00	-	-
4	T1(011)/4	160	195	85	53.13	110	9	B	17	77	70.00	2	11.76
5	T1(011)/1	310	459	185	59.68	274	21	B	37	168	61.31	6	16.22
6	T1(011)/2	100	168	65	65.00	103	8	B	13	71	68.93	1	7.69
7	T1(011)/3	200	282	100	50.00	182	15	-	-	-	0.00	-	-
8	T1(011)/4	160	195	85	53.13	110	10	B	17	77	70.00	4	23.53
9	T2(000)/1	230	275	130	56.52	145	11	-	-	-	0.00	-	-
10	T2(000)/2	190	246	120	63.16	126	11	-	-	-	0.00	-	-
11	T2(000)/3	160	218	90	56.25	128	9	D	65	118	92.19	10	15.38
12	T2(000)/4	240	323	135	56.25	188	15	B	27	127	67.55	2	7.41
13	T2(000)/1	240	301	130	54.17	171	15	B	26	111	64.91	2	7.69
14	T2(000)/2	190	274	120	63.16	154	11	-	-	-	0.00	-	-
15	T2(000)/3	180	238	90	50.00	148	12	-	-	-	0.00	-	-
16	T2(000)/4	230	323	135	58.70	188	16	B	27	127	67.55	6	22.22
17	T3(110)/1	150	202	90	60.00	112	8	-	-	-	0.00	-	-
18	T3(110)/2	180	252	110	61.11	142	13	B	22	104	73.24	4	18.18
19	T3(110)/3	220	305	115	52.27	190	14	E	115	190	100.00	11	9.57
20	T3(110)/4	200	270	140	70.00	130	12	-	-	-	0.00	-	-
21	T3(110)/1	140	210	90	64.29	120	9	B	18	87	72.50	0	0.00
22	T3(110)/2	220	294	110	50.00	184	15	B	22	125	67.93	4	18.18
23	T3(110)/3	200	254	115	57.50	139	13	-	-	-	0.00	-	-
24	T3(110)/4	260	326	140	53.85	186	17	C	92	146	78.49	12	13.04
25	T4(101)/1	110	181	75	68.18	106	7	D	54	100	94.34	13	24.07
26	T4(101)/2	230	343	150	65.22	193	15	-	-	-	0.00	-	-
27	T4(101)/3	200	354	115	57.50	239	14	E	115	239	100.00	2	1.74
28	T4(101)/4	150	224	85	56.67	139	10	E	85	139	100.00	4	4.71
29	T4(101)/1	150	232	75	50.00	157	9	E	75	157	100.00	6	8.00
30	T4(101)/2	290	404	150	51.72	254	20	D	108	235	92.52	9	8.33
31	T4(101)/3	180	300	115	63.89	185	14	D	83	174	94.05	2	2.41
32	T4(101)/4	160	217	85	53.13	132	11	D	61	122	92.42	1	1.64

*: "(cbd)" stands for the binary design vector (communication, 3 bundles, threshold cost disclosure)

Table 4.

		Relative efficiency equation [2a]		Seller profit equation [2b]	
		Estimate	P-value	Estimate	P-value
Design variables	Communication allowed:	1.485	0.062	-5.8954	0.295
	Low number of bundles presented:	-0.2404	0.323	4.4158	0.027
	Threshold costs disclosed:	1.3351	0.061	-13.337	0.011
Nuisance variables	Threshold cost of the bundle that maximizes social surplus (% of group endowment):	-4.2499	0.007	---	---
	Max achievable net benefit per person:	0.1537	0.01	0.0365	0.874
	Threshold cost disclosure *x* Max achievable net benefit per person:	-0.0077	0.08	0.0653	0.043
	Auction run no.:	0.2406	0.068	1.2031	0.124
	Auction run no. *x* Communication allowed:	-0.2685	0.243	1.7812	0.268
Statistics	Standard deviations (σ_v / σ_ε):	0.4241	< 0.0001	2.7377	< 0.0001
	Correlation coef. (ρ):	Estimate = 0.4379; P-value = 0.198			
	Log. Likelihood:	-51.915			
	Sample size (N):	24		16	

Appendix: Experimental Protocol

Instructions

Thank you for agreeing to take part in this experiment conducted by University of Washington researchers. This project provides an opportunity to earn a considerable amount of money, but only if you are careful to follow directions, make good decisions, and pay attention to the decisions that others are making. Therefore, it is important for you (and for our research!) that you take your time to understand the instructions. These instructions are your private information. Please do not communicate with the other participants unless expressly encouraged to do so. If you have any questions, please ask us.

Throughout the experiment we will use Experimental Monetary Units (EMUs) rather than U.S. dollars. At the end of the experiment your EMU earnings will be converted to U.S. dollars at an exchange rate of 1 EMU = 0.25 U.S. dollars (25 cents).

You have picked an envelope containing a randomly assigned sequence of experiments that you will participate in. A computer randomly generated that sequence, and it is important that you follow your own instructions for the duration of the experiment. We have 4 different classrooms where experiments are conducted simultaneously. Your envelope contains your individual sequence of classrooms. Please move to the classroom indicated when we ask you.

Your task

The experiment consists of you participating in a series of mock auctions. Each auction will last for 5 bidding rounds. At the beginning of each auction, you will be given a randomly assigned amount of EMUs. We will refer to that amount as your “endowment”. Your EMUs do not carry over between auctions: that is, you cannot use the EMUs you used in one room in another room. You are assigned EMUs in each experiment and it is important to remember that each auction is a new research trial. However, your EMUs accumulate, and at the end of the experiment you will be paid (total EMUs accumulated/4) dollars. Therefore you should seek to maximize your EMUs in each auction.

In each auction, you and other participants in your room will be presented with a number of ‘projects’. Each project has a threshold cost associated with it. If the sum of participants’ bids exceeds the project threshold cost, the project will “win” and you will earn the amount of EMUs indicated on your instructions sheet. Your earnings represent the “value” you place on the project. Only one project can “win”. If contributions to more than one project exceed the threshold cost, for the project for which contribution exceed the cost by the largest amount, wins. Contributions in excess of the threshold cost are kept by the experimenter.

You can bid for multiple projects. Exact bidding rules will be explained to you once you are ready to begin actual bidding. If a project does not “win”, you do not have to actually pay your bid. However, if the project you bid for “wins”, you MUST surrender the EMUs you bid on that project. If no project accumulates enough bids to cover its cost, you get to keep your endowment, but you earn no additional money.

After each round of bidding, you will be informed of 1) the total bids for each project and 2) whether any project is "winning". The "winner" is determined by the outcome the 5th bidding round. If, after the last round of bidding, a project "wins", you must put the EMUs you bid on the winning project in the envelope and hand it to us.

Example and Control Questions

In order for you to better understand the auction, let's go through a simple example. The values below are NOT the values you will see in actual auctions, and are for illustrative purposes only. Let's walk through the bidding rounds of a sample auction:

Projects, costs, and earnings

Project	Threshold Cost (EMU)	Your earnings if project wins (EMU)
A	100	5
B	200	12
C	300	15

Suppose your endowment is 10 EMUs. Now, the bidding starts, and we orient you to the auction:

Round 1

Project	Threshold Cost, (EMU)	Your earnings if project wins (EMU)	Your bid, (EMU)	Total group bid (EMU)	Project winning?
A	100	5	2	150	Yes
B	200	12	3	210	No
C	300	15	5	250	No

Both projects A and B have sufficient bids to cover their threshold costs, but total bids for A exceeds the cost by 50 EMUs, while total bids for B exceed the cost by only 10 EMUs, so, after Round 1, A is "winning".

Round 2

Project	Threshold Cost (EMU)	Your earnings if project wins, (EMU)	Your bid, (EMU)	Total group bid (EMU)	Project winning?
A	100	5	0	130	No
B	200	12	5	240	Yes
C	300	15	5	250	No

Both project A and B have sufficient bids to cover their threshold costs, but total bids for B exceed the cost by 40 EMUs, while the total bids for A exceed the cost by only 30 EMUs, so, after Round 2, B is "winning".

Round 3

Project	Threshold Cost (EMU)	Your earnings if project wins (EMU)	Your bid, (EMU)	Total group bid (EMU)	Project winning?
A	100	5	0	110	No
B	200	12	3	220	Yes
C	300	15	6	280	No

Round 4

Project	Threshold Cost (EMU)	Your earnings if project wins, (EMU)	Your bid, (EMU)	Total group bid (EMU)	Project winning?
A	100	5	0	110	No
B	200	12	0	215	No
C	300	15	8	320	Yes

Round 5 (Final round)

Project	Threshold Cost (EMU)	Your earnings if project wins (EMU)	Your bid, (EMU)	Total group bid (EMU)	Project winning?
A	100	5	0	102	No
B	200	12	2	210	Yes
C	300	15	3	298	No

The auction ends, with project B "winning". Since you bid 2 EMUs on project B, you have to give us 2 EMUs. Your bid on project C does not have to be paid, since project C did not win. In addition, you win 12 EMUs.

Your total earnings are:

10 EMUs given to you – 2 EMUs you have to pay + 12 EMUs you earn = 20 EMUs ($5)

Self Test—Let's see how well you understand the procedure.

1. If we give you 20 EMUs for the first auction, and 15 EMUs for the second auction, how many EMUs do you have to bid with in auction 2? ______________
2. If the sample auction above ended after Round 3,
   a. Which projects would "win"? _____
   b. How much would you be required to pay? ___
   c. What would be your earnings from the auction? ____
3. If, at the end of the entire experiment, you have accumulated 45 EMUs from Auction 1, 20 EMUs from Auction 2, 40 EMUs from Auction 3, and 55 EMUs from Auction 4,
   a. How many EMUs have you accumulated at the end? _______
   b. How many dollars would you be paid for your participation? _______

Instructions for the different auction types were presented to subjects using a Powerpoint presentation. For auctions in the first four rooms (top four rows of the experimental design table), the bidding rules were described as follows:

- We will begin bidding shortly
- The total of your bids cannot exceed your total EMU endowment
- For example, if projects A,B,C are presented, and you were given 10 EMUs
  - Bid of 5 on A, 2 on B is ok
  - Bid of 8 on C is ok
  - Bid of 5 on B and 8 on C is NOT OK

Auction T1: No Communication, 3 Projects, Costs Disclosed

Script: You will now participate in an auction, where we will ask you for the bids you wish to place on projects A, B, or C. Please open the envelope for this auction [insert run number]. You are given an endowment of EMUs for this auction. You have 5 bid sheets, one for each round of bidding. On the bid sheets, we tell you how much each project needs to accumulate in contributions in order to have a potential to "win". On the bid sheets, we tell you how many EMUs you will earn if a particular project "wins". Your endowment and earnings is private information! DO NOT SHARE IT WITH ANY ONE! Please do not communicate in any way with other participants in the room! If you have a question, please raise your hand and we will come to your assistance. After each round of bidding, we will tell you the total bids for each project. After the last round of bidding, if you bid any amount on the winning project, please place those EMUs in an envelope and return them to us.

Auction T2: No Communication, 5 Projects, No Costs Disclosed

Script: You will now participate in an auction, where we will ask you for the bids you wish to place on projects A,B,C,D, or E. Please open the envelope for this auction [insert run number]. You are given an endowment of EMUs for this auction. You have 5 bid sheets, one for each round of bidding. On the bid sheets, we tell you how many EMUs you will earn if a particular project “wins”. Your endowment and earnings is private information! DO NOT SHARE IT WITH ANY ONE! Please do not communicate in any way with other participants in the room! If you have a question, please raise your hand and we will come to your assistance. After each round, we will simply tell you whether the total bids for the project are higher or lower than the threshold cost. You will not know the threshold cost exactly. After the last round of bidding, if you bid any amount on the winning project, please place those EMUs in an envelope and return them to us.

Auction T3: Communication, 3 Projects, No Costs Disclosed

Script: You will now participate in an auction, where we will ask you for the bids you wish to place on projects A,B, or C. Please open the envelope for this auction [insert run number]. You You are given an endowment of EMUs for this auction. have 5 bid sheets, one for each round of bidding. On the bid sheets, we tell you how many EMUs you will earn if a particular project “wins”. Your endowment and earnings is private information! HOWEVER, YOU MAY DISCUSS YOUR BIDDING STRATEGY WITH OTHERS. EXPERIMENTER MAY STOP ALL COMMUNICATION IF DEEMED NECESSARY. If you have a question, please still raise your hand and we will come to your assistance. After each round, we will simply tell you whether the total bids for the project are higher or lower than the threshold cost. You will not know the threshold cost exactly. After the last round of bidding, if you bid any amount on the winning project, please place those EMUs in an envelope and return them to us.

Auction T4: Communication, 5 Projects, Costs disclosed

Script: You will now participate in an auction, where we will ask you for the bids you wish to place on projects A,B,C,D, or E. Please open the envelope for this auction [insert run number]. You are given an endowment of EMUs for this auction. You have 5 bid sheets, one for each round of bidding. On the bid sheets, we tell you how much each project needs to accumulate in contributions in order to have a potential to “win”. On the bid sheets, we tell you how many EMUs you will earn if a particular project “wins”. Your endowment and earnings is private information! HOWEVER, YOU MAY DISCUSS YOUR BIDDING STRATEGY WITH OTHERS. EXPERIMENTER MAY STOP ALL COMMUNICATION IF DEEMED NECESSARY. If you have a question, please still raise your hand and we will come to your assistance. After each round of bidding, we will tell you the total bids for each project. After the last round of bidding, if you bid any amount on the winning project, please place those EMUs in an envelope and return them to us.