Allocation in environmental markets: A field experiment with tree planting contracts in Malawi*

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Abstract

Revealing private information to improve allocation and pricing in carbon offset projects can help improve the competitiveness of developing country offsets on global carbon markets. This study provides the first evidence from a developing country to directly compare alternative allocation mechanisms: a uniform-price, sealed bid procurement auction and a posted offer market. The field experiment was conducted in Malawi for the allocation of tree planting contracts. Results reveal highly divergent outcomes for the two strategically equivalent mechanisms. The auction set the clearing price for both mechanisms and enrolled the 38 percent of the auction treatment group that bid below the price. In the posted offer treatment group, 99.5 percent of participants accepted the contract at the auction clearing price. Compliance results show significantly more trees surviving per contract allocated under the auction. At the clearing price, the auction achieves a better selection of high compliance landholders, but potentially at greater cost than the posted offer market. Results confirm the presence of information asymmetries in these markets and demonstrate that project design affects both the cost effectiveness and the environmental effectiveness of carbon offset projects. Implications of the findings extend to other types of payments for environmental services projects.

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1 Introduction

In 2008, 135 billion dollars were traded on global carbon markets (Capoor & Ambrosi 2009). Between 6.5 and 7 billion dollars flowed to developing countries in the form of project based investments in carbon offset projects (Hamilton et al. 2009). As carbon and other types of environmental markets continue to expand, these funding sources have the potential to rival more traditional sources of overseas development assistance, which totaled 119 billion dollars in 2008 (OECD 2009). Forestry-based offsets, in particular, may divert some of these investments toward small landholders. However, the eligibility of forestry offsets, particularly those from developing countries, are a current source of contentious debate in international climate agreements and domestic policy. How these rules are decided will have a large impact on the distributional implications of climate regulation, yet little rigorous evidence at the project level currently informs the debate. In particular, project-level design decisions are likely to have affect the overall costs associated with establishing carbon offsets, on the prices that landholders accept, and on long-run carbon sequestration outcomes. Incorporating market based approaches into project design can potentially increase the cost effectiveness and the environmental effectiveness of forestry based carbon offsets, improving their viability on global carbon markets.

This study sheds light on the importance of offset project design in determining carbon offset prices, landholder participation, and carbon sequestration outcomes. The research design directly compared two alternative mechanisms for allocating tree planting contracts to smallholder farmers in Malawi. Random assignment to a uniform-price, sealed bid procurement auction or a posted offer market facilitated comparison of allocation and contract compliance results.[1] Though the two mechanisms are theoretically equivalent, results revealed a dramatic difference in their performance. The auction determined the clearing price in both mechanisms and enrolled the 38 percent of landholders with bids below that price. In the posted offer treatment group 99.5 percent of participants accepted the contract at the clearing price. Though the posted offer market generated higher supply at the auction clearing price, the auction out-performed the posted offer mechanism in terms of mean tree survival outcomes. Compliance, measured by the number of surviving trees, was 7.4 percentage points or over a third of a standard deviation higher among landholders who received the contract through the auction, though all contracts paid only for surviving trees.

[1] The uniform price was set by the first rejected offer, making it strategically equivalent to a single unit second price auction, in which truthful bidding is incentive compatible (Vickrey 1961). A fixed budget determined total demand.

The divergence in mechanism performance suggests a violation of one of the assumptions underlying the theoretical proposition of equivalence of the sealed-bid, uniform price auction and the posted offer market. Three necessary assumptions are examined in turn. The first two, independent private value and no collusion, are upheld by a combination of the main results and supplementary data. The third assumption, individual rationality, cannot be supported. The observed patterns of behavior are consistent with a systematic underweighting of private information under the posted offer market. Consequently, the same price does not clear different markets, making outcomes sensitive to the choice of mechanism. Simulation of alternative allocation rules used by a social planner shows that selection on observable landholder characteristics cannot match the selection under the auction in terms of tree survival outcomes.

In the context of carbon offsets or other environmental services, designing mechanisms to reveal private information can improve the selection of landholders into the program (Mason & Plantinga 2010, Sheriff 2009, Ferraro 2008). The benefits from improved selection will depend on the degree of information asymmetry and heterogeneities among landholders. At the same time, the empirical literature, most of which comes from the economics laboratory, finds that market outcomes are sensitive to the design of market institutions (Lusk et al. 2004, Lucking-Reiley 1999). This sensitivity is exacerbated in new markets involving inexperienced participants and unfamiliar goods and services (List & Shogren 1999) and in one-shot markets where learning opportunities are limited (Fehr & Tyran 2005). Unlike much of the rest of the carbon market, forestry-based offset projects will typically involve one-shot allocations because of high fixed costs or long-term benefits (Whitten et al. 2003). Complex mechanisms that perform well in theory or in repeated settings may not achieve efficient outcomes if participants do not understand the payoffs (Nalebuff & Bulow 1993). Both the academic and practitioner literatures recognize this tradeoff between efficiency and simplicity in the choice of market mechanism (FAO 2007, Kagel & Levin 2009).

The allocation mechanisms examine in the study highlight the tradeoffs facing a policy maker. An auction and a posted offer market both select for the lowest cost sellers, yet the posted offer market relies on a price determined ex ante while the auction reveals the clearing price. Though this property makes the auction more efficient in the face of private cost information, responding to a fixed price presents a simpler valuation task to a market participant than does identifying the dominant bidding strategy in an auction. The potential for tradeoffs between mechanism efficiency and simplicity may be exacerbated in developing countries. Higher transaction costs in developing countries limit trading opportunities and make one-shot outcomes more important (Blackman & Harrington 2000). Poorly functioning ancillary markets for inputs and outputs makes it more difficult for a policy-maker to estimate opportunity costs and set prices ex ante. Finally, market participants in developing countries may disproportionately benefit from the learning opportunities associated with repeated markets. The empirical results highlight a slightly different tradeoff between the relatively more efficient auction and the relatively simple posted price offer market. In this study, quantity in the initial allocation is traded off with quality in the implementation. Findings confirm the presence of a significant information asymmetry between landholders and the policy maker, which affects both price-setting and allocation. The results demonstrate that project design can dramatically affect the competitiveness of afforestation offsets and also their ability to deliver contracted carbon sequestration outcomes. However, more nuanced policy implications of the study are limited since the experimental results provide no information about the sensitivity of compliance outcomes to contract prices.

Individual behavior that interacts with mechanism design can dramatically affect outcomes and undermine theoretical predictions (McFadden 2009). Economists increasingly use experimental methods to "test bed" mechanism design (Plott 1994), including in environmental policy (Holt et al. 2008). Moving beyond the economics laboratory to relevant populations and real transactions may improve the external validity of these approaches by capturing the stakes, beliefs, experiences and preferences likely to affect future projects or policies. Though the findings of the simple experiment shown here fall far short of resolving the debate around the eligibility of developing country afforestation projects on global carbon markets, the methodology offers an approach for generating causal evidence at the project scale to inform both policy makers and policy developers. The potential of the methodology extends beyond carbon offset projects to the design of all types of market based environmental policies. The need for rigorous evidence on design is particularly large in developing countries, where government programs have spent over a billion dollars in recent years on incentives for land use changes that improve environmental outcomes (Ortiz & Kellenberg 2002, Uchida et al. 2005, Munoz-Pina et al. 2008).

The next section offers a simple conceptual framework for the field experiment. Section 3 describes the experiment and data collection. Results from the allocation mechanisms and the contract compliance are presented in Section 4. Section 5 uses the main results and ancillary data to test the validity of the three assumptions underlying the proposition of equivalent performance. Section 6 discusses implications for the design of future policy and simulates the allocation outcomes for contract allocation by a social planner. Section 7 concludes.

2 Conceptual framework

Afforestation or reforestation activities on private land impose costs that are borne by the landholder. To the extent that the planted trees provide positive externalities in the form of carbon sequestration or other environmental benefits, subsidies to encourage tree planting may be socially desirable. The social planner wishes to maximize

$$V(t) + (\pi(t) + p - \pi^*) - (1 + e)p$$

subject to the participation constraint $\pi(\bar{t}) + p \geq \pi^*$, where $V(t)$ is the social value of trees, π^* is the landholder's maximized profit in the absence of the contract, and $\pi(\bar{t})$ is his profit constrained by the tree planting contract. The marginal social cost of public funds is e, and is increasing in the number of contracts offered, due to transaction costs associated with each individual contract. The landholder's opportunity cost, $\alpha = \pi(\bar{t}) - \pi^*$, includes the direct costs of tree planting, such as labor investments, and foregone income from land and labor allocated to the tree planting contract.

If the social planner can observe opportunity costs α, then she can solve the optimization problem, which yields first order conditions that determine optimal tree planting $\bar{t}$ and compensation payment p.

$$(1 + e)\pi'(\bar{t}) = -V'(\bar{t})$$

$$\bar{p} = \pi^* - \pi(\bar{t})$$

Only landholders with $\alpha \leq \bar{p}$ will be enrolled in the scheme. If, on the other hand, opportunity cost is heterogeneous and unobservable, then the social planner requires a mechanism to reveal α or otherwise sort landholders according to opportunity cost. A number of alternative mechanisms are available to the social planner, which vary in complexity. Two simple approaches are investigated. The first, a sealed bid, uniform price auction, is designed to reveal α and endogenously determine p. In the mechanism studied, $\bar{t}$ is pre-determined and fixed across landholders, which simplifies the mechanism but moves away from the first best solution.[2] The second mechanism, a posted price offer, relies on both a pre-determined price $\bar{p}$ and a pre-determined quantity $\bar{t}$.

[2] A more complex mechanism could endogenously determine $\bar{t}$ and improve social welfare outcomes relative to the mechanism studied here. However, the experimental design relies on a uniform contract across landholders to isolate the impacts of mechanism design on outcomes.

Proposition. *Under assumptions of (1) private and independent values, (2) no collusion and (3) purely rational individuals, a sealed bid, uniform price (generalized Vickrey) auction will result in the same allocation as a posted offer market that uses the auction clearing price as the offer price.*

Proof. As shown in the standard results for a sealed bid second price auction with single unit demand and independent private values, rational bidders who do not collude have a dominant strategy to bid their value $\hat{\alpha}$ (Vickrey 1961, Krishna 2002).[3] The auction therefore leads to a ranking of bids by willingness to accept and all bidders with valuations below the clearing price (set by the first rejected bid), $\hat{\alpha} < P$, receive a single object in a procurement setting.

In a one-shot posted offer market, individuals have a dominant strategy to accept the price offer if it is greater than their true value, $P > \hat{\alpha}$. If indifferent individuals reject the offer, then the allocation, defined by who receives a contract, is the same as for the uniform price auction at a given price.■

Implementation occurs as follows. In the first period, the social planner announces the mechanism and contract parameters, including a set quantity of trees T and a payment scheme of a piece rate p paid per surviving tree t, with $pT = P$. The landholder then estimates his opportunity cost of implementing the contract: $\hat{\alpha} = \pi^* - \pi(\hat{T})$. The estimate of $\hat{\alpha}$ may be inaccurate, and the degree of inaccuracy may be affected by the mechanism.

In the second period, the landholder engages with the allocation mechanism. Under the auction, he submits a bid of $\hat{\alpha}$. The auction clears at P and all landholders with bids below P receive a contract. Under the posted offer, the price P is announced and the landholder accepts the contract if $\hat{\alpha} < P$. Under both mechanisms, the contract parameters remain the same across all contracted landholders.

In the third period, the landholder incurs a one-time investment cost K associated with planting the trees. He learns his true α, which may be above or below his original estimate $\hat{\alpha}$. His costs are not covered by the price if $\hat{\alpha} - \alpha < 0$.

In the fourth period, the landholder incurs recurrent investment costs k associated with maintaining the trees. If $\alpha > \hat{\alpha}$, he may underinvest in c, and keep fewer than T trees alive.

In the fifth period, trees are monitored and the landholder receives a payment pt.

Indicate the auction market and the posted offer market by the subscript $M = \{A, PO\}$. Let the allocation at price P be described by the supply, $y_M(P)$, and compliance be the aggregate tree survival outcomes, conditional on the allocation, $c|y_M(P)$. All individuals with valuations $\hat{\alpha} < P$ should receive a tree planting

[3] Risk aversion does not affect bidding incentives in a Vickrey auction Krishna (2002).

contract whether a uniform price sealed bid auction or a posted offer market is used to allocate the contracts. Therefore, both the number and type of households allocated a contract should be equivalent, as should the compliance with the contract.

$$y_A(P) = y_{PO}(P)$$
$$c|y_A(P) = c|y_{PO}(P)$$

Experimental outcomes that contradict these predictions indicate a failure of one of the assumptions to the proposition: 1) independent private values, 2) no collusion or 3) individual rationality. Specifically, higher supply implies lower $\hat{\alpha}$ estimates. Compliance is increasing in the difference between the estimated opportunity cost and the actual opportunity cost, $\partial c / \partial(\hat{\alpha} - \alpha) > 0$.

3 Experimental context and design

In cooperation with an international organization, I implemented a study designed to test the equivalence of a uniform price, sealed bid auction and a posted price offer market in Ntchisi District in Malawi. The study location is in a relatively flat and arid part of the country, heavily dependent on rainfed agriculture. Households in the District own an average of 7.25 acres and grow primarily maize, soya, tobacco and potatoes. Tree planting on private land produces both private benefits, including soil fertility and timber income, and public benefits, including carbon sequestration. The temporal delays associated with the private benefits and the externalities associated with the public benefits result in little private investment in tree planting. A number of organizations currently implement projects in Malawi that offer payments for avoided deforestation, carbon sequestration, and watershed services (Chiotha & Kayambazinthu 2009). The research was coordinated with ongoing activities implemented by The World Agroforestry Centre (ICRAF) and the Malawi government, and employed an experimental design at the allocation stage of a program to subsidize tree planting on private land.

While the small size of the intervention limits actual carbon sequestration impacts, the questions of program design are similar to those faced by potential carbon offset projects and environmental service programs at much larger scales. For example, in designing its payments for hydrological services scheme, Mexico's government considered the use of a procurement auction to elicit opportunity costs associated with forest conservation, however, officials rejected the approach as "too innovative" (Munoz-Pina et al. 2008). A posted offer price was eventually offered, based on estimates of the opportunity cost of foregone deforestation. Mexico allocated an annual budget of 18 million dollars to payments, but more households signed up for the program at the offered price than could be paid under the budget, which may indicate that the price was too high. Other programs in developing countries have similarly favored posted offer markets for their simplicity (FAO 2007), potentially at the expense of the efficiency gains that developed country programs have achieved through the use of auctions (Latacz-Lohmann & Van der Hamsvoort 1997, Latacz-Lohmann & Schilizzi 2005). As carbon markets continue to stabilize, the competitiveness of different sources of carbon sequestration will be determined by suppliers' willingness to accept.

The data presented in this paper include a baseline household survey, allocation of tree planting contracts and the first of four contract monitoring rounds, six months after the initial allocation.

3.1 Study sample and baseline survey

Data on covariates relevant to the household model presented in Section 2 were collected in a baseline survey of 472 households in June of 2008. Every household in 23 villages spread over four extension planning areas responded to an extensive household questionnaire. The implementing organization selected the villages based on their previous involvement in ICRAF activities and the capacity of the government extension staff to assist with the study. The initial selection of villages for participation in the study is therefore not random, though treatment assignment within the sample is random. The baseline survey originally included 27 villages, four of which were later dropped from the study for budgetary reasons (one from each of the four extension planning areas included in the study). The survey collected household information on labor, land and household characteristics and preferences. A simple random draw assigned eligible households to the auction or the posted offer treatment group. Households reporting less than one acre of private land in the baseline survey were deemed ineligible to receive a contract and excluded from the randomization.

Summary statistics are shown in Table1). Education levels are low in the study population, with the average survey respondent attaining only some primary school education (category = 2). Casual labor markets are active but very seasonal. Around 40 percent of households participate in labor-sharing and around two-thirds seek casual labor for income. Tree planting under the contract coincides with the planting of other crops and also the peak period of labor demand. The average household reports food shortages for over four months of the year. Landholdings are slightly below the official district average, with the average household reporting five acres of land on which they plant just over three different types of crop. Around half had some trees growing on their land at the time of the baseline survey. Access to formal credit is very low (around 4 percent), though many respondents report informal borrowing.

3.2 Contract allocation

Invitations to participate in the allocation mechanisms were delivered by government extension agents one week in advance, and participants were told the date of the event, informed about the show up fee and told they would be given a chance to make some decisions about whether their household wanted to be involved in a tree planting project. The invitation provided no specific detail about the contract or the allocation process. The invitations balanced concerns about collusion with a need for enough information to encourage participation by the relevant household decision-maker. Households were pre-assigned to one of the two treatment groups, though the project staff involved were not aware of the assignment at the time of invitation delivery.

Of the 472 invited households, 433 (91.7 percent) participated in the allocation of contracts. Participants were significantly more likely to be part of a labor sharing group, less likely to seek casual labor as a source of income, and have significantly more fields than non-participants. Compared with non-participants, participants are also less frequently female, are significantly less patient, and have more trust in outsiders. Participation was significantly higher among households assigned to the auction treatment group than the posted offer group ($p < 0.05$), a difference that is attributed to chance since invitations to the two groups were identical and invitations did not differ by treatment group.

Randomization balance is tested on the subset of individuals who participated in the allocation mechanisms. Table 1 shows that the treatments are balanced for the set of variables likely to influence the opportunity cost of the contract. These variables are used as regressors in the subsequent analyses.

[Table 1]

The only variable that differs at the $p < 0.10$ level is response to a question measuring prior contact with the implementing organization. A slightly greater number of individuals in the auction treatment report past interactions with the implementing organization. All other variables are statistically equivalent between treatment groups. A joint F-test on these variables indicates no statistical difference between the treatment groups ($F(24, 429) = 1.12$).

The treatments were implemented at the same time, to avoid information spillovers between treatment groups. During registration, which occurred in the same place for both treatment groups, the treatment assignment determined which of two locations the participants were sent to, and the color-coded participation materials that they received. The two treatments had different enumerators, but the scripts revealed exactly the same information except for the description of the mechanism through which the contracts would be allocated. In both mechanisms, the contract was fully explained to individuals before they were asked to make any decisions. Auction participants heard a thorough explanation of the auction rules and the bidding incentives and received several examples.[4] They were specifically told that the best strategy was to bid the lowest price that would make them willing to accept the contract. The enumerator explained that the budget available to purchase tree planting contracts was limited, but the size of the budget was not announced.[5]

Posted offer participants were given a take it or leave it price, but were not informed about the source of the price. Decisions in both the auction and the posted offer market were submitted via sealed bid. In both treatments, individuals used color coded slips with pre-printed identification numbers to record their decisions, which were then collected by assistants based on approximate seating location.

3.3 Monitoring and payments

The tree planting contract requires that land holders set aside half an acre of land and plant 50 seedlings provided by the implementing organization. At each of the four monitoring periods over three years, landholders are paid a fixed price for each surviving tree. The costs to the landholder associated with the contract are further examined in Section 4.3.

During the first monitoring period, a project representative visited all individuals who received a contract one week after the allocation for contract signing. In-home visits gave individuals a chance to decline the contract if reflection after the allocation stage led them to change their minds about the contract terms. Between September and February, project staff and government officials conducted three trainings for contract holders to ensure that heterogeneities in information about tree planting

[4]Examples illustrated the mechanism but used bidding scenarios unrelated to the contract and too low to anchor participant values.

[5]Note that in a procurement setting, either a quantity constraint or a budget constraint must be used to set supply. In this case, due to the real constraints faced by the implementing organization, a budget constraint was used. Therefore, the budget constraint must bind for the auction to be incentive compatible. Preliminary qualitative work determined that the budget would bind and participants were explicitly told that the budget was insufficient to cover all bids.

and care did not drive differences in compliance outcomes. All contract holders received 50 seedlings in December 2008, just before the planting season. Contract compliance was measured six months after seedlings delivery, with payments based on the number of trees surviving at the time of monitoring.

A team of representatives from the government, the implementing organization and local officials conducted the monitoring. The landholder accompanied the monitoring team to the field where the trees were planted and conducted a count of surviving trees, based on pre-determined criteria. Landholders received notice approximately one week in advance of the monitoring, so some may have taken precautions to improve the field before the visit, but the advanced notice was unlikely to affect survival rates. The landholder and the monitoring team reached consensus on the survival status of each tree before moving on to the next tree. At the end of the session, the landholder signed the monitoring ledger to verify agreement on the survival outcomes. The lead monitor also conducted an assessment of the maintenance of the field including checks for several land care practices that had been part of the trainings. These included constructing firebreaks around the edge of the field, pits to catch water around each tree, weeding and distributing mulch for soil fertility. The monitor assigned a score based on these criteria without knowing the treatment group to which the individual belonged. Payments were delivered to the individual's home one week after the conclusion of monitoring and all aspects of the monitoring results remained private.

3.4 Attrition

Overall, pure attrition rates between contract allocation and the first monitoring period are very low. Four individuals out of the 176 who received contracts did not plant the trees. Two of the cases of attrition occurred in each of the treatment groups. Exit interviews were conducted on all individuals who dropped the contract. One individual from the posted offer group did not sign the contract after receiving it through the lottery, saying that he would be traveling too much in the coming months to implement the contract. Another individual, also from the posted offer group, moved away after receiving the contract. Two other individuals, from the auction group, also dropped the contract and both cited unanticipated shocks as a reason for not continuing with the contract.[6] A fifth individual is dropped from

[6]One individual refers to illness in the family that reduced the labor supply and the other individual claims that the seedlings were stolen. The latter could have arguably been prevented with greater effort (watchfulness).

the analysis because of malicious interference by a neighbor.[7] In addition, two individuals who participated in the allocation process had died by the time of the first monitoring period, though neither had received a contract. In the analysis of contract performance, the emphasis is on the intensive margin, or choice of effort, rather than idiosyncratic factors that lead to the described attrition on the extensive margin. Intention to treat estimates are obtained as robustness checks by assigning non-participants a tree survival outcome of zero.

4 Results

The primary results from the field experiment include the number and type of individuals willing to accept the contract at the clearing price under each of the allocation mechanisms and the contract compliance for all individuals receiving a contract. Allocation outcomes are examined first, followed by data on contract compliance, which includes an investigation of spatial determinants of outcomes. Market prices for inputs and outputs under alternative land uses and under the contract calibrate the experimental results.

Table 2 summarizes allocation and compliance results. Eighty-five individuals (37.4 percent of the market) received contracts through the auction, which revealed a clearing price of Malawi Kwacha (MWK) 12,000 based on the first rejected offer and the available budget.[8] The clearing price was offered to individuals in the posted offer, 99.5 percent of whom accepted the contract. Over twice as many individuals in the posted offer treatment group as in the auction treatment group revealed a willingness to accept below the auction clearing price. The budget available to purchase tree planting contracts was approximately split between the two treatments, which forced the implementing organization to use a lottery to allocate contracts among those who accepted the price in the posted offer treatment. The lottery was conducted on the spot. Ninety-one individuals received contracts under the lottery conducted after the posted offer announcement, resulting in a random allocation of contracts in the posted offer market.

[7]The individual, from the auction treatment group, planted the trees but they were uprooted by a neighbor who claimed that the land belonged to her. The village chief ruled in favor of the contract recipient, but at that point the trees had already died. This observation represents the sole case of an involuntarily ended contract, and is dropped from the analysis. The individual received a payment in the first monitoring period equal to the average payout in his village.

[8]1 USD = 140 MWK. As a point of reference, Malawi's per capita gross national income (GNI) was USD 290 or MWK 40,600 in 2008 (World Bank 2008). The contract pays MWK 6,000 or about 15 percent of GNI in the first year and MWK 3,000 or about 7 percent of GNI in the second year.

A probit regression model of the probability of receiving a contract estimates the overall significance of selection under each of the mechanisms, conditional on the baseline survey measures reported in Table 1.

$$\Pr(contract_i = 1|\mathbf{x}_i) = \Phi(\mathbf{x}_i'\beta),$$

where Φ is the cumulative distribution function of the standard normal random variable and $\mathbf{x}$ is a vector of variables from the baseline survey. The likelihood ratio chi-square for the model is statistically significant for the auction treatment but not for the posted offer treatment, consistent with the randomness of the lottery. The final row of Table 2 shows that compliance under the auction, in terms of number of surviving trees, was higher than under the posted offer mechanism, implying that the selection effectively identified individuals most able to comply with the contract.

[Table 2]

The remainder of Section 4 performs further analysis of these summary results, which point to divergent performance by the two strategically equivalent allocation mechanisms and a failure of the theoretical proposition. Section 5 examines alternative explanations for the outcomes.

4.1 Contract allocation outcomes

A comparison of contract allocation outcomes under the two mechanisms provides the first test of the proposition of equal performance. Figure 1 shows the bidding pattern in the auction as a cumulative distribution function, with a positively skewed distribution, a mean of approximately MWK 60,000 and a median of MWK 20,000 (bid curve is scaled in logs). The clearing price is shown by the vertical line at MWK 12,000 on the graph, which crosses the bid distribution just above 0.38 on the cumulative distribution function. Only a single price point is observed in the distribution of willingness to accept for the posted offer treatment group, which coincides with the 99.5th percentile on the vertical axis. The clearing price of MWK 12,000 therefore represents an upper bound on the willingness to accept of 99.5 percent of the posted offer treatment group.

[Figure 1]

4.1.1 Determinants of allocation: Auction

One of the advantages of the auction from the policy maker's perspective is the information revealed through the bids. Bids based on estimated willingness to accept, $\hat{\alpha}$, should lead to sorting on the characteristics driving landholder opportunity cost, as measured by a series of baseline survey questions. Table 3 reports the estimates from regressing bids on household characteristics ($\mathbf{x}_i$). The first and second column report a linear OLS regression of logarithm bid on household survey variables. In column 2, village indicator variables A test for heteroskedasticity (Breusch-Pagan / Cook-Weisberg) rejects the null of constant variance, so robust standard errors are reported. Adding village indicator variables de-means the data at the village level, which accounts for a substantial share of the variation in bids.

[Table 3]

Regressing auction bids on these baseline survey measures shows that predictive ability of these characteristics is modest, in part because of the large number of binary or categorical explanatory variables. Village indicator variables (column 2) eliminate the significance of several individual regressors that vary more between villages than within villages. A high intraclass correlation in log bids at the village level ($\rho = 0.315$) falls when bids are conditioned on $\mathbf{x}_i$ ($\rho = 0.194$). The regressions in columns 1 and 2 are log-linear so coefficients on independent variables can be viewed as percent changes in the dependent variable.

In column 3, bid ranks are used as the outcome variable in a linear OLS regression, since a simple ranking of bids preserves the ordinal sorting of the auction while eliminating outliers due to bid shading or miscalculation. Replacing the outcome variable in Table 3 with bid rank yields very similar qualitative results, including the direction and significance (though obviously different coefficients) for regression coefficients and the regression model overall. Column 4 estimates the quantile regression of bid rank on household variables at the 38th centile, which is the contract cut-off. The selection variation therefore occurs around this centile.

Several explanatory variables are consistently signed and significant in at least some specifications. Household size, income from casual labor, time spent gathering firewood, female bidder, prior contact with the implementing organization, time preference (lower discount rate), and household assets are all negatively related to bids. Education level, indicating a labor constraint on higher agricultural output, production of cash crops and informal borrowing are all positively related to bids. The sign on these explanatory variables is intuitive in most cases. For example, larger households tend to have more available labor and consequently a lower opportunity cost of implementing the contract. Households that produce cash crops tend to earn more from current activities and therefore have a higher opportunity cost from reallocating land or labor away from these activities. Though the direction of selection appears consistent with an intuitive model of opportunity cost, the overall explanatory power of these regressions is modest.

4.1.2 Determinants of allocation: Posted offer

Table 2, above, shows that the overall insignificance of household level variables for predicting allocation under the posted offer is consistent with the randomness of the lottery used to determine allocation conditional on accepting the price offer. Household variables are jointly statistically indistinguishable between those who did and did not receive a contract ($F(24, 201) = 0.99$), though the lack of stratification and the small sample size results in some significant differences using a two sample t-test for equal means. Mean education level for both those who did and did not receive a contract under the posted offer market lottery is "some primary school" though those who received contracts had slightly higher average attainment ($p = 0.086$). Those who receive a contract have an average of 1.51 fields versus 1.33 fields among those who did not receive a contract ($p = 0.089$). Finally, 90 percent of those who received a contract sell cash crops compared to only 74 percent of those who did not receive a contract ($p = 0.003$). The theoretical impact of these jointly insignificant selection effects in the lottery are mixed. Higher levels of education and more cash crop sales are associated with higher willingness to accept, while a greater number of fields is associated with lower willingness to accept. These variables will be further studied in the section on contract compliance to ascertain whether they directly affect landholder compliance with the contract.

4.2 Contract implementation outcomes

Compliance outcomes under the two allocation mechanisms are predicted to be equivalent, conditional on equivalence in allocation. Given the allocation results, this prediction no longer holds. However, comparison of compliance outcomes across the mechanisms offers insights into nature of the divergent allocation. While selection on observable household characteristics as shown in Table 3 is mixed, selection only matters to the extent that it operates on opportunity cost and affects compliance outcomes. The primary outcome for measuring contract compliance is the number of healthy trees, out of 50, at the time of the first monitoring mission, supplemented by the score assigned by the monitor. The number of healthy trees is highly correlated with the monitoring score (0.77). Though the score is a subjective qualitative measure, it is potentially a better indicator of the effort that the landholder is exerting in implementing the contract, because it is not subject to shocks that may affect tree survival but are outside of the landholder's control. Nineteen individuals were in full compliance with the contract, with all 50 trees classified as healthy. Tree survival rates are left skewed for both treatment groups, with a mean of around 40 (81 percent survival), a minimum of 3 and a maximum that is truncated at 50. Figure 2 shows the CDF of healthy trees, by treatment group.

[Figure 2]

Both the mean and the distribution of survival rates are significantly higher for individuals who received the contract through the auction. A two sample t-test for equal means shows a difference in means of 3.68 trees ($p = 0.011$). Comparing distributions in a two-sample Kolmogorov-Smirnov test for equality of distribution also shows a significant difference between the treatment groups ($p = 0.024$).

4.2.1 Individual-level contract implementation

Two outcome measures associated with contract performance, the number of surviving trees and the monitoring score, are used to assess compliance in a regression framework, reported in Table 4.

[Table 4]

Panel A presents the results of a linear regression of the number of surviving trees on treatment indicators and village indicator variables (columns 2 and 3), using ordinary least squares with robust standard errors to correct for the heteroskedasticity in the data. To account for the small number of village level clusters that may affect survival outcomes, a wild bootstrap p-value of 0.06 is calculated for the treatment effect (Cameron et al. 2008). The estimates show approximately 3.7 more trees surviving for contracts allocated through the auction than contracts allocated through the posted offer market. Some of the variation in survival outcomes is correlated at the village level, which are jointly significant in predicting tree survival outcomes. De-meaning the data to address the intracluster correlation, by adding village indicator variables, lowers the magnitude of the effect to 2.6 more trees surviving in the auction treatment group.

The linear specification in Panel A does not capture the count nature of the outcome variable, nor does it reflect the implicit censoring of the outcome variable at 50 surviving trees, which is the number handed out by the program and therefore the maximum that any individual could have kept alive, regardless of effort levels.

Since approximately 11 percent of landholders kept all 50 trees alive, the data suggest that some of these participants exerted effort sufficient to keep more than 50 trees alive. A negative binomial regression accommodates the nonlinearity of count data and the overdispersion in the data better than a Poisson distribution Cameron & Trivedi (1998). A censored negative binomial regression adjusts the distribution to account for the fact that the maximum outcome is censored at 50 surviving trees.

The censored negative binomial regression is estimated by maximizing the likelihood function

$$L(\theta) = \textstyle\sum_{i=1}^{N} \{d_i \ln f(y_i|\mathbf{x}_i, \theta) + (1 - d_i) \ln(1 - \sum_{j=0}^{c-1} f(j|\mathbf{x}_i, \theta)\},$$

where d_i is equal to one if the observation is uncensored and to zero if the observation is censored, and c is equal to 50. The uncensored density function $f(y_i|\mathbf{x}_i, \theta)$ is equal to the negative binomial distribution, and the censored density equals $(1 - F(c - 1|\mathbf{x}, \theta))$ when $y = c$.

The censored negative binomial regression coefficients are shown in Panel B of Table 4 and show a significant treatment effect. The coefficients represent the difference in the logs of expected counts of the response variable for a one unit change in the predictor variable, given the other predictor variables in the model are held constant. The marginal effects for the treatment indicator show similar results to the linear regression, with 3.68 more trees surviving for individuals who received a contract through the auction.[9]

The ordered logit regressions reported in Panel C use the monitoring score as the dependent variable and a latent variable model for each of the four cutoffs associated with the monitoring score. The score regressions (Panel C) report the odds ratio for the treatment indicator and show a stronger treatment effect than the survival outcomes. The marginal effects associated with the coefficients show that the effect is non-linear and receiving the contract through the auction increases the probability of receiving the highest monitoring score by 9 percent and decreases the probability of having the lowest score by 4 percent.

To detect the effect of the attrition described in Section 3.4, I re-run the main specification (OLS) to include the four individuals who did not implement the contract. Coding the number of surviving trees and the monitoring score for these individuals as zeroes slightly lowers the coefficients on the regression of outcome on

[9]As a robustness check, the analysis is run without the censoring, and as a Poisson model. The marginal effects and the significance are robust to these alternative specifications. Inverting the outcome measure to regress the number of dead trees on explanatory variables, with censoring at zero, also produces equivalent results.

treatment, and increases the standard errors slightly. Treatment effects retain their significance levels when dropped contracts are included.

Pooling the treatment groups combines the direct effect of regressors on compliance outcomes with the effects of selection in the auction. Restricting the regression of tree survival outcomes on baseline survey variables to the posted offer group uses the random assignment under the lottery to isolate the effect of regressors on outcomes that is independent of the selection effects in the auction. Table 5 shows estimates of the direct relationship between contract compliance and household characteristics for the posted offer group. A linear model and a censored negative binomial model are reported in Table 5, with the latter accounting for the count nature and the truncation of the outcome variable as described above.

[Table 5]

Some coefficients, such as level of education and months of food shortage, both significantly predict bids in Table 3 and tree survival outcomes in Table 5. Section 4.1.2 described some selection in the posted offer market lottery outcomes for individuals with higher levels of education, more fields and cash crop production. Education and cash crops are both significantly related to lower tree survival, suggesting that the selection may have lowered compliance relative to a lottery outcome balanced on those two variables. Comparing mean education levels and cash crop sales for posted offer contract recipients with those who received a contract through the auction shows no significant difference across treatments, and indicates that the observed contract compliance differences are unlikely to be explained by these two variables.[10]

4.2.2 Village effects on contract implementation

Though treatment groups were balanced at the village level, the village in which a contract recipient lives is predictive of both selection under the auction and contract compliance, which could be due to a number of factors. First, villages may proxy for other unobservable determinants of willingness to accept or opportunity cost, such as social capital, which should affect auction selection. Second, some villages may be located in microclimates or soil conditions more suitable for tree cultivation, which will affect auction selection if individuals are aware of these factors. Third, information flows more easily within villages and contract holders within a village

[10] The variable measuring previous experience with the implementing organization is also balanced among contract holders across the two treatments. Thus, differential contract enforcement based on past interactions should not affect compliance results.

may have learned from each other about how to keep the trees healthy, which occurs after contract allocation and is therefore less likely to affect auction selection.

The random allocation under the posted offer mechanism allows for a separation of the effects of village location on contract compliance that function via selection from effects that are due to ex post learning or social influences. The coefficients in Table 6 report regressions of selection (contract allocation) and contract compliance (tree survival) on village indicator variables, separated by treatment group for ease of interpretation.

[Table 6]

Column 3 replaces the village level fixed effects with two different explanatory variables that describe how others in the village received their contracts. A count of the number of contract holders in the village who received the contract as a result of selection under the auction as well as a count of those who received the contract as a result of random allocation both enter on the righthand side of the estimation and are normalized for the village population. In the posted offer market (Panel B), village indicators do not significantly predict contract allocation (Column 1) but do predict contract compliance (Column 2), suggesting that spatial location is important for survival even if allocation is random.

As a simple correlation, the relationship between the number of individuals with contracts in the village and compliance outcomes appears positive and highly significant ($p = 0.006$). Breaking the effect apart by treatment shows that the effect is heterogeneous. Controlling for the share of village members who received a contract through the auction, an increase in the number of individuals selected for under the auction does not improve performance for the auction treatment group (Panel A, column 3), but does have a significant positive effect for the posted offer treatment (Panel B, column 3). An exogenous increase in the number of contracts in the village as a result of the lottery has positive and marginally significant effect on compliance outcomes in the auction treatment group (Panel A, Column 3), and an insignificant and negatively signed effect for the posted offer group (Panel B, Column 3). Overall, the clearest benefits from an additional contract awarded within a village accrue to someone who received the contract through the lottery, and only if the additional contract in the village was selected for under the auction. These results offer some evidence for positive spillovers in contract implementation associated with the selection under the auction.

4.3 Calibration of allocation and compliance results

Combining market prices with household survey data can help calibrate the highly divergent performance of the auction and posted offer markets, both in terms of the willingness to accept values revealed at the allocation stage and the relative compliance outcomes. Given local market imperfections in land, labor and credit markets, market prices for inputs and outputs do not accurately reflect the true costs associated with implementation of the contract. However, they do offer an estimate of magnitudes and the relative importance of different constraints. To calibrate the willingness to accept values revealed by the auction, market prices are used as a rough proxy for labor, land and other input costs, shown in Panel A of Table 7. The contract requires that landholders set aside half an acre of land for tree planting, so I base all cost estimates on inputs and outputs for half an acre for the two leading alternative land uses, local maize and soya bean, and for tree planting. Total costs for the three years of the contract are shown. Interviews with District Agriculture and Development officers provided information on labor requirements for land clearing, field preparation and planting, and weeding and harvest. All figures in this section can be compared with 2008 per capita gross national income of MWK 40,600 for Malawi (World Bank 2008).

4.3.1 Opportunity cost calibration

As shown in Panel A of Table 7, land clearing is a one-time cost associated with conversion of idle land to production, while field preparation and planting is a recurrent cost that is slightly higher for the tree planting contract than for maize or soya bean production. The contract demands slightly less labor for weeding and harvest than do alternative land uses, though these costs are variable. Total labor input costs over three years fall slightly if land is converted from maize or soya (MWK 25,800 to 31,200) to tree production (MWK 18,400). Annual input costs of MWK 800 for local maize or MWK 100 for soya production fall to zero under conversion to the tree planting contract, which requires no input expenditure on seeds or fertilizer. Foregone income from crop production represents the largest cost associated with reallocating half an acre of land to the tree planting contract, which pays up to MWK 12,000 over the course of three years.

A household that trades at market prices for labor, land and other inputs loses between MWK 114,010 and 426,550 over the three years of the contract. However, poorly functioning input markets make the contract profitable for some households that operate on one or more of these margins. For example, a cash constrained household that faces missing labor and land markets cannot exchange labor and land for other inputs such as fertilizer. Since the tree planting contract requires reallocation of land and labor but no other inputs, opportunity cost $\pi(t) - \pi^*$ costs only the value of foregone leisure time if other inputs are the only limiting factor of production in the absence of the contract.

These values cover much of the relevant range of the observed bid curve, ranging from the value of foregone leisure to MWK 426,550. With precise data on pre-contract production decisions and the input and output prices faced by each household, I could estimate shadow prices for each of the primary constraints faced by the household. While this calibration exercise would be improved by detailed input and output data at the household level, bids were not out of line with estimates based on market prices.[11]

[Table 7]

4.3.2 Contract implementation

In the absence of these data, I use observed patterns of production adjustments to examine the constraint faced by contract holders. Of the 171 households that implemented a contract, 47 reallocated productive land to the contract without bringing other new land into production or holding other idle land. Another 38 have other idle land but still reallocated productive land and did not bring other land into production, which suggests a labor constraint. Differences in household constraints have implications for the cost estimates shown in Table 7.

5 Discussion of mechanism performance

The allocation and compliance results clearly demonstrate that the two allocation mechanisms diverge in their outcomes in this context. Taken alone, the allocation results suggest that a posted offer mechanism generates a higher quantity of supply than does a uniform price auction. The estimated opportunity cost $\hat{\alpha}$ elicited through the posted offer mechanism is below that elicited through the auction. However, the compliance outcomes show that the auction successfully selects for high compliance individuals. While the opportunity cost estimates elicited by the auction were higher,

[11] Market prices may provide a lower bound on opportunity cost, if the household chooses not to participate in the market because shadow prices are higher than market prices. Missing markets may also be due to high transaction costs Key et al. (2000), or to a simple lack of input accessibility in some places, which would not necessarily imply that market prices are a lower bound.

on average, they were also more accurate. At the clearing price, the auction is the more efficient mechanism per contract.

These results are by no means the first to show differences in performance across strategically equivalent mechanisms, though the precise institutions studied here have not been subject to previous experimental comparison.[12] In a laboratory setting, Lusk, Fedlkamp and Schroeder (2004) compare four incentive compatible mechanisms and find significant differences in both first-round and later market outcomes. They also review other experimental studies that find divergence among theoretically equivalent institutions. Examples from outside of the laboratory are less common, though the Internet has become a popular setting for empirical comparisons of market institutions (e.g., Lucking-Reiley 1999). Lee and Malmendier (forthcoming) use buying behavior on the Internet site eBay to provide a comparison of mechanisms similar to those studied here. They find that bidders in second-price auctions pay considerably above posted-offer prices and attribute the results to irrational behavior, including competitive arousal. The subject pools, stakes and the context for these studies differ considerably from the setting I study and no experimental evidence exists to date on the performance of theoretically equivalent mechanisms in developing countries.

In the experimental results, the failure of the proposition of equal performance implies a violation of one of the necessary assumptions. Each of the three assumptions is examined below: 1) independent private value, 2) no collusion, and 3) individual rationality.

5.1 Assumption 1: Independent private value

The equivalence of the auction and posted offer mechanisms assumes that valuations are private and independent, which implies that the value of the contract is known to the to the individual and that the values or information held by others does not affect his own valuation.[13] Individual valuations do not fit this assumption if contracts have some common value element or other source of interdependence. If, for example, the labor inputs for the contract are the same for all households but bidders do not know the labor requirements with certainty, then heterogeneous shadow prices for

[12] Several studies have compared variations on posted offers and auctions, including the early series of experiments to compare repeated posted offer and double auction institutions by Ketcham, Smith and Williams (1984).

[13] Note that private values can be uncertain and still meet the assumption. For example, in an art auction with no resale market, a bidder may be uncertain as to how much he will enjoy having the sculpture in his house, but the values and information held by others do not affect her own uncertain private value.

inputs will lead to a mixed common and private value for the contract.[14] A pure common value is the extreme version of this, in which true willingness to accept, α, is the same for all households. In a mixed private and common value auction, more information reduces the weight that individuals place on the common value component of the valuation, and improves the efficiency of the outcomes (Milgrom & Weber 1982, Krishna 2002). Winning in these circumstances is usually taken as bad news about the true value of the object relative to the winning bid. In a single unit procurement setting, this leads to upward bid shading, though Hernando-Veciana (2004) shows that in multi-unit auctions with single unit demand, a risk of losing a contract at a favorable price can also lead to downward bid shading. Thus, the direction of bid shading from a failure of private independent values is potentially ambiguous.[15]

By announcing a price for the contract, the posted offer market provides more information than the sealed bid auction. However, this only improves allocation if the price conveys relevant information about the contract value. Empirical evidence on the benefits of price information in posted offer markets is relatively scarce. Holt and Sherman (1990) examine a market with both product price and quality chosen by the seller. They find that information asymmetries reduce efficiency and that information about the price - but not the quality - does not improve outcomes.[16] In the posted offer market, a simple signal extraction model predicts updating from α to $\alpha' = \rho P + (1-\rho)\alpha$, with $\rho = \sigma^2/(1+\sigma^2)$ so that the posterior valuation (α') converges to the price P as uncertainty increases.

My experimental results reveal nearly full acceptance of the price in the posted offer market, which implies that posted offer participants place nearly full weight on the price offer when updating prior value signals as revealed by the bids.[17] Uninformative prior value signals indicate a pure common value to the contract. However, the auction would not be expected to sort individuals according to their willingness

[14]Survey questions were administered in the baseline survey to evaluate individual perceptions of the value structure of a tree planting contract. Fewer than one-quarter of participants agreed that the effort to plant trees is the same for all families.

[15]For winner's curse to generate substantial upward bid shading, it has to dominate the loser's curse effect, which is increasing in the number of units being purchased. After the auction, a subsample of respondents indicated that, on average, they expected around 50 percent of participants to receive contracts. These expectations balance winner's curse and loser's curse bid shading.

[16]Uncertain private value will not generate the observed updating results in the posted offer mechanism. Unless values are common or otherwise affiliated, the price offer does not contain information about the contract's value to any particular individual without imposing additional assumptions about individual beliefs.

[17]Here, I assume that all other assumptions, including individual rationality, hold so that participants are assumed to bid according to their dominant strategy.

to accept in a pure common value setting, since the true α would be the same for all bidders. The significantly higher compliance outcomes in the auction treatment group are inconsistent with a pure common value to the contract, which is required for the allocation outcome to result from a failure of Assumption 1. An assumption of independent private values appears more consistent with the data than other standard assumptions about value structures.

5.2 Assumption 2: No collusion

The proposition of equal performance assumes that bidders do not collude to affect prices in the auction. In the face of collusive behavior, an auction no longer offers the benefit of correctly determining a clearing price for the population. Second price auctions are susceptible to collusion, though sealed-bids and one-shot bidding reduce collusion (Robinson 1985). Real world examples of collusion range from the Internet (Ariely et al. 2005) to large public tenders (Baldwin et al. 1997, Cramton & Schwartz 2000). In the literature on conservation auctions, efforts at collusion are observed in experiments that allow for communication among participants (Cummings et al. 2004) though greater numbers of bidders and less feedback between rounds successfully limits collusion (Cason et al. 2003).[18] Collusive behavior in a posted offer market is only likely in the face of repetition, where demand withholding in early periods can affect later prices, which is not a concern in the one-shot setting studied here.

Collusive behavior in the auction will increase bids above the dominant strategy, leading to a higher quantity of supply in the posted offer market than in the procurement auction. If bids are driven upward by collusion then auction participants receive greater rents and may exhibit better compliance. Allocation and compliance results are consistent with collusive behavior in the auction. However, a great deal of care was taken during the invitation process to minimize the risk of collusion and to ensure that it could be detected if it did occur. No information about the specific nature of the contracts or bidding was revealed in advance. The government staff who delivered the invitations to the villages did not have enough detail about the contract requirements to provide an anchor from which collusion could take place.

[18]Another form of strategic behavior in the form of bid-shading for rent extraction has been observed in conservation auctions in the United States and Australia Stoneham et al. (2003), Kirwan et al. (2005), Claassen et al. (2008). Generally, the shading observed in these settings can be attributed to the presence of a scoring rule that considers the ecological benefits of a land parcel, though it may also be due to efforts at rent extraction due to a misinterpretation of bidding incentives (e.g., Laury 2002). Shading under the described auction rules should be limited to bid shading due to common value.

Though village is an important determinant of bid, results on the relationship between village and contract compliance indicate that this selection can be attributed to unobservable characteristics that vary at the village level. Random spot checks during the registration process also suggested that people were not aware of the specifics of the activities.

Concern about collusion is not limited to communication in advance of the auction. Though individuals were encouraged not to talk during the auction process, it would have been possible for them to see each others' bids. Transmitting this information beyond the individuals seated immediately next to the bidder would have been difficult. Bids were collected in order of seating to detect this type of collusion. Analyzing the correlation of bids of those seated near each other during the auction further rules out collusion that took place at the time of allocation. The bids of nearest neighbors are marginally correlated, which is reasonable if similar individuals chose to sit near each other, though this correlation dissipates quickly with distance. Figure 3 shows autocorrelations between bids for each pairwise comparison of seated neighbors (leftmost bar is nearest neighbor).

[Figure 3]

Supplementary data upholds Assumption 2 and confirms that collusion did not cause the divergent mechanism performance.

5.3 Assumption 3: Individual rationality

The proposition of equal performance assumes fully rational behavior by market participants. Bounded rationality may affect behavior under the auction, the posted offer market, or both. The imprecision of the predictions associated with a failure of Assumption 3 make it difficult to reject as a description of the empirical results. However, support for the first two assumptions points to failure of rational behavior.

The greater complexity of the auction compared to the posted offer market raises the possibility that irrational or naïve bidding drove the divergence in the mechanisms. Substantial experimental evidence on behavior in second-price auctions indicates that naïve bidders frequently deviate from dominant bidding strategies (Kagel & Levin 1993, Kagel 1995). Bidding errors should, however, lead to inferior sorting in the auction and lower compliance among auction participants, which contradicts my empirical evidence. At the same time, superior sorting under the auction does not necessarily imply that bids revealed true willingness to accept or that the clearing price was correct. Cognitive measures collected during the follow up survey also do not suggest any relationship between cognitive ability and bidding behavior.[19]

Bounded rationality may also lead to mechanism outcomes that are sensitive to how values are elicited, a phenomenon documented in the literature on preference reversals and contingent valuation studies. Procedure invariance requires that strategically equivalent elicitation methods reveal the same preferences, and is a standard assumption in economics. However, Tversky et al. (1990) provide evidence that violations of procedure invariance explain many instances of preference reversals. Their experiment compares pricing and choice decisions for lotteries and shows greater attention to payoffs in pricing the lotteries and a greater attention to probabilities in the choice decision, a result that has been replicated by many others (Seidl 2002). The literature on non-market valuation also cites numerous violations of procedure invariance including differences between open-ended and dichotomous choice elicitation procedures (Harrison 2006). The comparison between an auction and a posted offer market has parallels with the elicitation mechanisms studied in these two literatures: the auction resembles an open ended pricing decision while the posted offer market resembles a dichotomous choice decision. The direction of valuation divergence described in both preference reversal studies and the valuation literature is consistent with higher willingness to accept under the auction than under the posted offer market. These literatures also offer numerous explanations of why these differences are observed, without clear consensus on which provides the "true" valuation.

The experimental results are consistent with an underweighting of prior value signals when the outside organization suggests a price. While rational updating cannot explain both the selection and compliance results (Section 5.1), they can be explained by a similar process in which all participants place full weight on the value signal provided by the offer price regardless of the strength of their prior signal. Such a process undermines the sorting power of the posted price offer market, leading to inferior compliance. It is also consistent with low rates of contract default before one-time investment costs are incurred, even in the posted offer treatment group.

5.4 Alternative explanations

In addition to the hypotheses explored, the proposition of equal performance also requires that individuals do not accept the contract purely for its option value, which is borne out in the result that instances of pure attrition or defection are extremely

[19] A series of reverse digit spans tests, in which the respondent was read a series of numbers and asked to recite them back in reverse order after a brief pause. The test measures both active memory and ability to abstractly manipulate numbers.

low.[20] A positive option value does not predict divergent mechanism outcomes since bids should unravel and all positive posted offer prices should be accepted. However, it is worth noting that the structure of many allocation or selection problems relies on the performance of selected agents, making ex post incentives and uncertainty important at the selection stage. Laffont and Tirole (1987) and McAfee and McMillan (1986) examine this problem, and both suggest a tradeoff between ex ante selection of the lowest cost offer and ex post performance. Like most environmental payment program, the contracts studied here do not stipulate penalties or fines for non-compliance (Choe & Fraser 1999, Chomitz et al. 1999). Had the compliance results shown substantial default at the start of the implementation period, the contract incentives would be a greater concern as a source of high acceptance rates under the posted offer market. Other potential alternative explanations that would affect willingness to accept, such as a temporary income effect due to the show up fee, do not explain divergence between the mechanisms.

6 Implications of the findings

Results from the field experiment can be used to investigate the implications for environmental policy and alternative approaches to carbon offset projects. First, outcomes are simulated for allocation of contracts by a social planner, based on criteria identified by relevant stakeholders in Malawi. Second, cost-benefit implications are reviewed, including estimates of the carbon sequestration provided by the program. Finally, the findings are discussed in light of climate policy.

6.1 Social planner alternatives

Allocation of contracts based on observable characteristics of eligible landholders offers an alternative approach to contract allocation, and is often used to identify recipients for publicly funded programs. Consultation with relevant stakeholders in Malawi suggested criteria that a social planner would use to select households into a tree planting program. Informal interviews with the implementing organization and with government officials generated consensus that priority characteristics include: land size, available labor and information about trees. It was also suggested that some individuals have a greater preference for trees than others. I simulated a social planner's selection based on five variables selected from the baseline survey to proxy

[20] This assumption is analogous to the assumption of no budget constraint, which is needed for the bidding strategies in both markets to hold Krishna (2002).

for these characteristics: total acres owned, household size, participation in the labor market, past experience with the implementing organization and past tree planting.[21]

The random assignment resulting from the lottery conducted to allocate contracts in the posted offer market provided a representative sample of contract holders. These observations allowed me to use the baseline survey data and tree survival outcomes to simulate how contract implementation varies with selection on different household characteristics. The 89 contract holders from the posted offer treatment were used to generate random samples of 205 individuals (the number of participants in the treatment). The relevant selection criteria led to a ranking of households based on their desirability and the contract implementation outcomes for the top 89 provided a measure of mean performance for the selection. Figure 4 shows the results of 10,000 repetitions of the simulated selection outcomes for each of 7 selection rules.

In the first 5 rules, the social planner selects for the households with the largest landholdings, the greatest number of family members, participation in the labor market, past interaction with the NGO and past tree planting. In the sixth rule, each of these variables is normalized to one and summed into a linear index of the characteristics. In the seventh selection rule, a linear regression of the number of surviving trees on the five household variables for the 89 randomly selected posted offer contract recipients provides weighting coefficients, which are then used to create a weighted index for selection.

[Figure 4]

As shown in Figure 4, the distribution of the simulated mean tree survival outcomes falls well below the auction selection mean for all selection rules. The three top performing selection rules are past tree planting, the linear index of household characteristics and the regression weighted index. All perform better than the random posted offer selection but worse than the auction selection. The mean of the distribution of simulated means is 40.52 for past tree planting selection, and 40.58 for the linear selection index. Auction selected individuals keep, on average, 42.51 trees alive. Though the sample sizes used to conduct the simulation are on the small side, they do constitute a random sample so the outcomes suggest that the auction selected on unobservable or difficult to measure characteristics that would not be available to a social planner.

The superior selection under the auction clearly demonstrates the existence of an information asymmetry in the market. One approach to setting prices in settings characterized by information asymmetries is to conduct an auction with a representative sub-sample of the population to set market prices Athey et al. (2002). However,

[21] The approach is similar to what is used by Jack et al. (2008) for data from Indonesia.

the posted offer responses in both the incentive compatible allocation experiment and to the hypothetical survey questions suggest that such an approach may not work in this context. If the mechanism used to elicit values has a large impact on willingness to accept, then the same price will not clear different markets. The observed excessively high acceptance rates that resulted in lower performance means that posting a price may not lead to separation of households by opportunity cost around that price.

6.2 Program evaluation

The benefits side of a cost-benefit analysis of the project is complicated by fact that biological carbon sequestration is not permanent. For example, sequestration benefits are reversed if the tree is used for firewood, so the species of tree planted under the project was selected for its use as timber, which improves its lifetime carbon profile but does not resolve concerns about long-term sequestration. Leaving aside important questions of how to value biological carbon sinks and the extent of their substitutability with emissions reductions (van Kooten 2008), a rough program evaluation considers a simplified approximation of benefits. Whether the prices elicited by the auction justify payments for tree planting, from an efficiency standpoint, can be evaluated by comparing projections of carbon sequestered under the program with the total payments to contract holders.[22] Table 8 shows the projected carbon sequestration value per tree, based on estimates of above- and below-ground biomass as the trees grow. The payments for the contract are around USD 1.70 per tree and provide an estimate of the cost per ton of carbon, if the tree survives up to the age specified in the year column. Carbon prices associated with reforestation and afforestation projects under the Clean Development mechanism were around USD 16 in 2008 and around USD 6.4 on the voluntary markets (Capoor & Ambrosi 2009), so the cost per ton of carbon sequestered enters the range of current carbon prices between the 15th and 25th year of tree growth.

[Table 8]

Cost effectiveness comparisons based on compliance outcomes between the two allocation mechanisms are irrelevant since the payments are delivered only for surviving trees. However, the payments under the contract are only a component of the overall program costs, which contain a fixed component for each allocated contract.

[22]This estimate of benefits includes neither benefits nor costs accrued by the individual landholder, nor does it include project implementation costs in the price of the contract payments.

The transaction costs associated with the delivery of each contract make the auction the more cost effective of the mechanisms, holding implementation costs and contract prices constant, though it may also be the more expensive of the two mechanisms to implement and almost certainly results in higher prices for a given level of supply.

Evaluation of the relative performance of the auction and posted offer mechanisms is limited by the lack of experimental results on the price elasticity of compliance. However, a simple example illustrates the potential value in lower contract prices. At an offer price of MWK 1,500, the budget used in the auction could purchase 656 contracts or eight times as many as were purchased through the auction. To result in the same total number of surviving trees as observed under the auction, the average contract recipient would only need to keep 5.3 trees alive, which is 12 percent of the number kept alive by the average auction participant. Since the contracts pay on a per surviving tree basis, total payments under an MWK 1,500 posted offer approach would be USD 741.28 versus USD 5925.90 under the auction, with the same number of surviving trees.

These cost effectiveness numbers ignore the welfare implications of enrollment under the posted offer mechanism. The high one-time investment costs under the tree planting contract imply that low survival rates, and therefore low levels of compensation for the landholder, may make him worse off under the contract. While remaining active in the contract is voluntary, the cost structure of the necessary investments suggest that very low contract prices may create welfare losses even if they increase cost effectiveness of carbon sequestration outcomes.

6.3 Environmental policy

Concerns about verifiability and the environmental integrity of biological carbon offsets, such as those obtained through afforestation and reforestation projects, have arisen in reviews of the Clean Development Mechanism of the Kyoto Protocol (Wara & Victor 2008) and discussions of pending United States climate legislation (e.g., Olander 2008). The difficulty in monitoring and enforcing projects that fail to deliver promised carbon reductions has led to discounting of biological carbon credits and limits on the total quantity of offsets in recent climate legislation. While auctions and other approaches to allocation have received a fair amount of attention in discussions of the initial distribution of emissions allowances, the role of allocation in offset projects has received little attention. The divergent performance of the auction and the posted offer mechanisms in terms of the contract compliance demonstrates the role of selection in addressing these concerns.

To scale the magnitude of compliance differences to a policy relevant scale, consider proposed legislation in the United States in 2009 (House bill HR2454), which allows up to one billion tons of carbon dioxide-equivalent from international offsets. If five percent of that total amount (50 million tons) were purchased through afforestation projects that used individual level contracts allocated under a posted offer market, then, extrapolating from my results on compliance after six months, total tons of carbon dioxide sequestered after 25 years would be 3.75 million tons less than if auctions were used to select landholders into the offset projects. Though this rough estimate relies on extreme assumptions of equal prices under each of the allocation mechanisms and equal long and short run compliance rates, it does suggest that the selection effects are non-negligible. On the other hand, a posted offer approach will clearly generate higher supplies at lower prices, potentially making it more attractive as an approach for maximizing offset supplies, particularly if concerns about long run compliance can be overcome through innovative contract design and lowered monitoring costs.

The particular findings on the behavioral response of inexperienced market participants in developing country settings suggest that individuals may underweight their private information about the opportunity cost of engaging in land use change when provided with a price by an international organization. Such a tendency obstructs the design of markets that select for low cost landholders. Overall, the importance of an allocation mechanism that selects for high-compliance individuals is sensitive to the intersection of supply and demand. The demonstrated information asymmetry in the market together with potential welfare implications from improved selection further justifies the use of market mechanisms at the project level.

7 Conclusion

The design of allocation mechanisms for environmental policy has received a fair amount of academic attention (e.g., Muller & Mestelman 1998, Goeree et al. 2009, Sheriff 2009), however, this is the first field experiment to examine the one-shot allocation problem in environmental markets. Results show that both initial contract allocation and subsequent compliance outcomes are sensitive to the choice of mechanism. Explanations for the observed higher supply quantity under a relatively simple posted offer mechanism and the better quality selection under a sealed bid, uniform price auction are not consistent with the theoretical prediction of equal performance under an independent private values framework. The results point to a violation of procedure invariance, similar to the observed differences in preferences over risky choices elicited in the studies on preference reversals (e.g., Seidl 2002, Tversky et al. 1990)or the divergence in valuations elicited by dichotomous choice and open ended questions in contingent valuation studies (e.g., Balistreri et al. 2001). Results in this context are consistent with market participants disregarding their own private value signal when faced with an externally determined price offered by an international organization.

The auction and the posted offer market trade off quantity and quality, which is a somewhat different tradeoff than the more frequently cited choice between efficiency and simplicity in market institutions. Policy implications from the findings depend to some extent on the policy objective, though the overarching message is that instrument choice matters. If the goal is to maximize the number of trees grown for the least amount of money, then naming a very low price in a posted offer market is likely to out-perform an auction. What is gained in cost effectiveness may be lost in efficiency. The posted offer market has little selection effect and so such an approach will not necessarily identify high compliance landholders, defined as those with the lowest opportunity cost or willingness to accept. Thus, if allocational efficiency is important, as may be the case in carbon offset markets, then an auction is preferred. The results clearly identify the presence of information asymmetries in the market that motivate future use of mechanisms to reveal private information in similar settings.

The results are inconclusive from a welfare standpoint, which depends to some extent on whether the auction clearing price actually equalized willingness to accept and contract price on the margin. The posted offer supply response suggests that the clearing price from the auction was high, while cost calibration suggest that the price was low. Given the cost structure of investments under the contract, mechanisms that generate more errors in the evaluation of opportunity cost may make participants worse off. Counterintuitively, the more complex auction treatment generated fewer errors in opportunity cost if compliance can be taken as a measure of the initial accuracy of the estimate.

Future research can test the robustness of the experimental results and help to pinpoint the cause of the violation of procedure invariance. For example, adding a third treatment that requires posted offer participants to assess and write down their willingness to accept before observing the posted price offer would test whether the divergence is due to the greater cognitive effort exerted during the auction that allows for better selection. Varying the price in the posted offer market would offer evidence on the effect of price on acceptance and compliance. Testing the generalizability of these findings beyond environmental policy settings may also lend insights into the behavioral patterns that characterize the results.

With the expansion of market mechanisms as a tool for environmental policy in developing countries, the performance of standard market formats in new settings and with new goods and services deserves further research. Better understanding of the tradeoffs faced by alternative allocation and pricing mechanisms is particularly important in contexts where imperfect input and output markets make setting prices difficult because of the prevalence of household-specific shadow prices, and also where one-shot mechanisms do not allow for learning and price adjustment. Carbon offset projects in developing countries are an important example of new market settings that are likely to be highly sensitive to the allocation mechanism used to select landholders into a project. The financial viability and the environmental integrity of international offset projects will be affected by the mechanisms used to determine the initial allocation of contracts for sequestration activities.

References

Ariely, D., Ockenfels, A. & Roth, A. E. (2005), 'An experimental analysis of ending rules in internet auctions', *Rand Journal of Economics* **36**(4), 890–907.

Athey, S., Cramton, P. & Ingraham, A. (2002), Auction-based timber pricing and complementary market reforms in british columbia, Technical report, Market Design Inc. and Criterion Auctions.

Baldwin, L. H., Marshall, R. C. & Richard, J. F. (1997), 'Bidder collusion at forest service timber sales', *Journal of Political Economy* **105**(4), 657–699.

Balistreri, E., McClelland, G., Poe, G. & Schulze, W. (2001), 'Can hypothetical questions reveal true values? a laboratory comparison of dichotomous choice and open-ended contingent values with auction values', *Environmental and Resource Economics* **18**(3), 275–292.

Bank, W. (2008), 'Key development data & statistics: Malawi'.

Blackman, A. & Harrington, W. (2000), 'The use of economic incentives in developing countries: Lessons from international experience with industrial air pollution', *Journal of Environment and Development* **9**(1).

Cameron, A. C. & Trivedi, P. K. (1998), *Regression analysis of count data*, Cambridge Univ Pr.

Cameron, A., Gelbach, J. & Miller, D. (2008), 'Bootstrap-based improvements for inference with clustered errors', *The Review of Economics and Statistics* **90**(3), 414–427.

Capoor, K. & Ambrosi, P. (2009), 'State and trends of the carbon market 2009', *Washington DC: The World Bank* .

Cason, T. N., Gangadharan, L. & Duke, C. (2003), 'A laboratory study of auctions for reducing non-point source pollution', *Journal of Environmental Economics and Management* **46**(3), 446–471.

Chiotha, S. & Kayambazinthu, D. (2009), Potential payment for ecosystem service (pes) in malawi, Technical report, Eastern and Southern Africa Katoomba Network.

Choe, C. & Fraser, I. (1999), ‘Compliance monitoring and agri-environmental policy’, *Journal of agricultural economics* **50**(3), 468–487.

Chomitz, K. W., Brenes, E. & Constantino, L. (1999), ‘Financing environmental services: The costa rican experience and its implications’, *The Science of the Total Environment* **240**, 157–169.

Claassen, R., Cattaneo, A. & Johansson, R. (2008), ‘Cost-effective design of agri-environmental payment programs: U.s. experience in theory and practice’, *Ecological Economics* **65**(4), 737–752.

Cramton, P. & Schwartz, J. A. (2000), ‘Collusive bidding: Lessons from the fcc spectrum auctions’, *Journal of Regulatory Economics* **17**(3), 229–252.

Cummings, R., Holt, C. & Laury, S. (2004), ‘Using laboratory experiments for policy making: An example from the georgia irrigation reduction auction’, *Journal of Policy Analysis and Management* **23**(2), 341–363.

FAO (2007), *State of food and agriculture: Paying farmers for environmental services*, Food and Agriculture Organization of the United Nations, Rome.

Fehr, E. & Tyran, J. R. (2005), ‘Individual irrationality and aggregate outcomes’, *Journal of Economic Perspectives* **19**(4), 43–66.

Ferraro, P. J. (2008), ‘Asymmetric information and contract design for payments for environmental services’, *Ecological Economics* **65**(4), 810–821.

Goeree, J. K., Holt, C. A., Palmer, K., Shobe, W. & Burtraw, D. (2009), ‘An experimental study of auctions versus grandfathering to assign pollution permits’, *IEW-Working Papers* .

Hamilton, K., Sjardin, M., Shapiro, A. & Marcello, T. (2009), Fortifying the foundation: State of the voluntary carbon markets 2009, Technical report, Ecosystem Marketplace.

Harrison, G. W. (2006), ‘Experimental evidence on alternative environmental valuation methods’, *Environmental and Resource Economics* **34**(1), 125–162.

Hernando-Veciana, A. (2004), ‘Successful uninformed bidding’, *Games and Economic Behavior* **48**(1), 29–53.

Holt, C. & Sherman, R. (1990), ‘Advertising and product quality in posted-offer experiments’, *Economic Inquiry* **28**(1), 39–56.

Holt, C., Shobe, W., Burtraw, D., Palmer, K. & Goeree, J. (2008), Auction design for selling co2 emission allowances under the regional greenhouse gas initiative, Technical report, Regional Greenhouse Gas Initiative.

Jack, B. K., Leimona, B. & Ferraro, P. J. (2008), 'A revealed preference approach to estimating supply curves for ecosystem services: Use of auctions to set payments for soil erosion control in indonesia', *Conservation Biology* **23**(2), 358–367.

Kagel, J. H. (1995), Auctions: A survey of experimental research, *in* J. H. Kagel & A. E. Roth, eds, 'The Handbook of Experimental Economics', Princeton University Press, Princeton, N.J., pp. 501–557.

Kagel, J. H. & Levin, D. (1993), 'Independent private value auctions: Bidder behaviour in first-, second-and third-price auctions with varying numbers of bidders', *Economic Journal* **103**, 868–868.

Kagel, J. H. & Levin, D. (2009), 'Implementing efficient multi-object auction institutions: an experimental study of the performance of boundedly rational agents', *Games and Economic Behavior* **66**(1), 221–237.

Ketcham, J., Smith, V. L. & Williams, A. W. (1984), 'A comparison of posted-offer and double-auction pricing institutions', *The Review of Economic Studies* pp. 595–614.

Key, N., Sadoulet, E. & De Janvry, A. (2000), 'Transactions costs and agricultural household supply response', *American Journal of Agricultural Economics* **82**(2), 245–259.

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

Krishna, V. (2002), *Auction Theory*, Academic Press, London.

Laffont, J. J. & Tirole, J. (1987), 'Auctioning incentive contracts', *The Journal of Political Economy* **95**(5), 921–937.

Latacz-Lohmann, U. & Schilizzi, S. (2005), Auctions for conservation contracts: A review of the theoretical and empirical literature, Technical report, Scottish Executive Environment and Rural Affairs Department.

Latacz-Lohmann, U. & Van der Hamsvoort, C. (1997), ‘Auctioning conservation contracts: A theoretical analysis and an application’, *American Journal of Agricultural Economics* **79**(2), 407–418.

Laury, S. K. (2002), ‘Enhancing and improving designs for auction mechanisms that can be used by the epd for irrigation auctions’.

Lee, Y. & Malmendier, U. (forthcoming), ‘The bidder’s curse’, *The American Economic Review* .

List, J. A. & Shogren, J. F. (1999), ‘Price information and bidding behavior in repeated second-price auctions’, *American Journal of Agricultural Economics* **81**(4), 942–949.

Lucking-Reiley, D. (1999), ‘Using field experiments to test equivalence between auction formats: Magic on the internet’, *The American Economic Review* **89**(5), 1063–1080.

Lusk, J. L., Feldkamp, T. & Schroeder, T. C. (2004), ‘Experimental auction procedure: Impact on valuation of quality differentiated goods’, *American Journal of Agricultural Economics* **86**(2), 389–405.

Mason, C. & Plantinga, A. (2010), ‘The additionality problem with offsets: Optimal contracts for carbon sequestration in forests’, *Working Paper* .

McAfee, R. P. & McMillan, J. (1986), ‘Bidding for contracts: a principal-agent analysis’, *Rand Journal of Economics* **17**(3), 326–338.

McFadden, D. (2009), ‘The human side of mechanism design: a tribute to leo hurwicz and jean-jacque laffont’, *Review of Economic Design* **13**(1), 77–100.

Milgrom, P. R. & Weber, R. J. (1982), ‘A theory of auctions and competitive bidding’, *Econometrica* **50**(5), 1089–1122.

Muller, R. A. & Mestelman, S. (1998), ‘What have we learned from emissions trading experiments?’, *Managerial and Decision Economics* **19**(4), 225–238.

Munoz-Pina, C., Guevara, A., Torres, J. M. & Brana, J. (2008), ‘Paying for the hydrological services of mexico’s forests: Analysis, negotiations and results’, *Ecological Economics* **65**(4), 725–736.

Nalebuff, B. & Bulow, J. (1993), Designing the pcs auction, Technical report, Comment to the FCC on behalf of Bell Atlantic.

Olander, L. (2008), 'Designing offsets policy for the us: Principles, challenges, and options for encouraging domestic and international emissions reductions and sequestration from uncapped entities as part of a federal cap-and-trade for greenhouse gases', *Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC. 130p* .

Ortiz, E. & Kellenberg, J. (2002), Program of payments for ecological services in costa rica, *in* 'Workshop on Forest and Landscape Restoration', Heredia, Costa Rica.

Plott, C. R. (1994), 'Experimental methods in economics and political science: The design testing of policy options', *Human Dimensions Quarterly* **1**, 5–8.

Robinson, M. S. (1985), 'Collusion and the choice of auction', *Rand Journal of Economics* **16**(1), 141–145.

Seidl, C. (2002), 'Preference reversal', *Journal of Economic Surveys* **16**, 621–655.

Sheriff, G. (2009), 'Implementing second-best environmental policy under adverse selection', *Journal of Environmental Economics and Management* **57**(3), 253–268.

Stoneham, G., Chaudhri, V., Ha, A. & Strappazzon, L. (2003), 'Auctions for conservation contracts: An empirical examination of victoria's bushtender trial', *Australian Journal of Agricultural and Resource Economics* **47**(4), 477–500.

Tversky, A., Slovic, P. & Kahneman, D. (1990), 'The causes of preference reversal', *American Economic Review* **80**(1), 204–217.

Uchida, E., Xu, J. & Rozelle, S. (2005), 'Grain for green: Cost-effectiveness and sustainability of china's conservation set-aside program', *Land Economics* **81**(2), 247.

van Kooten, G. C. (2008), 'Biological carbon sequestration and carbon trading revisited', *Climatic Change* pp. 1–15.

Vickrey, W. (1961), 'Counterspeculation, auctions, and competitive sealed tenders', *Journal of finance* pp. 8–37.

Wara, M. W. & Victor, D. G. (2008), 'A realistic policy on international carbon offsets', *Program on Energy and Sustainable Development Working Paper* **74**.

Whitten, S., Salzman, J., Shelton, D. & Proctor, W. (2003), Markets for ecosystem services: applying the concepts, *in* '47th Annual Conference of the Australian Agricultural and Resource Economics Society', Fremantle, Australia.

Table 1: Household characteristics by treatment group

	Treatment 1 Auction		Treatment 2 Posted offer		Difference p-value
HH size	4.636	[2.083]	4.439	[2.103]	0.329
Education (1-5)[a]	2.154	[0.844]	2.283	[0.839]	0.111
Laborsharing group (0/1)	0.465	[0.500]	0.4	[0.491]	0.174
Casual labor income (0/1)	0.662	[0.474]	0.663	[0.474]	0.98
Use family labor only (0/1)	0.759	[0.429]	0.761	[0.428]	0.957
Stated labor constraint (0/1)	0.0439	[0.205]	0.0439	[0.205]	0.998
Minutes gathering firewood	111.4	[95.74]	121.4	[84.72]	0.254
Total landholding (acres)	4.97	[3.012]	4.94	[3.540]	0.925
Number of fields	1.373	[0.606]	1.41	[0.719]	0.562
Total number of crops	3.035	[1.106]	3.137	[1.221]	0.365
Minutes from home to field	23.93	[24.99]	20.65	[18.79]	0.126
Cash crops (0/1)	0.829	[0.377]	0.81	[0.393]	0.605
Stated land constraint (0/1)	0.0482	[0.215]	0.0244	[0.155]	0.19
Past borrowing (0/1)	0.307	[0.462]	0.312	[0.465]	0.908
Age of the participant	38.77	[15.90]	37.8	[16.04]	0.53
Female participant (0/1)	0.522	[0.501]	0.449	[0.499]	0.129
Months of food shortage	4.211	[2.229]	4.19	[2.116]	0.923
Prior tree planting (0/1)	0.5	[0.501]	0.488	[0.501]	0.801
Prior contact with NGO (0/1)	0.325	[0.469]	0.244	[0.430]	0.064
Risk preferences (1-3)[b]	2.123	[0.921]	2.148	[0.938]	0.781
Time preferences (1-6)[b]	3.344	[2.189]	3.223	[2.175]	0.565
Mistrusts outsiders (1-3)	1.81	[0.753]	1.912	[0.766]	0.163
Willingness to try tech (1-3)	1.23	[1.314]	1.344	[1.343]	0.371
Asset index	11.35	[3.102]	11.11	[3.498]	0.451
Observations	205		228		
Joint F-statistic for village indicators					0.13

Notes: Means are reported for each of the treatment groups with standard deviations in brackets. Difference in means: * p<0.10, ** p<0.05, *** p<0.001. (a) The range for categorical variables is provided in parentheses. (0/1) indicates a binary dummy variable, coded 1 if the response is yes. (b) Time preferences and risk preferences are elicited using survey questions. Higher risk preference corresponds to lower risk aversion. Higher time preference corresponds to a lower discount rate.

Table 2: Summary allocation and compliance outcomes for each treatment group

	Treatment 1 Auction	Treatment 2 Posted offer
Number of participants	228	205
Willingness to accept < clearing price (% of treatment)	37.4	99.5
Received contract (% of treatment)[a]	37.4	43.4
Mean contract outcome (% compliance)[b]	85.02	77.66
Probit regression of 0/1 contracting outcome on baseline variables[c]		
Likelihood ratio chi-square	38.76**	22.96

Notes: (a) A lottery was used to resolve the oversubscription in the posted offer market. (b) Percent compliance is measured as the percent of the maximum of 50 trees surviving after six months. (b) Probit regression of binary contract outcome variable on survey measures from Table 1. P-value for the likelihood ration chi-quare statistic is indicated * p<0.10, ** p<0.05, *** p<0.001.

Table 3: Baseline predictors of bids

	Logarithm bid				Bid rank			
	(1)		(2)		(3)		(4)	
HH size	-0.039	(0.064)	-0.089	(0.055)	-1.093	(2.302)	-2.315*	(1.397)
Education (1-5)	0.240	(0.151)	0.247**	(0.123)	8.554	(5.395)	7.288**	(3.390)
Laborsharing group (0/1)	-0.253	(0.255)	0.090	(0.255)	-10.710	(9.138)	-21.428***	(5.753)
Casual labor income (0/1)	-0.498*	(0.285)	-0.467	(0.291)	-16.747	(10.414)	-15.542**	(7.274)
Use family labor only (0/1)	0.274	(0.336)	0.202	(0.330)	10.069	(11.726)	5.823	(7.307)
Stated labor constraint (0/1)	1.141**	(0.493)	0.588	(0.401)	37.146*	(19.451)	53.178***	(13.45)
Minutes gathering firewood	-0.004***	(0.001)	-0.002	(0.001)	-0.129***	(0.046)	-0.086***	(0.028)
Total landholding (acres)	0.038	(0.048)	0.020	(0.043)	1.171	(1.795)	-1.453	(1.033)
Number of fields	-0.334	(0.218)	0.039	(0.211)	-12.211	(7.918)	-3.722	(4.771)
Total number of crops	-0.073	(0.150)	-0.019	(0.132)	-3.598	(4.547)	0.339	(3.205)
Minutes from home to field	-0.004	(0.004)	-0.001	(0.004)	-0.240	(0.179)	-0.138	(0.107)
Cash crops (0/1)	0.177	(0.348)	0.081	(0.318)	10.116	(12.695)	22.197**	(8.609)
Stated land constraint (0/1)	-0.988	(0.637)	-0.518	(0.713)	-29.665	(17.957)	-14.654	(13.60)
Past borrowing (0/1)	0.420	(0.269)	0.327	(0.264)	12.122	(9.258)	15.175**	(6.333)
Age of the participant	0.000	(0.008)	0.001	(0.009)	0.017	(0.317)	-0.356*	(0.210)
Female participant (0/1)	-0.491*	(0.252)	-0.295	(0.241)	-16.202*	(9.081)	-33.172***	(5.952)
Months of food shortage	-0.019	(0.071)	0.014	(0.059)	-2.064	(2.331)	-3.592**	(1.539)
Prior tree planting (0/1)	0.060	(0.268)	0.208	(0.242)	3.775	(9.568)	-5.802	(6.208)
Prior contact with NGO (0/1)	-0.505*	(0.275)	-0.611**	(0.268)	-16.354*	(9.872)	-17.035***	(6.332)
Risk preferences (1-3)	0.059	(0.129)	-0.041	(0.129)	2.699	(4.686)	8.876***	(2.986)
Time preferences (1-6)	-0.174***	(0.057)	-0.089	(0.055)	-5.401***	(2.012)	-6.549***	(1.287)
Mistrusts outsiders (1-3)	0.176	(0.157)	0.189	(0.155)	6.954	(5.652)	5.695	(3.827)
Willingness to try tech (1-3)	-0.104	(0.094)	-0.099	(0.084)	-3.215	(3.460)	-1.852	(2.195)
Asset index	-0.040	(0.055)	-0.020	(0.052)	-1.179	(1.901)	-3.163**	(1.243)
Constant	11.541***	(0.939)	9.004***	(1.173)	176.241***	(35.507)	181.809***	(23.59)
Joint F-statistic for village indicators			4.29***					
Adjusted R-squared	0.118		0.324		0.112			

Notes: Regressions of bids on baseline survey variables. (1) and (2) are OLS regressions with log(bid) as the dependent variable. (3) is an OLS regression of bid rank on explanatory variables and (4) is a quantile regression of bid rank at the 38th centile. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.001. See Table 1 for description of regressors.

Table 4: Regressions of tree survival on treatment

A. Survival	(1)	(2)	(3)
Auction	3.681**		2.646*
	(1.424)		(1.370)
Wild bootstrapped p-value[a]	0.06		
Village F-stat[b]		4.13***	4.45***
Constant	38.831***	46.125***	44.141***
	(1.105)	(1.127)	(1.789)
Adjusted R-sq	0.037	0.254	0.255
B. Survival	**(1)**	**(2)**	**(3)**
Auction	0.085**		0.061*
	(0.038)		(0.036)
Marginal effect	3.68		3.67
Village chi-square		97.66***	98.68***
Constant	3.634***	3.819***	3.767***
	(0.030)	(0.023)	(0.041)
C. Score (ordered logit)[c]	**(1)**	**(2)**	**(3)**
Auction	2.291***		2.405***
	(0.672)		(0.790)
Village chi2		39.37***	38.78**
Adjusted R-squared	0.047	0.096	0.129

Notes: N=171. Panel A reports an ordinary least squares (OLS) regressions of survival (number of trees) and monitoring score (out of 5) on treatment. Panel B reports a censored negative binomial regression of survival on treatment with an upper limit at 50. Panel C reports the odds ratio for an ordered logit model with monitoring scores ranging from 1 to 5. Robust standard errors are in parentheses (Panels A and B), bootstrapped VCE in Panel C; * p<0.10, ** p<0.05, *** p<0.001. (a) Panel A, Column 1 reports wild cluster bootstrapped p-value for the treatment effect. (b) Village F-stat reports the joint F-statistic and significance of village indicator variables. (c) The ordered logit estimates the constant at each cutoff in the outcome variable, not shown.

Table 5: Linear and censored regressions of tree survival on baseline measures for posted offer treatment

	OLS (1)		Negative binomial (2)	
HH size	0.002	(0.899)	0.001	(0.022)
Education (1-5)[a]	-2.149	(1.674)	-0.065*	(0.036)
Laborsharing group (D)	-0.937	(3.714)	-0.044	(0.080)
Casual labor income (D)	-0.040	(3.373)	-0.024	(0.077)
Use family labor only (D)	2.441	(4.295)	0.046	(0.101)
Stated labor constraint (D)	1.163	(5.513)	-0.047	(0.127)
Minutes gathering firewood	0.005	(0.015)	0.000	(0.000)
Total landholding (acres)	-0.354	(0.670)	-0.012	(0.016)
Number of fields	2.256	(2.571)	0.062	(0.056)
Total number of crops	-0.142	(1.246)	-0.005	(0.026)
Minutes from home to field	-0.038	(0.075)	-0.001	(0.002)
Cash crops (D)	-8.322	(5.936)	-0.218	(0.133)
Stated land constraint (D)	-0.109	(8.074)	0.051	(0.168)
Past borrowing (D)	5.992*	(3.250)	0.172**	(0.077)
Age of the participant	0.136	(0.098)	0.004*	(0.002)
Female participant (D)	-2.797	(3.262)	-0.108	(0.077)
Months of food shortage	0.925	(0.940)	0.032	(0.023)
Prior tree planting (D)	4.907*	(2.681)	0.156***	(0.060)
Prior contact with NGO (D)	-0.998	(4.318)	-0.020	(0.091)
Risk preferences (1-3)	-3.054**	(1.427)	-0.094***	(0.033)
Time preferences (1-6)	-1.036	(0.763)	-0.032*	(0.018)
Mistrusts outsiders (1-3)	0.231	(1.780)	0.013	(0.043)
Willingness to try tech (1-3)	-1.866*	(1.104)	-0.061**	(0.025)
Asset index	0.836	(0.632)	0.022	(0.014)
Constant	41.686**	(16.440)	3.722***	(0.380)
Village F-stat[b]	2.29**		50.57***	
Adjusted R-squared	0.161			

Notes: N = 89. OLS (1) and censored negative binomial (2) regressions of tree survival on survey regressors for posted offer treatment only. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.001. (a) See Table 1 for a description of regressors. (b) Village F-stat reports the joint F-statistic and significance of village indicator variables.

Table 6: Village effects on contract allocation and compliance, by treatment

	Contract allocation (1)	Tree survival (2)	Tree survival (3)
A. Auction treatment			
Village F-stat	46.06***	3.89***	
Contracts in village[a]			
received via auction			3.326
			(6.900)
received via lottery			19.558*
			(10.908)
Constant	0.674	45.167***	37.220***
	(0.482)	(1.312)	(3.171)
N	204	82	82
R-squared	0.199	0.406	0.043
B. Posted offer treatment			
Village F-stat	16.13	20.40***	
Contracts in village			
received via auction			17.445**
			(7.668)
received via lottery			-9.945
			(13.280)
Constant	-0.566	49.000***	37.524***
	(0.503)	(0.815)	(3.981)
N	204	89	89
R-squared	0.061	0.333	0.057

Notes: Probit (1) and OLS (2 and 3) regressions of outcomes on village variables, by treatment. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.001. (a) The number of contracts in the village, by treatment group, are normalized for village size.

Table 7: Estimated contract costs and household constraints

	Labor costs		Input costs	Land costs	
	Field preparation and planting (annual)[a]	Weeding and harvest (annual, variable)	Inputs (annual)	Production income (annual)[b]	Net
Alternative land uses					
Local maize	8400	22800	2400	141210	107610
Soya	10200	15600	300	445050	418950
Tree planting contract	(one-time)	(annual, variable)		(annual)	
Productive land	4000	14400	0	12000	-6400
Idle land	5200	14400	0	12000	-7600

Notes: All data are from Ntchisi District Agriculture and Development Officers and the 2007 Crop Estimate Report for Ntchisi District, Malawi. (a)Labor costs calculated at average market wage rate for day casual labor. (b) Crop income calculated using local market rates from 2008 and average yields from 2007.

Table 8: Carbon sequestration projections and carbon prices

Year	Above ground biomass	Below ground biomass	Total tons/tree	Carbon cost ($/ton)[a]
5	0.01	0.003	0.013	136
10	0.01	0.003	0.013	136
15	0.06	0.016	0.076	22.517
20	0.16	0.041	0.201	8.479
25	0.51	0.127	0.637	2.669
30	0.64	0.160	0.800	2.126
35	0.65	0.161	0.811	2.096
40	0.47	0.117	0.587	2.896

Notes: Biomass estimates by Kachamba, D. (2008) Report on carbon storage potential of M'bawa trees in Central Malawi. (a) Carbon price based on the total tons of carbon per tree multiplied by the total contract payment of ~USD 1.70/tree.

Figure 1: Individual bids for tree planting contracts and allocation by treatment

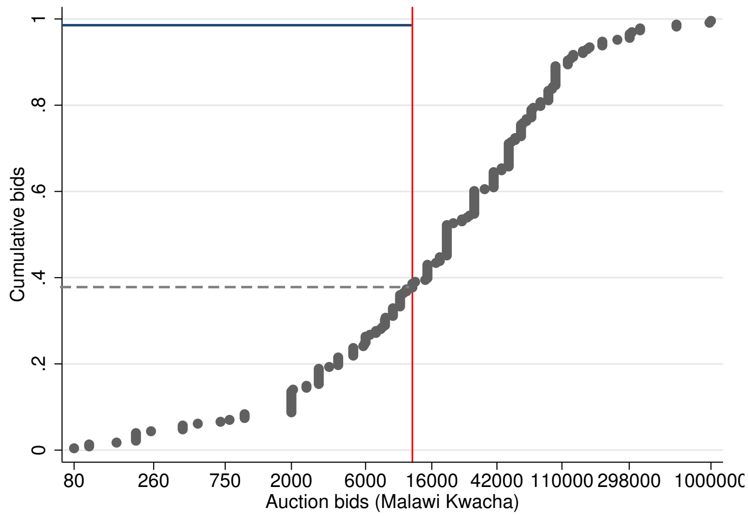


Figure 2: Tree survival outcomes by treatment group

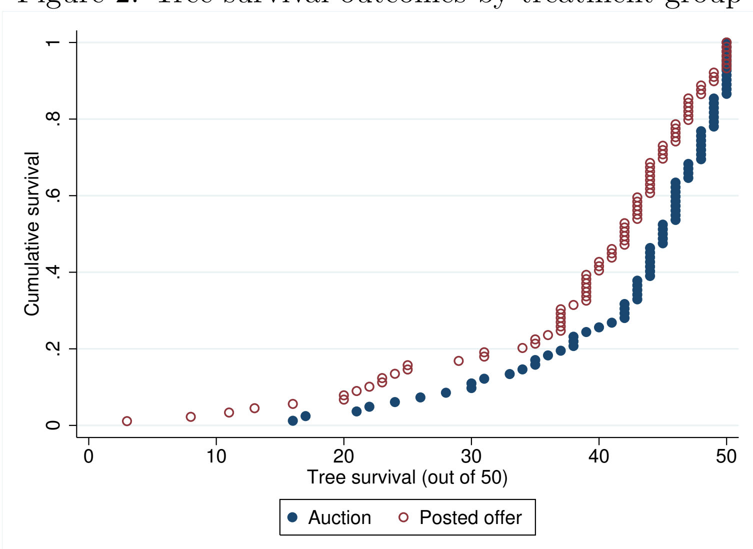


Figure 3: Correlation of bids based on auction seating location

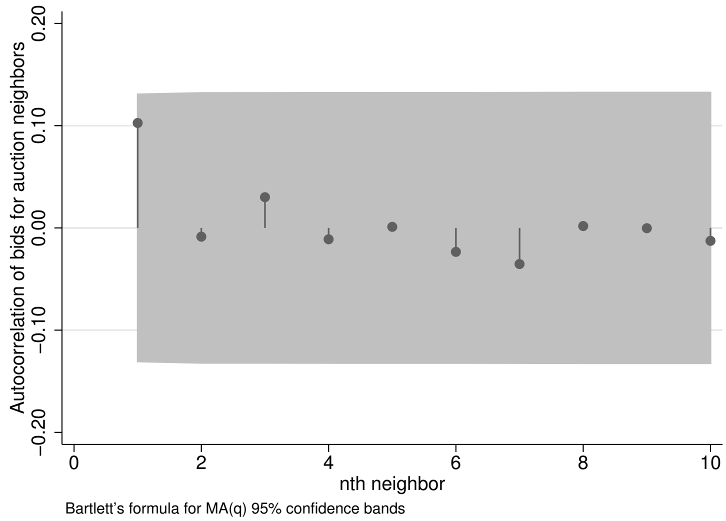
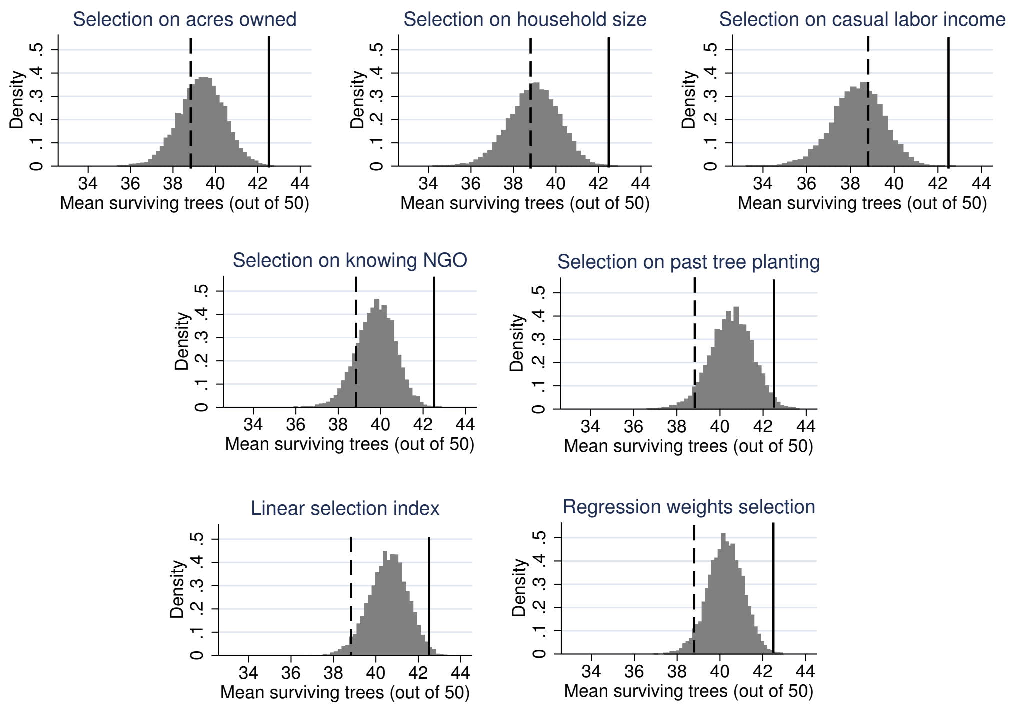


Figure 4: Simulated contract outcomes for selection on observables by a social planner



Notes: Histograms of mean survival rates from simulations of social planner selections using randomly drawn samples from the posted offer contract recipients. Each histogram describes simulated outcomes from a different selection criterion. The dashed line shows the mean tree survival rate from the posted offer selection. The solid line shows the mean tree survival rate from the auction.