A Laboratory Study of Auctions for Reducing Non-Point Source Pollution*

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A Laboratory Study of Auctions for Reducing Non-Point Source Pollution*

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Abstract

Non-point source pollution, such as nutrient runoff to waterways from agricultural production, is an environmental problem that typically involves asymmetric information. Land use changes to reduce pollution incur opportunity costs that are privately known to landholders, but these changes provide environmental benefits that may be more accurately estimated by regulators. This paper reports a testbed laboratory experiment in which landholder/sellers in multi-round, sealed-offer auctions compete to obtain part of a fixed budget allocated by the regulator to subsidize pollution abatement. In one treatment the regulator reveals to landholders the environmental benefits estimated for their alternative projects, and in another treatment the regulator conceals the potential projects' "environmental quality." The results show that sellers' offers misrepresent their costs more for high quality projects when quality is revealed, so total abatement is lower and seller profits are higher when landholders know their projects' environmental benefits. This suggests that concealing this information may improve regulatory efficiency.

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1. Introduction

The export of pollutants within watersheds originates from both point and non-point sources. For point source production decisions where the source's abatement responsibility can be identified, the resulting export of pollutants has historically been managed through regulatory policy mechanisms such as command and control, taxes (subsidies) and tradable permits. Large portions of pollutant loads occur due to activities undertaken by non-point sources, however, where export occurs via overland run-off and movement of water through the soil profile thereby making identification impossible or prohibitively expensive. For example, the Port Phillip Watershed located in southern Victoria, Australia, is comprised of various land uses: Urban (Greater Melbourne City) which includes industrial and commercial activities, households and public parks; pasture land upon which broadacre and grazing farming is undertaken, and horticulture. The watershed also includes point sources such as sewerage treatment facilities and fish farms. The estimated total pollutant load (nitrogen) exported from non-point sources is 4,394 tons per annum, compared to 3,390 tons per annum for point sources (Argent and Mitchell, 1998). Non-point sources are even more significant in other areas; for example, agricultural non-point sources represent over 90 percent of the nitrogen load exported to the Gulf of Mexico (Doering et al., 1999). These large relative loads clearly indicate that regulators need to engage non-point sources in environmental protection to mitigate the external impact of these sources' activities.

An important challenge is that regulation for nutrient control and environmental protection must operate in a setting of incomplete information. Sources of pollution and regulators possess different information, resulting in a dual information asymmetry. Regulators, working for centralized agencies with hydrologists, biophysical modelers and others with scientific expertise, may be able to more accurately estimate the relationship between various land management changes and environmental benefits. Landholders, however, possess private information regarding their opportunity cost of production under alternative land management programs. An incentive mechanism would therefore be useful to encourage heterogeneous landholders to reveal their private opportunity cost of land management changes, and permit the regulator to identify those management changes with greatest environmental benefit but lowest opportunity cost.

Auction mechanisms are an obvious candidate because they encourage economic agents to reveal private information about the value of goods. Auctions are being increasingly used for this purpose. For example, The U.S. Forest Service employs a first price sealed bid auction with a reserve price to obtain information about the private marginal valuations of environmental resources, specifically timber harvesting contracts on public lands. Another example is the U.S. Department of Agriculture's Conservation Reserve Program (CRP), which uses a sealed bid discriminative auction to obtain information about private landholder opportunity cost to divert land from agricultural production and increase the provision of conservation goods (Latacz-Lohmann and Van der Hamsvoort, 1997). A recent new example, operated by the Victoria Department of Natural Resources and Environment in northern Victoria, Australia, is called Bush Tender. This pilot program employs a sealed bid discriminative price auction to obtain information about landholders' opportunity cost for management changes that protect existing native flora and fauna.[1]

This paper reports a testbed laboratory auction to study the relationship between an

[1] Stoneham, Chaudhri, Stierna and Doering (2000) describe the design of this single offer round auction.

auction's information structure and landholders' incentives to reveal their costs.[2] The goal is to identify information conditions that allow the regulator to award land management contracts to maximize pollution abatement for a fixed auction budget. The experiments use parameters that approximate the cost of undertaking changes in land use and management practices and the consequent improvements in the environment in Port Phillip watershed, in southern Victoria, Australia. The experiments are designed to make specific contributions to environmental policy in this region, and the auctions tested could potentially be implemented in the Port Phillip watershed. The lessons learned from this testbed exercise can be obviously applied to other regions and environmental contexts, however. The research is deliberately policy-oriented rather than designed to test any specific auction theory. In fact, while the auction design introduces complications to make it closer to the field environment relevant for this region, these complications make it difficult to test specific auction theories. We discuss this in more detail in Section 2.2.

The auctions evaluated in this paper employ multiple rounds of sealed bids and a discriminative pricing rule. The regulator's budget constraint is fixed but unknown to sellers. This auction attempts to encourage private landholder/sellers to reveal their opportunity cost of land management changes that mitigate the environmental impacts of nitrogen loads. The experiment manipulates the amount of information available to landholders as the primary treatment variable. In one treatment we conceal the environmental benefit (quality) of the sellers' proposed land use changes from the sellers. In the other main treatment sellers learn their projects' environmental benefits before submitting offers. The regulator may wish to reveal the environmental benefits for several reasons – such as to increase the perceived fairness and

[2] Plott (1994) describes 'experimental testbedding' as a method by which a policy is first implemented in a simple laboratory environment. If the policy does not work, or it works but is not theoretically understandable, then there is no reason to expect it to work in a more complex field setting.

transparency of the auction, to educate landholders about the most beneficial land use changes, or to promote philanthropic behavior since goodwill is likely to be greater if landholders are aware of the environmental significance of their land.

This multi-round auction would be conducted annually, so it is reasonable to expect that sellers could eventually infer the regulator's value (price) of the environmental benefits from the prices paid for successful contracts. Successful offers in this discriminative price auction may therefore converge to a uniform price per unit of environmental benefit (Cason and Plott, 1996). If this occurs, because of the heterogeneity of landholders' cost some landholders will be "overpaid" in the sense that they receive payments from the regulator that may substantially exceed their opportunity cost.

The CRP uses an environmental benefits index and Bush Tender uses a biodiversity benefits index to enable the regulator to discriminate on the basis of environmental benefit. In an attempt to pay landholders closer to their true opportunity cost, the CRP only reveals the index ex post and changes the index between auctions. For similar reasons, Bush Tender reveals only part of the benefits index (Stoneham et al, 2000). But whether concealing this information results in differences in seller behavior has not been carefully evaluated in laboratory or field experiments. By manipulating as a treatment variable whether sellers know the environmental quality of the land use changes they can offer, this experiment can provide some initial evidence to indicate the impact of more limited information on regulatory efficiency.

Another issue that our experiments address is the potential for collusion between landholders. In the early rounds of this multi-round auction, landholders could signal the minimum opportunity cost at which to offer land use changes and tacitly agree to keep prices high as auction rounds continue. Collusion concerns would probably not be important if hundreds of landholders participate in the same auction, but it is likely that smaller, targeted auctions will be conducted separately and focus on one type of land use or region. Klemperer (2002) highlights the need to design "collusion-resistant" auctions and cites the 1999 German spectrum auction as one where bidders colluded by signaling proposed final shares of spectrum bands. Cramton and Schwartz (2000) showed how bidders used the last three digits of multi-million dollar bids to signal the telephone codes of the areas they wished to purchase. The U.S. Forest service changed from an open auction to a sealed-bid because of collusion problems (Stoneham et al., 2000). Ausubel and Milgrom (2001) explore the trade-off between success of a bid and the incentive for bidders to reduce incomplete information through signaling. Agents may collude in early rounds to reduce incomplete information but the incentive to collude declines as rounds increase. In our laboratory auctions we provide minimal information feedback to bidders between rounds to minimize the opportunity for collusion. But since it is practically impossible to limit communication across auctions (which would be held annually) we allow bidders to communicate freely between auction periods, with only the restriction that they cannot reveal "verifiable" private cost information by showing each other their record sheets.[3]

Our results show that abatement is lower and landholder/seller profits are higher when environmental quality is revealed to sellers. Lower seller profits are better from the government's perspective, because low profits indicate that sellers are not "overpaid" to deliver improvements in environmental quality. Our results also indicate that even though we allow subjects to communicate between trading periods in all the sessions, sellers successfully colluded to raise their offer prices above costs in only one session. Finally, the analysis of seller offer behavior indicates that the main impact of environmental quality information is to raise the variance of the

[3] Cummings, Holt and Laury (2001) also recognize how it is practically impossible to prohibit communications between landholders, so they also allow bidders to communicate between periods of their laboratory auctions for irrigation permits.

offers, with sellers significantly increasing offers when they know that a project is high quality. These high quality projects are therefore more frequently excluded from the projects purchased in the auction when quality information is revealed, which is the source of the reduced environmental benefits realized in this treatment.

The remainder of the paper is organized as follows. Section 2 describes the experimental design and Section 3 presents the results. Section 4 provides a brief summary and discussion of the findings.

2. Experimental Design and Models

Section 2.1 describes the features of the auction used in the experimental testbed, and Section 2.2 discusses the theoretical intuition guiding the choice of these features.

2.1 Design

We report 11 sessions, each with eight seller subjects who offer units in a computerized auction. In each offer round, sellers submitted electronic "offer sheets" using a web browser. These offer sheets specify a desired sale price for each of two or three different "items" that correspond to different land use change or land management projects. The instructions emphasized that no more than one item (if any) would be bought from each seller. We imposed this rule because sellers usually do not obtain the same marginal environmental impact of a land use or management change if another land use change has already been implemented. Because of this interaction, the value of two "items" is not the sum of their individual benefits.[4] The

[4] For example, if a grower installs grassed swale drains with sediment traps to reduce nutrient loads, this reduces the marginal environmental impact of reducing fertilizer applications. The environmental benefits provided by different landholders' projects may also be interrelated. For example, if one landholder leaves a buffer zone between his production land and a major creek, then the environmental benefits provided by reduced fertilizer applications by an uphill landholder are reduced. This raises some interesting dynamic considerations; for example, landholders might agree to undertake a project in an early auction round before the regulator accepts other projects that reduce their own project's benefits. We leave the study of this important type of interaction for future research. Since our

instructions used neutral (color) terms to refer to the different items that sellers could offer, and neutral terminology was used throughout the instructions and sessions, as is the common practice in experimental economics. For example, the instructions describe the environmental benefits simply as the "quality" of the items desired by the experimenter-buyer. The appendix contains the experiment instructions.

Each auction concludes and trades are consummated at the end of a *period*, and each period consists of multiple offer *rounds*. Figure 1 presents a timeline that summarizes the steps of each period. The auction employs a discriminative price rule (each successful seller receives her offer price for her sold item). We employ a multi-round auction so that sellers have an opportunity to revise offers in these annual auctions. To limit the potential for collusion, however, sellers receive the minimum amount of feedback between rounds; in particular, they learn only which (if any) of their offers were provisionally accepted in the auction, and not the market clearing prices or other projects accepted from other sellers. The auction is declared final when the set of successful sellers is unchanged from the previous round, or when a predetermined (unannounced) maximum number of rounds is reached. This maximum number of rounds varied from period to period, and was determined randomly by dice roles before data collection began. The maximum ranged from 4 to 9 rounds, and this limit was usually not binding.

We focus on the impact of an information treatment variable: whether or not sellers have information about the environmental quality of the land use or management changes they offer. In the *Quality Revealed* treatment, sellers know both the cost and the environmental benefit

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experiment does not include the potential interaction of landholders' projects, it represents the reasonable case in which the regulator requires adjacent landholdings to participate in different auctions.

(quality) supplied by each of their land use change projects. In the *Quality Unknown* treatment, sellers know only the cost of their land use change projects.

Table 1 presents the cost and quality ranges used in the experiment. The exact costs and qualities of each land use or management change were drawn independently from a uniform distribution with the indicated ranges. We used the same set of drawn values in all 11 sessions to minimize across session variation. Sellers knew only their own projects' costs (or their own costs and quality in the Quality Revealed treatment). They did not receive any information about other sellers' costs or qualities, nor did they learn the distributions governing the costs and qualities. Sellers also did not know the government's budget, which was fixed at 35,000 experimental dollars in all periods.

We selected cost and quality parameters that approximate the opportunities for environmental improvement through land use and management changes in the Port Philip watershed.[5] Broadacre and grazing activities make up the largest land use in the watershed (57 percent) and contribute 53 percent of the annual nitrogen load. Built up areas represent 39 percent of land use and contribute 40 percent of annual load, and Horticulture represents 2 percent of land use and 7 percent of annual load (Argent and Mitchell, 1998). The nitrogen reduction ranges were developed through expert panel consultation with Natural Resources and Environment, Melbourne Water and the Cooperative Research Centre for Catchment Hydrology at the University of Melbourne. They represent the best estimates given Port Phillip soil type and topography. The cost ranges were developed through consultation with private landholders. These cost and opportunity ranges are contained within a biophysical model of the catchment called FILTER (Argent and Mitchell, 1998). Horticulture was over represented in the experiment

[5] Hong and Plott (1982) and Grether and Plott (1984) also choose parameters to approximate the economic conditions underlying their policy applications, in completely different contexts.

(with two of the eight sellers) because of the significant environmental benefit potential from heavily recruiting this land use if the auction is implemented in the field.

All subjects were undergraduate students from Purdue University and the University of Melbourne. Subjects were randomly assigned the various seller roles upon arrival at the laboratory. Subjects had costs and made offers in experimental dollars, and sales led to profits that were converted at the end of the session to local currency, and paid along with a non-salient show-up fee of US$10 or A$20. The experimental dollars were converted at different rates for different subjects, since the experimental dollar earnings were quite different for the different subject types due to differences in costs and environmental benefits across types (see Table 1). Most subjects earned between US $15 and $40, with a mean of US$25 based on an exchange rate of 2 Australian dollars = 1 U.S. dollar. Sessions lasted nearly 2 hours.

Table 2 summarizes the site, number of periods and treatment for each session. The design is (nearly) balanced, with multiple sessions of each treatment at each site. Some sessions included more trading periods than others because we completed as many periods as possible that fit comfortably in the 2-hour lab session. The number of rounds each period (and therefore the required clock time for each period) was endogenous. As explained in the instructions, between trading periods sellers were "free to discuss all aspects of the market fully for up to two minutes… [but they could] not show each other any information on [their] record sheets." As noted in the introduction, we implemented these communication rules because it was considered likely that sellers could communicate between these (annual) auctions. It was therefore important to evaluate whether the employed auction institution was resistant to potential attempts at collusion. We did not permit sellers to show each other their record sheets because it is unlikely that cost claims in the field are verifiable.

2.2 Auction Models

Auctions are a popular mechanism to allocate goods and services across multiple parties. The most commonly used and analyzed auctions are the English, first price sealed bid, second price sealed bid and the Dutch auction. According to the Revenue Equivalence Theorem, under the assumptions of bidder risk neutrality, independent private valuations, symmetry among bidders, single unit demand, payments a function of bids only and zero transaction costs incurred in bid construction and implementation, all of these major auction designs will, on average, result in the same prices and allocations.

The provision of environmental goods (nitrogen reductions in this case) by private landholders violates some of these benchmark assumptions, however. Private landholders may be risk averse (Bond and Wonder, 1980, and Quiggin, 1981), and they can also supply multiple units of environmental benefit through their land use changes. Moreover, independent private values may be a reasonable approximation for the provision of environmental goods, but bidder symmetry certainly is not (Latacz-Lohmann and Van der Hamsvoort, 1997). Asymmetry arises, for example, from land location differences, which result in differences in opportunity cost and external benefits of land management change. Further, heterogeneity of landholders, due to skill and extent of off farm activities (for example), adds to the differences in opportunity cost. The Revenue Equivalence Theorem therefore does not apply in this setting, and a uniform price, first rejected offer (Vickrey) auction is not incentive compatible.

The variability in costs and environmental benefits in this application leads to an important additional complication. For an optimal allocation in most procurement auctions, efficiency requires that the items be purchased from the lowest-cost sellers. In the case of environmental goods, however, if payment is awarded to the lowest offers, the auction outcome may generate low (external) environmental benefits. Our auction addresses this problem by employing a discriminative price auction in which the regulator discriminates on the basis of revealed cost (offer) *and* estimated environmental benefit or quality.[6] In our laboratory environment payments are functions of offers only, and we have (near) zero transaction costs in offer construction and implementation.[7]

The auctions studied in this paper introduce other complications such as multiple offer rounds per period and multiple potential projects per seller. Only the final offer round determines the purchased projects and no more than one project can be accepted from each seller. Hence our environment is not consistent with any specific, existing theoretical model. The auction design used in this paper was chosen for its policy relevance rather than for theoretical tractability.

Nevertheless, our auction design choices are guided by both theoretical intuition and practical experience with laboratory and field auctions. We employ a sealed-bid rather than ascending price auction because sealed-bid auctions are less susceptible to tacit collusion and because they encourage entry by (potentially weaker) bidders, thus enhancing competition (Klemperer, 2003).[8] We chose a discriminative rather than uniform price rule so that potential critics would not perceive that the auction leaves obvious "money on the table" when paying landholders more than their offer price. But we also chose a discriminative rule because it can lead to lower procurement expenditures than a uniform price auction in the presence of risk aversion (Harris and Raviv, 1981) and because of claims that collusion is more likely in uniform

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[6] This approach is similar to the Conservation Reserve Program, which uses an environmental benefits index as a mechanism to identify homogenous classes of bidders based on natural circumstances; see Baneth (1994), Latacz-Lohmann (1993) and Stoneham et al. (2000).

[7] Payments as a function of offers only and zero transaction costs may not hold in the field, of course; see Stoneham et al. (2000).

[8] Another benefit of sealed-bid auctions in this type of procurement setting with elastic demand is that potential sellers have the incentive to lower offer prices in order to increase sales quantity (Hansen, 1988). That benefit does not apply to our environment, however, since sellers can only supply up to one project each, and these discrete projects deliver a fixed quantity of environmental improvement.

price auctions, such as in the electricity spot markets in the U.K. and California (Klemperer, 2003).[9] Finally, we chose a multiround auction so that feedback from earlier auction rounds might improve efficiency by allowing the auction to select the least costly, high quality projects. As we will see, however, offers tended to increase for high quality projects in later rounds, possibly reducing efficiency.

3. Results

3.1 Overview and Preliminaries

Figure 2 summarizes the offer data using a scatterplot of the final round seller offers against their cost draws. Like most of the analysis that follows, this figure is based on the first five periods of data.[10] The solid line at offer=cost in Figure 2 provides a reference point for zero payoff offers. Some offers are very close to costs (and a couple of offer mistakes are below cost), but others are much higher than cost. Offer variability appears to be greater in the Quality Revealed treatment, displayed in the upper panel of the figure. We document this statistically in Section 3.3, and show how the greater variability is related to the quality variation that sellers observe only in the Quality Revealed treatment.

The variability of the offers in the (lower panel) Quality Unknown treatment also seems lower if we exclude session MU3. This is the collusive session that has offers displayed with

[9] These claims are controversial, however, and observers have argued that uniform price auctions are more competitive than discriminative price auctions for government debt (Bartolini and Cottarelli, 1997) and electricity (Kahn et al., 2001). Moreover, the available laboratory evidence suggests that revenues may not be higher in multiunit discriminative auctions than in uniform price auctions, as implied by standard theory (Cox et al., 1985). In future research we plan to compare the present discrimative pricing rule results with those from auctions conducted under uniform price rules.

[10] We focus on the first five periods because those data are more comparable across sessions and treatments. Different sessions included different numbers of periods (Table 2), so if we include the later periods then subject experience is not held constant across sessions. Recall also that we employed the same set of random cost and quality draws in all sessions. The sessions that completed more periods sample from a different set of draws in the late periods.

open circles. Although we allowed sellers to communicate between periods in all sessions, this is the only session in which sellers succeeded in implementing a collusive agreement to raise their offer prices well above costs. Behavior and market outcomes in this session were completely different from the other ten sessions. For example, the median final round "markup" of offers over costs for the 72 periods conducted in the ten noncollusive sessions ranged from 0.1 percent to 24 percent, with median markups of less than 9 percent in 67 of the 72 periods. By contrast, in all 8 periods after the first seller discussion in session MU3, median markups exceeded 19 percent, and markups ranged between 210 percent and 1317 percent in periods 5 through 10. Because this collusive session was very different from all of the others, in the results we present calculations both with and without pooling its data with the noncollusive sessions.

3.2 Overall Market Performance

In this subsection we present results regarding overall market performance, and defer the detailed analysis of seller offer behavior to subsection 3.3. The market performance measures that we use in this paper differ from the standard allocative efficiency measures typically applied in laboratory auction research. For the auction to be allocatively efficient, the auction must select the least costly projects. But in this policy application, for efficiency the auction also needs to select projects with high environmental benefits (quality). The first market performance measure, which we call P-MAR (for the *Percentage of Maximum Abatement Realized*), is the amount of pollution abatement realized by the auction mechanism, as a percentage of the highest amount of abatement that could be achieved with the government's auction budget. This maximum is based on the realized cost and benefit draws each period. This maximum abatement target could be achieved, for example, if the government knew both the cost and quality of each project and could implement its selected projects at their cost.[11]

The second market performance measure provides an alternative summary of the auctions' ability to obtain the most abatement with the government resources. We use P-OCER (for the *Percentage of Optimal Cost-Effectiveness Realized*) to refer to the actual quantity of abatement per dollar spent in the auction, as a percentage of the quantity of abatement per dollar spent in the "maximal abatement" solution to this problem described above. It differs from P-MAR because different amounts are spent in this auction when it selects a discrete set of projects; i.e., sometimes substantially less than the $35,000 budget is spent. Presumably these unspent resources have some alternative value, so a reasonable objective is to maximize the abatement per dollar.

The third performance measure is seller profits. Since seller profits represent money "left on the table" that the government "overspends" (relative to the actual cost of implementing the land use changes), lower seller profits are better from the government's perspective. Obviously, seller profits are zero at the offer=cost benchmark.

Figure 3 displays these three market performance measures for the first 5 periods of the sessions. These measures do not differ much by treatment in periods 1 and 2, when the auction is able to generate about 90 percent of the maximum achievable abatement, and over 90 percent of the optimal abatement per dollar spent. In periods 3 through 5, however, in the Quality Unknown

[11] Sometimes this maximum abatement would occur if all sellers offer their projects in the auction at cost, but cost-revealing seller behavior does not always result in maximum abatement. Recall that the auction ranks the offers on the basis of their offer/quality ratio, and selects those with the lowest ratios. This does not always result in the maximum abatement achievable for a fixed budget, since some higher abatement projects could be excluded from the auction allocation due to a higher ratio. Some rearrangement of the selected projects can sometimes modestly increase the total abatement realized. To determine the selected projects that maximize pollution abatement, we calculated the total abatement for the $4^4 3^4$=20,736 possible project combinations, and determined the greatest abatement among all the affordable project combinations. For the particular random cost and quality draws used in the experiment, if all sellers used the offer=cost "full revelation" strategy then the auction selects the combination of projects that maximize abatement in 3 of the 10 periods. In 6 of the other 7 periods, this full cost revelation strategy would achieve at least 96 percent of the maximum possible abatement.

treatment both P-MAR and P-OCER are higher, and seller profits are lower, compared to the Quality Revealed treatment. This ranking holds regardless of whether the calculations include the collusive session MU3. Note that the trend is toward higher profits and lower abatement in later periods.

Table 3 compares these market performance measures for the two treatments using a set of panel regressions based on a random effects error structure. The session represents the random effect, in order to account for the correlation of market outcomes within a session. We employ random effects tobit models for P-MAR and P-OCER, since by definition these efficiency measures cannot exceed 100 percent. We include a dummy variable for the experiment site to control for any cultural or demographic differences across subjects. We also include ln(period) to allow the model to capture differences in performance across periods, and we include ln(rounds) to determine whether longer or shorter periods perform differently.

The P-MAR models on the left of Table 3 indicate that abatement (as a percentage of the maximum achievable) is about 6 percent lower when environmental quality is revealed to sellers, although this treatment effect is not statistically significant. The experiment location dummy and the number of rounds are also not significant. Other than the intercept term, the only significant variable in the P-MAR and P-OCER models is the time trend across periods. The negative ln(period) variables indicate that abatement decreases across periods, consistent with Figure 3. (We obtain similar results when using other specifications for this time trend, such as simply the period number or 1/period.) The substantial variation across sessions that is accounted for by the random effects error structure seems to be responsible for the lack of precision in several of the coefficient estimates. When these models are estimated without random effects, both the quality revealed dummy variable and the rounds variable are negative and statistically significant.

The seller profits models at the right of Table 3 mirror those of the abatement efficiency models. Seller profits are higher when quality is revealed, and this quality treatment effect is now marginally significant.[12] The positive ln(period) variable indicates that these profits rise over time, and the positive ln(rounds) variable indicates that sellers are able to extract greater profits in periods that involve a greater number of offer rounds.

Taken together, the most significant conclusion that can be drawn from Figure 3 and Table 3 is that market performance varies over time, and declines across periods. A limitation of the Table 3 models is that they permit only a level shift in market performance in the two quality information treatments, and the models assume that this shift is identical in early and late periods – contrary to the greater difference in later periods indicated in Figure 3. Table 4 reports an alternative set of empirical models for market performance that allow the quality information treatment effects to differ in the early and late periods. These models also permit inferences regarding the long-run market performance. As in Table 3, we estimate all models with a random effects error structure and employ tobit models for the efficiency regressions.

The coefficient estimate on the 1/period variable is a measure of performance in the first period because (period-1)/period is zero while 1/period is one. The coefficient estimate on (period–1)/period is a measure of long-run (asymptotic) performance because as period increases 1/period approaches zero while (period-1)/period approaches one. We interact these variables with the Quality Revealed dummy variable, so the estimates in the top two rows of Table 4 represent the early and late performance for the Quality Unknown treatment. The interaction terms in the lower two rows represent the *difference* introduced by revealing quality in early and late periods. To improve estimation efficiency, for these Table 4 models we drop the site dummy

[12] The higher seller profits when quality information is revealed is not particularly surprising from a mechanism design perspective. By giving up its information advantage the government-buyer would be expected to give up some information rents.

and the number of rounds in the period because their estimates were generally insignificant.

Consistent with Figure 3, the estimates indicate that performance declines in later periods. For example, the efficiency measures P-MAR and P-OCER fall toward around 84 percent in the Quality Unknown treatment (or around 91 percent when the collusive session MU3 is excluded), as indicated by the (period-1)/period coefficient estimate. The model indicates no difference between the two information treatments in the early periods, since the Quality Revealed dummy × (1/period) interaction is never significant in any model. But the coefficient estimates for the Quality Revealed dummy × (period-1)/period interaction indicate that efficiency is about 10 percentage points lower in later periods in the Quality Revealed treatment. The information treatment is not significant for seller profits, however. Overall, the results in Figure 3, Table 3 and Table 4 indicate that when significant differences exist between the information treatments, market performance is lower when quality information is revealed. The differences across treatments also appear to increase as sellers gain experience. The next subsection traces these performance differences to seller behavior.

3.3 Offer Behavior

This subsection presents an analysis of the individual seller offers. The results indicate that the auction performance differences between the information treatments arise from differences in the variability of offers across treatments, rather than simply from differences in average offers. In particular, sellers in the Quality Revealed treatment offer prices well above cost only for the high-quality projects. This extra "markup" over cost for high-quality projects does not occur in the Quality Unknown treatment because sellers cannot identify which of their projects are high quality. Offer variability is therefore greater when quality is revealed, since in this treatment sellers can condition their offers on this additional information. Moreover, this extra markup for priority projects leads to the greater seller profits documented above, and abatement performance suffers since this greater markup sometimes causes high-quality projects to be excluded from the set of winning projects.

We first use the offer/cost ratio as a convenient statistic to summarize the offers. Figure 4 presents the median offer/cost ratios for various cost ranges, using data from the final auction round in periods 1 through 5.[13] Pooled over all costs, the leftmost bars indicate that the median markup in the offers is less than 5 percent, and is greater in the Quality Unknown treatment. The other bars indicate that markups are much greater for the lowest cost ranges, and that the Quality Unknown treatment median markups are generally greater than the Quality Revealed median markups.

How can performance be inferior in the Quality Revealed treatment (Figure 3), even though offers are not greater on average in this treatment (Figure 4)? Figure 5 presents the variance of the offer/cost ratio for these same periods and cost ranges and provides the first clue to solve this puzzle. The variance is at least twice as great in the Quality Revealed compared to the Quality Unknown treatment for all intermediate cost ranges ($3,000 to 7,000) and when pooling across all cost draws. The variance ordering is reversed for the very low and the high cost draws, but these represent a minority (385/1058=36 percent) of the total cost draws in these periods, and an even smaller fraction (42/246=17 percent) of the sold projects.

Figure 6 shows that the source of this greater variability in offers for the Quality Revealed treatment is the substantially higher markups for high-quality projects. This figure

[13] We do not focus on the earlier round offers, since these offers do not affect market outcomes directly. Recall that the auction period is declared final if the set of sellers who succeed in selling a project does not change from the previous round, or when the auction reaches the exogenous maximum number of rounds. (This maximum is not announced and varies between 4 and 9 rounds, randomly across periods.) The exogenous maximum limit on the number of rounds was binding in only 6 of the 81 auction periods. The reason that this maximum is rarely binding is that auctions were often completed with only a few rounds. The median number of rounds was 3 in both the Quality Revealed and the Quality Unknown treatments, and the mean number of rounds was 3.7 and 3.5 in the Quality Revealed and Unknown treatments, respectively.

presents the median offer/cost ratio for all final round offers, separated by quality range, rather than separated by the cost range as in Figure 4. For low-quality projects, by contrast, sellers in the Quality Revealed treatment make offers that are much closer to cost. Markups vary much less across the different quality ranges in the Quality Unknown treatment. Averaged across all quality levels—as in Figure 4—markups are not higher in the Quality Revealed treatment. But Figure 6 shows that it is precisely those high-quality projects that receive priority in the auction and are sold at higher markups when quality is revealed, resulting in lower abatement and higher seller profits in this treatment.[14]

Table 5 presents random effects regressions of the seller offer function for the Quality Revealed treatment in order to document formally the greater offer markups for the high-quality projects. The dependent variable in these regressions is the seller's offer price. A major determinant of a seller's offer is his cost, which is included as an explanatory variable. We also include a dummy variable for experiment site and the natural logarithm of the period number to capture any shifts in the offer function across periods. (Similar results are obtained when using other specifications for this time trend, such as simply the period number or 1/period.)

The project cost coefficient is estimated very precisely and indicates the close relationship between costs and offers. But the main variables of interest are the quality level and the high-quality dummy variables added in Models 2 and 3. The positive and highly significant coefficients on these variables indicate a substantial increase in offers when sellers know that a

[14] The high (25-30 percent) markup for the high-quality (over 280) projects in the Quality Unknown treatment may appear surprising, since sellers did not observe quality directly in this treatment. But this reflects changes in offers across rounds due to outcomes from the pervious round. If a seller did not "provisionally" sell a project in the previous round, she was 5.4 times more likely to decrease rather than increase its offer price in the next round. By contrast, if she did "provisionally" sell a project in the previous round, she was 2.3 times more likely to increase rather than decrease its offer price in the next round. Since these high-quality projects were often provisionally accepted in early rounds, sellers tended to raise these projects' offer prices in later rounds. This led to the higher than average markup for high-quality projects in the final round even when the quality information was not revealed directly to sellers in the Quality Unknown treatment.

project is high quality. For example, Model 3 includes a dummy variable for projects that have a quality level of at least 160 (a cutoff suggested by Figure 6); the coefficient estimates indicate that sellers offer these high-quality projects at a price about $1600 higher than equally costly low-quality projects.

Table 6 presents another set of seller offer functions after pooling the final round offers across all sessions. To investigate whether the offer function shifts between the Quality Revealed and Quality Unknown treatments, we include a dummy variable for the Quality Revealed treatment, as well as an interaction term between the dummy variable and cost to allow the cost markup to differ between the Quality Revealed and Quality Unknown treatments. We also include the same control variables used in the earlier regressions. The previous (Table 5) results indicate a shift in the offer function for high-quality projects in the Quality Revealed treatment, so the right side of Table 6 reports results for only these important high-quality projects.

These models indicate a higher intercept but a lower cost slope in the Quality Revealed treatment, but the slope interaction term is typically not statistically significant. The intercept shift is not statistically significant in the version that includes all final round offers (Models 1 and 2), but the upward shift in offers in the Quality Revealed treatment is quite large and statistically significant for the high-quality projects (Models 3 and 4). Figure 7 illustrates the difference in the estimated offer functions fitted through these high quality projects, implied by the estimates in Model 3 of Table 6. This figure clearly shows the substantially higher markup for high quality projects when sellers know their projects' environmental quality.

4. Discussion

Non-point source pollution poses a variety challenges for regulators, including complications arising from the private information that allows landholders to misrepresent their true costs of undertaking environmental improvements. Land use change auctions are one useful mechanism to induce landholders to (imperfectly) reveal these costs. The testbed laboratory auctions reported in this paper show that market performance differs between the auction treatments in which environmental quality is revealed or unknown to sellers. When measured either as total abatement realized, as the abatement realized per dollar spent in the auction, or as reduced inefficient (seller profit) transfers to sellers, market performance is usually higher when sellers do not know their project's quality. In other words, maintaining the regulator's private information can at least partially offset the potential efficiency loss arising from landholders' private information.

Our analysis of seller offers indicates that this performance difference arises from landholders' ability to condition their offers on their projects' environmental quality when the regulator reveals quality information. Sellers in this treatment clearly make higher offers for high-quality projects, since they know that high quality gives these projects priority in the auction. This strategic incentive to raise a project's offer price when that project has a higher quality also leads to greater offer variance in this treatment. Consequently, some high-quality projects that should be undertaken for an efficient allocation of auction funds are excluded from the set of funded projects, so less abatement is acquired through the auction when sellers learn their projects' environmental quality.

Sellers' profits also increase when they learn their projects' environmental quality. This suggests that sellers have an incentive to illegally acquire this information if the regulator conceals environmental quality when the auction is implemented in the field. One can imagine, for example, a landholder paying a government agent for information regarding the output from her calculations of the estimated environmental benefit of alternative land use changes. One way to reduce the likelihood of such information "leakage" would be to include multidimensional environmental benefits with "weights" for each dimension that are concealed from agents and that vary from year to year. For example, habitat preservation and biodiversity could be goals other than reduced pollutant loads that are valued by the regulator. As noted in the introduction, the Conservation Reserve Program in the U.S. changes the weights on various environmental objectives from year to year when constructing an environmental benefits index, in part to maintain some information advantage over landholders (Latacz-Lohmann and Van der Hamsvoort, 1997, Stoneham et al., 2000). Illegal acquisition of quality information could be studied in future research that evaluates the differences in compliance generally between incentive regulations like these land use change auctions and more traditional command and control regulation.

Sellers gain experience as the number of (annual) auctions increase. In both treatments market efficiency decreases and seller profits increase in later auction periods. This performance decline is important to policy makers if sellers are able to participate in consecutive auctions. Another reason that policy makers may want to include weights for different pollution reducing projects and change these weights between auctions, similar to the CRP, is to reduce sellers' learning and exercise of strategic behavior in later auctions.

One could also consider different auction rules—such as those that do not base priority on the offer/quality ratio—to make the environmental quality information less valuable to sellers. Studying alternative auction designs is an obvious important extension of this research. For example, in a subsequent experiment we plan to compare the performance of the current discriminative price auction rules to alternative uniform price rules. Nevertheless, our current experiment identifies an important *informational* component that should be considered as a key feature of land use change auctions designed for the field. More information for landholders can induce strategic behavior that reduces auction performance.

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Table 1: Cost and Environmental Quality Parameters

Broadacre + Grazing on Pasture Land (57% of non-forest land area, 53% of N load) **4 Subjects (each representing 150 ha)**			Built Up Areas (non-Agricultural) (39% of non-forest land area, 40% of N load) **2 Subjects (each representing 150 ha)**			Horticulture (2% of non-forest land area, 7% of N load) **2 Subjects (each representing 50 ha)**		
Land Use or Management Change	Cost Range	Nitrogen Reduction Range	Land Use or Management Change	Cost Range	Nitrogen Reduction Range	Land Use or Management Change	Cost Range	Nitrogen Reduction Range
Filter/Buffer Strips	$15-65 per ha/year	0.35-0.875 kg/ha/year	Constructed Wetlands	$26.5-191.9 per ha/year	0.26-1.89 kg/ha/year	Fertilizer Changes	$64-80 per ha/year	0.51-5.1 kg/ha/year
Stabilize Soil Erosion	$15-65 per ha/year	0.28-1.05 kg/ha/year	Rainwater Tanks	$31.26-51.66 per ha/year	0.02-0.815 kg/ha/year	Grassed Swale Drains	$72-129.65 per ha/year	5.1-8.5 kg/ha/year
Best Management Practices	$17.5-65 per ha/year	0.35-0.70 kg/ha/year						

Sources: Argent, R.M. and Mitchell, V.G. (1998) FILTER: *A Nutrient Management Program for the Port Phillip Catchment*. Centre for Environmental Applied Hydrology, The University of Melbourne.
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Table 2: Summary of Experimental Sessions

Session Name	Information Treatment	Location	Number of Periods
MU1	Quality Revealed	Univ. of Melbourne	5
MU2	Quality Revealed	Univ. of Melbourne	5
MU6	Quality Revealed	Univ. of Melbourne	6
PU1	Quality Revealed	Purdue University	9
PU3	Quality Revealed	Purdue University	7
PU5	Quality Revealed	Purdue University	8
MU3	Quality Unknown	Univ. of Melbourne	9*
MU4	Quality Unknown	Univ. of Melbourne	5
MU5	Quality Unknown	Univ. of Melbourne	8
PU2	Quality Unknown	Purdue University	9
PU4	Quality Unknown	Purdue University	10

* 10 periods were conducted in session MU3, but the data from period 3 are incomplete due to a software problem.

Table 3: Regression Models for Market Performance Measures

	Percentage of Maximum Abatement Realized (P-MAR)		Percentage of Optimal Cost-Effectiveness Realized (P-OCER)		Seller Profits	
	All Sessions	Drop collusive MU3 session	All Sessions	Drop collusive MU3 session	All Sessions	Drop collusive MU3 session
Intercept	0.970** (0.086)	0.974** (0.060)	1.043** (0.052)	1.06** (0.123)	380.2 (1854.4)	-1006.0 (1789.7)
Dummy=1 iff Quality Revealed	-0.057 (0.070)	-0.060 (0.046)	-0.041 (0.122)	-0.050 (0.108)	2112.0 (1300.0)	3314.0† (1801.7)
Dummy=1 iff Site=Purdue	-0.055 (0.085)	-0.058 (0.066)	-0.056 (0.107)	-0.062 (0.148)	1815.8 (1297.2)	2772.7 (1865.3)
Ln(Period Number)	-0.052** (0.011)	-0.052** (0.016)	-0.081** (0.027)	-0.080* (0.033)	3753.9** (760.8)	3774.7** (331.5)
Ln(Total Rounds in Period)	-0.002 (0.049)	-0.001 (0.047)	-0.029 (0.064)	-0.039 (0.149)	1627.9† (985.3)	1368.8** (465.6)
Observations	54	50	54	50	54	50
Significance of the regression (*p*-value)	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001

Notes: Standard errors in parentheses. ** denotes a coefficient that is significantly different from zero at 1-percent; * denotes a coefficient that is significantly different from zero at 5-percent; † denotes a coefficient that is significantly different from zero at 10-percent (all two-tailed tests). Due to the differing session lengths, to provide comparable data all estimates employ only the data up to and including period 5. All models are estimated with a random effects error structure, with the session as the random effect.

Table 4: Regression Models for Early and Long-Run Market Performance

	Percentage of Maximum Abatement Realized (P-MAR)		Percentage of Optimal Cost-Effectiveness Realized (P-OCER)		Seller Profits	
	All Sessions	Drop collusive MU3 session	All Sessions	Drop collusive MU3 session	All Sessions	Drop collusive MU3 session
1/period	0.878** (0.129)	0.938** (0.069)	0.937** (0.097)	0.986** (0.064)	5829.9* (2695.6)	1959.8 (15453.0)
(period-1)/period	0.847** (0.048)	0.918** (0.041)	0.843** (0.098)	0.910** (0.032)	10792.6** (2651.5)	7006.6 (8271.9)
(Quality Revealed dummy)×(1/period)	0.002 (0.127)	0.005 (0.075)	-0.014 (0.115)	0.000 (0.068)	-2102.0 (3330.8)	1799.8 (15592.9)
(Quality Revealed dummy) × (period-1)/period	-0.108* (0.045)	-0.116** (0.035)	-0.090 (0.091)	-0.092† (0.050)	271.9 (3169.8)	4089.6 (8275.9)
Observations	54	50	54	50	54	50
Significance of the regression (*p*-value)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Notes: Standard errors in parentheses. ** denotes a coefficient that is significantly different from zero at 1-percent; * denotes a coefficient that is significantly different from zero at 5-percent; † denotes a coefficient that is significantly different from zero at 10-percent (all two-tailed tests). Due to the differing session lengths, to provide comparable data all estimates employ only the data up to and including period 5. All models are estimated with a random effects error structure, with the session as the random effect.

Table 5: Seller Offer Function for Quality Revealed Treatment Only (Final Round Offers)

	Model 1	Model 2	Model 3
Intercept	799.6* (351.1)	-123.0 (286.6)	355.5 (288.9)
Cost	0.959** (0.017)	0.930** (0.016)	0.985** (0.017)
Quality		8.537** (0.692)	
Dummy=1 iff Quality ≥ 160			1627.3** (178.2)
Dummy=1 iff Site=Purdue	373.8 (450.3)	350.9 (339.5)	351.0 (344.4)
Ln(Period Number)	399.7** (95.0)	383.4** (88.0)	466.5** (94.9)
Adj. R^2 Observations	0.714 596	0.799 596	0.778 596

Notes: Standard errors in parentheses. All models estimated with a random effects error structure, with the subject as the random effect. ** denotes a coefficient that is significantly different from zero at 1-percent; * denotes a coefficient that is significantly different from zero at 5-percent; † denotes a coefficient that is significantly different from zero at 10-percent (all two-tailed tests). Due to the differing session lengths, to provide comparable data all estimates employ only the data up to and including period 5.

Table 6: Seller Offer Function Models (Final Round Offers)

	All Final Offers		Only Quality Levels ≥ 160	
	All Sessions (Model 1)	Drop collusive MU3 session (Model 2)	All Sessions (Model 3)	Drop collusive MU3 session (Model 4)
Intercept	673.6* (279.2)	467.5 (310.8)	450.9 (755.8)	-49.1 (825.6)
Dummy=1 iff Quality Revealed	333.3 (331.0)	492.9 (342.3)	1806.2* (910.7)	2159.0* (948.3)
Cost	0.998** (0.019)	0.983** (0.019)	0.932** (0.086)	0.928** (0.089)
Cost × Dummy=1 iff Quality Revealed	-0.042† (0.025)	-0.026 (0.024)	-0.104 (0.112)	-0.102 (0.115)
Dummy=1 iff Site=Purdue	135.7 (283.0)	349.0 (293.2)	716.9 (542.5)	1014.3† (556.9)
Ln(Period Number)	318.0** (68.4)	250.2** (65.4)	1450.3** (251.6)	1467.8** (265.3)
Adj. R^2	0.767	0.775	0.531	0.543
Observations	1058	994	204	190

Notes: Standard errors in parentheses. All models estimated with a random effects error structure, with the subject as the random effect. ** denotes a coefficient that is significantly different from zero at 1-percent; * denotes a coefficient that is significantly different from zero at 5-percent; † denotes a coefficient that is significantly different from zero at 10-percent (all two-tailed tests). Due to the differing session lengths, to provide comparable data all estimates employ only the data up to and including period 5.

Figure 1: Timeline for each Auction Period

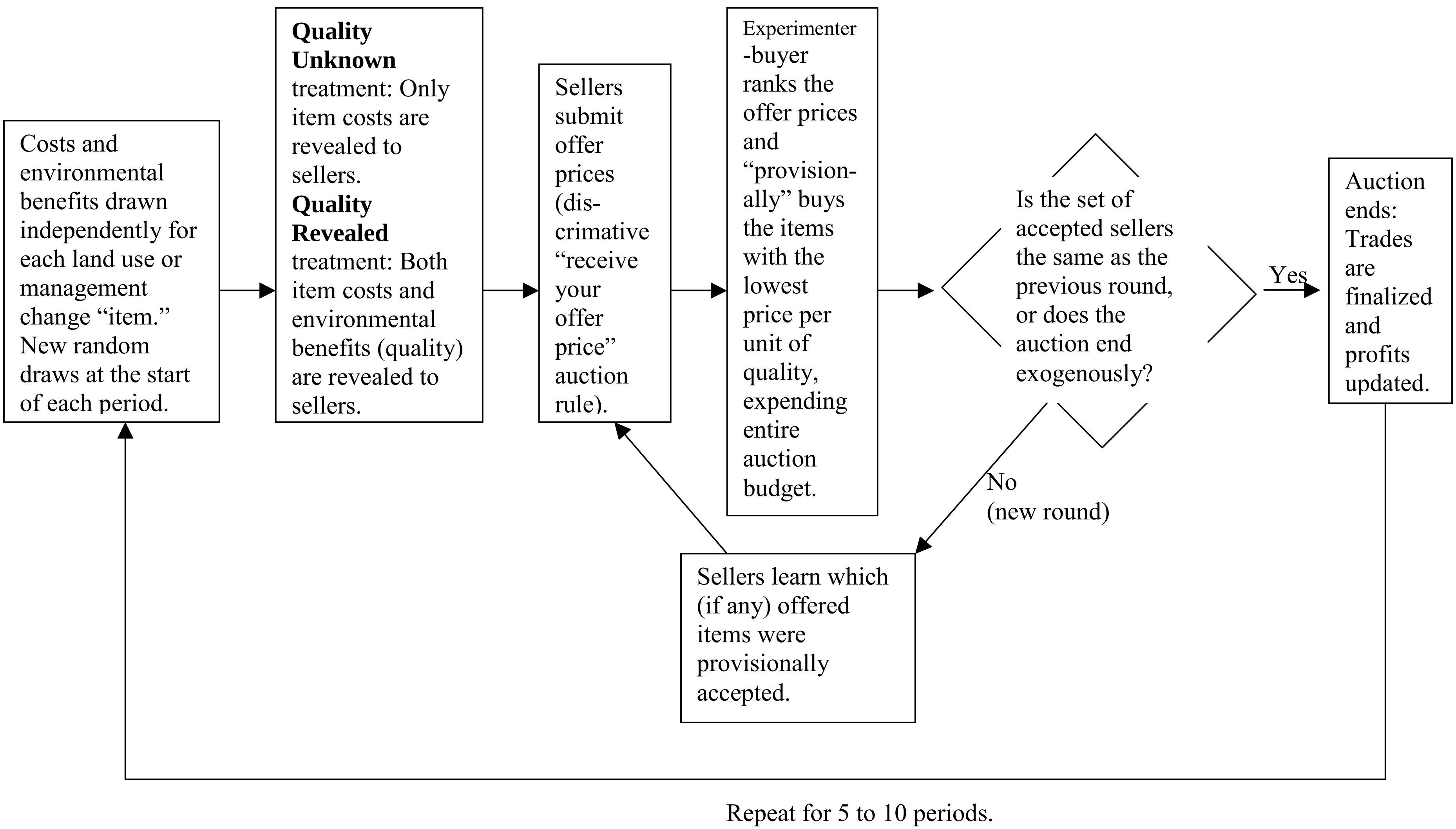
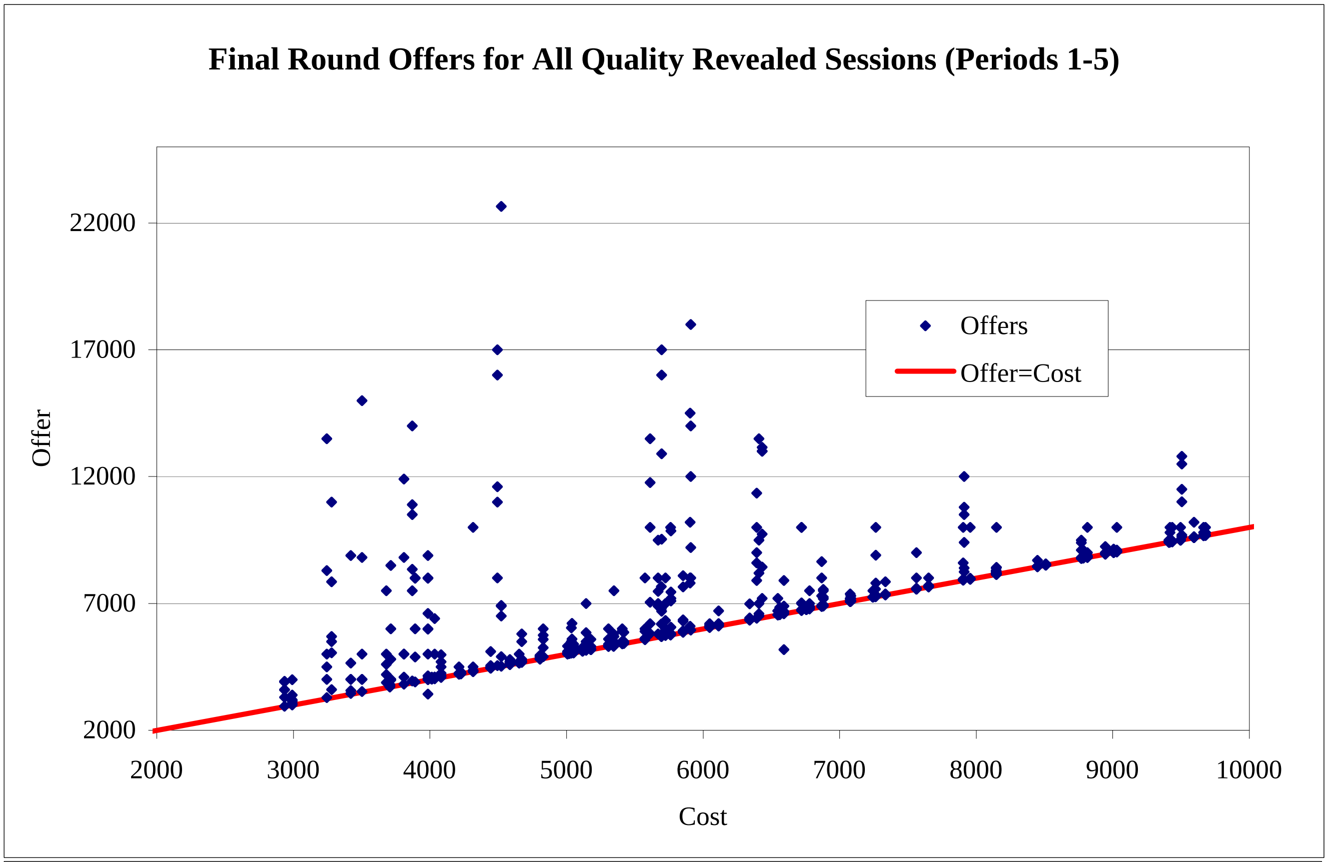


Figure 2:


Final Round Offers for All Quality Revealed Sessions (Periods 1-5)
Offers
Offer=Cost
Offer
22000
17000
12000
7000
2000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cost

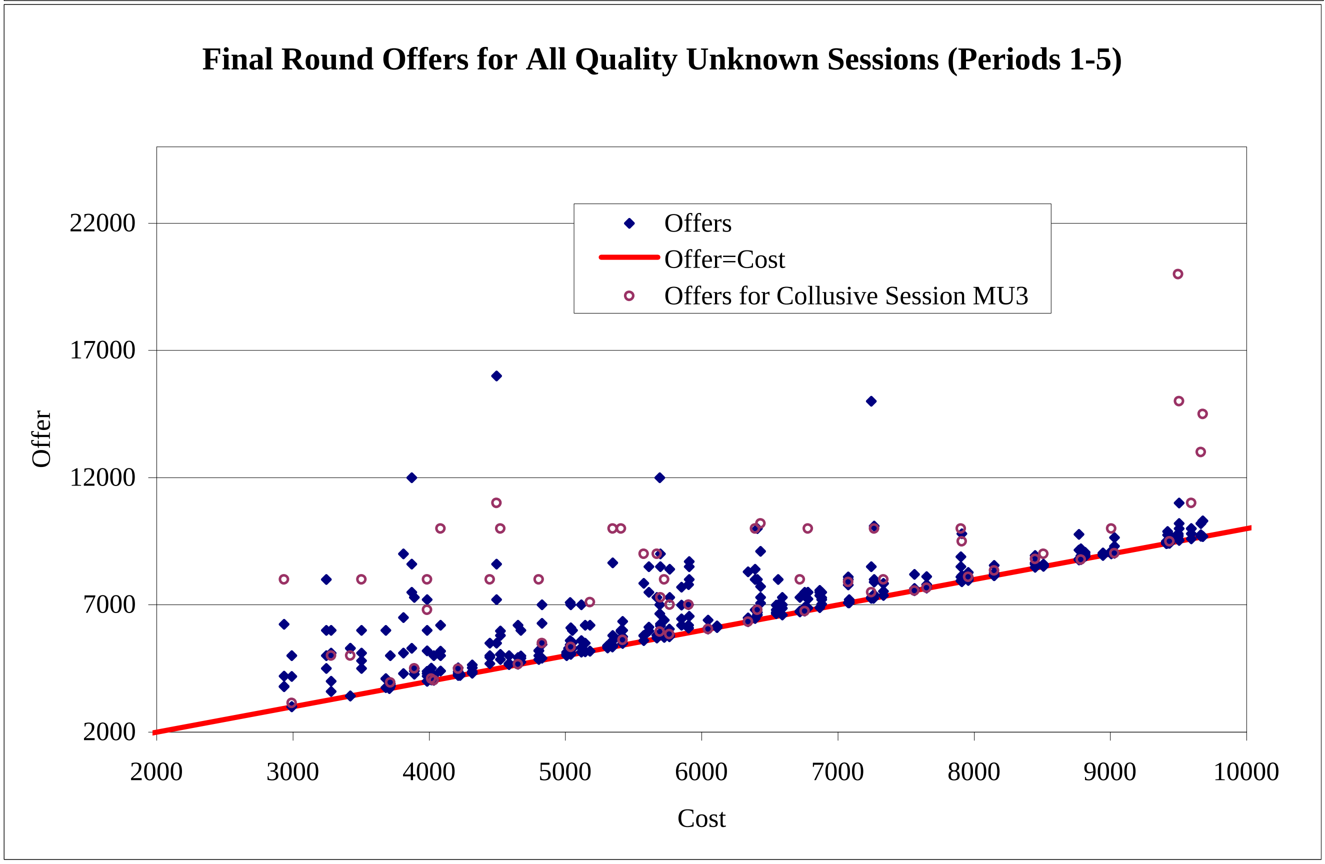
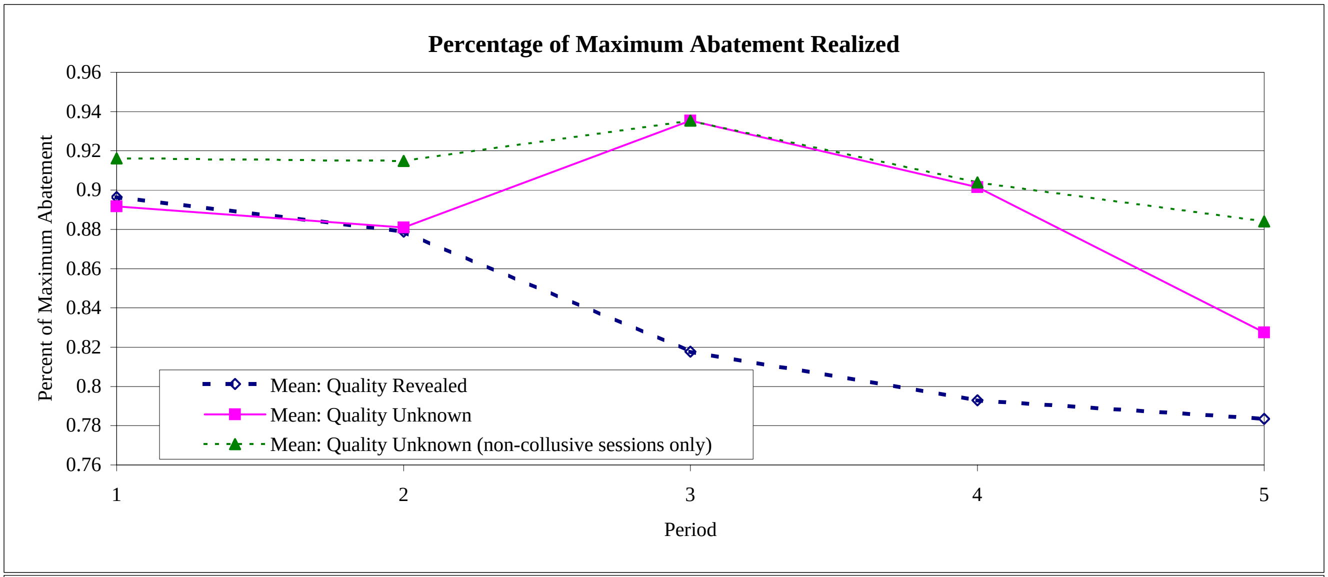
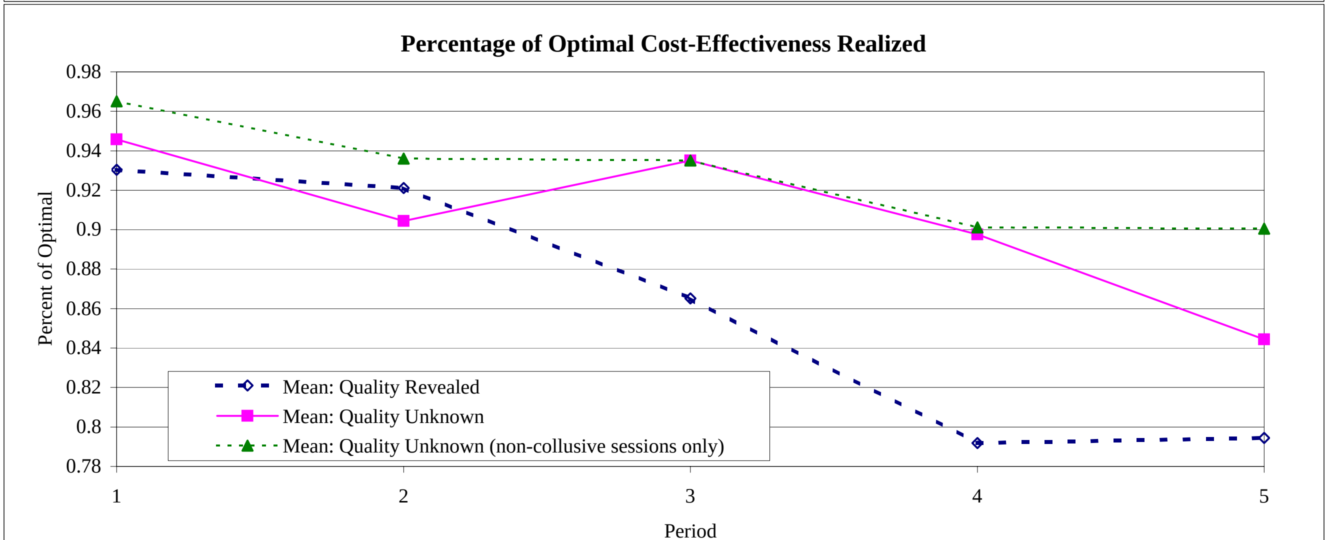

Final Round Offers for All Quality Unknown Sessions (Periods 1-5)
Offers
Offer=Cost
Offers for Collusive Session MU3
Offer
22000
17000
12000
7000
2000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cost

Figure 3:





Note: Cost-Effectiveness = Quantity of Abatement per Dollar Spent on Abatement

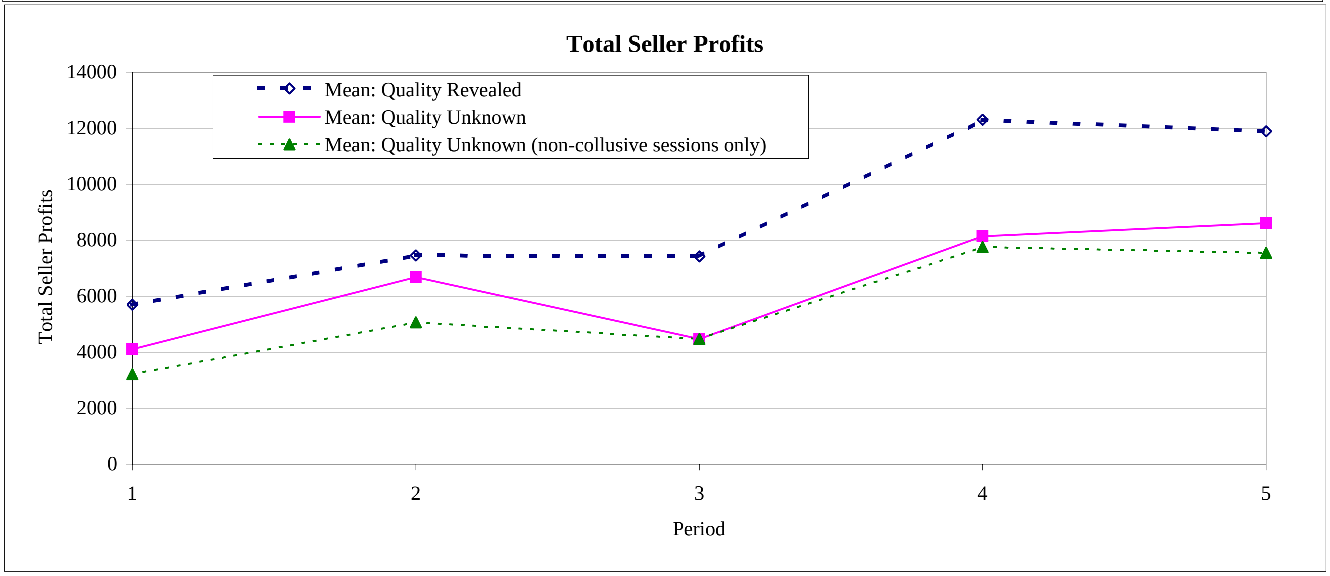
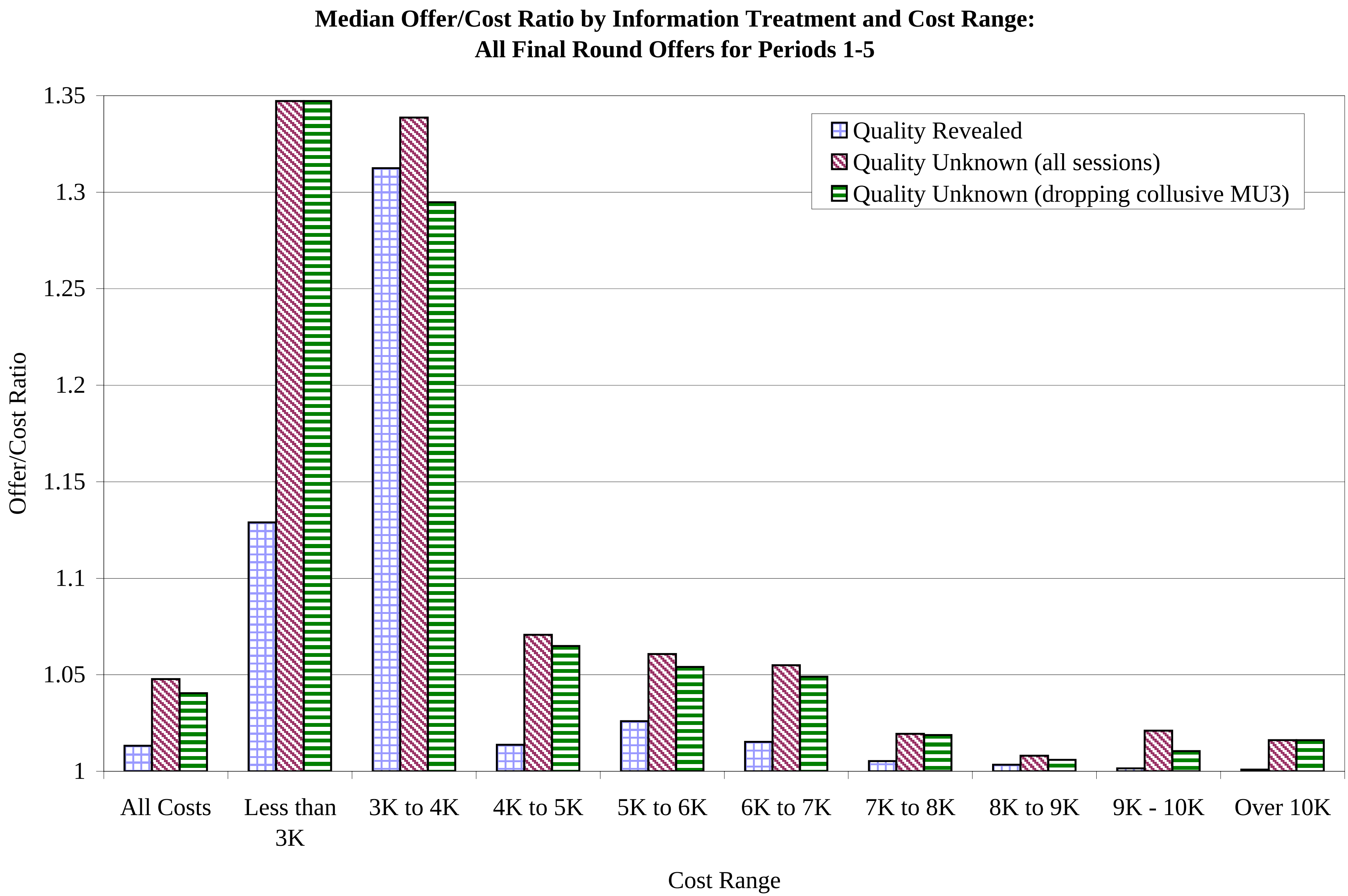


Figure 4:



Median Offer/Cost Ratio by Information Treatment and Cost Range:
All Final Round Offers for Periods 1-5
Quality Revealed
Quality Unknown (all sessions)
Quality Unknown (dropping collusive MU3)
Offer/Cost Ratio
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
All Costs
Less than 3K
3K to 4K
4K to 5K
5K to 6K
6K to 7K
7K to 8K
8K to 9K
9K - 10K
Over 10K
Cost Range

Figure 5:

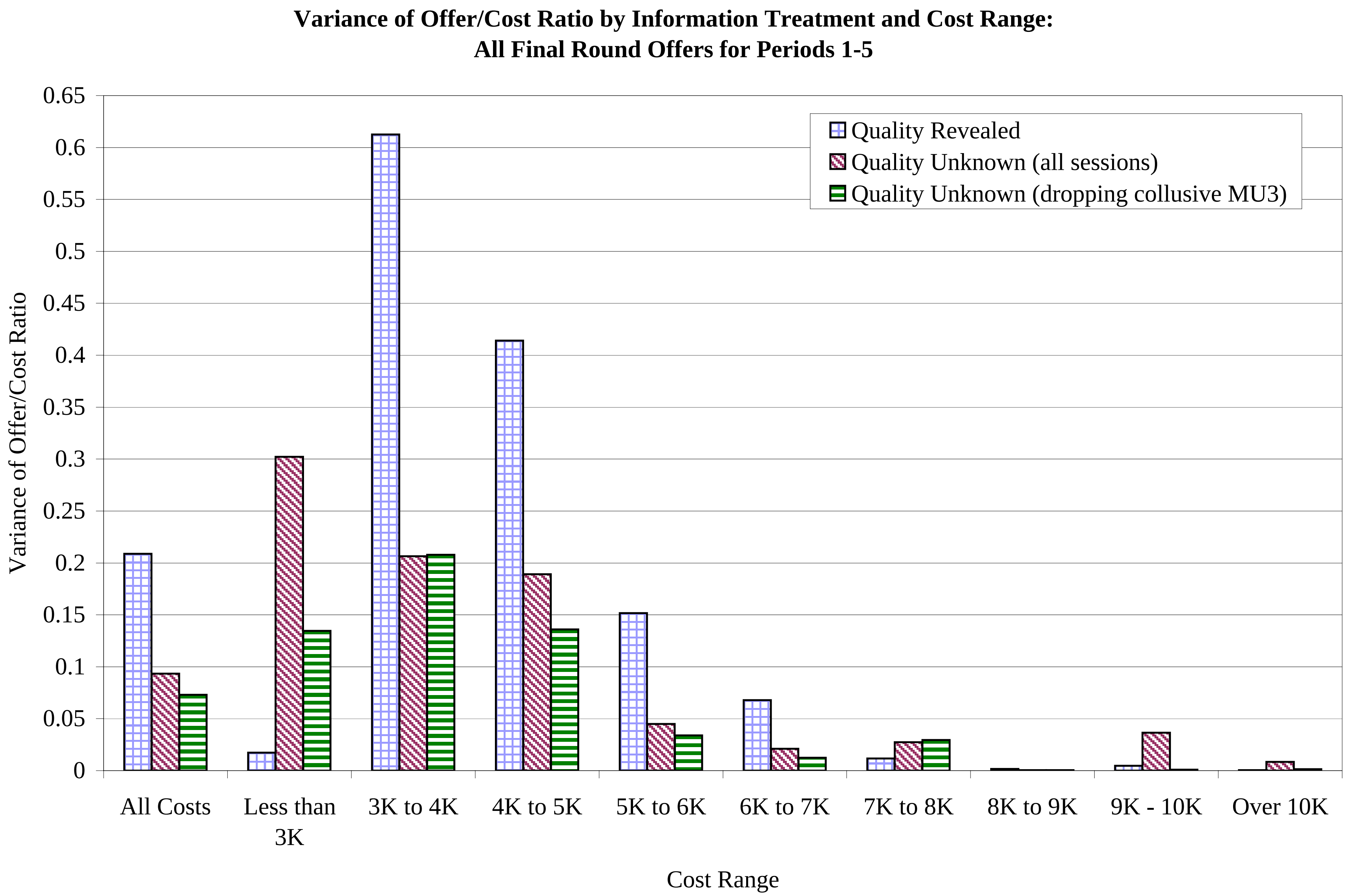
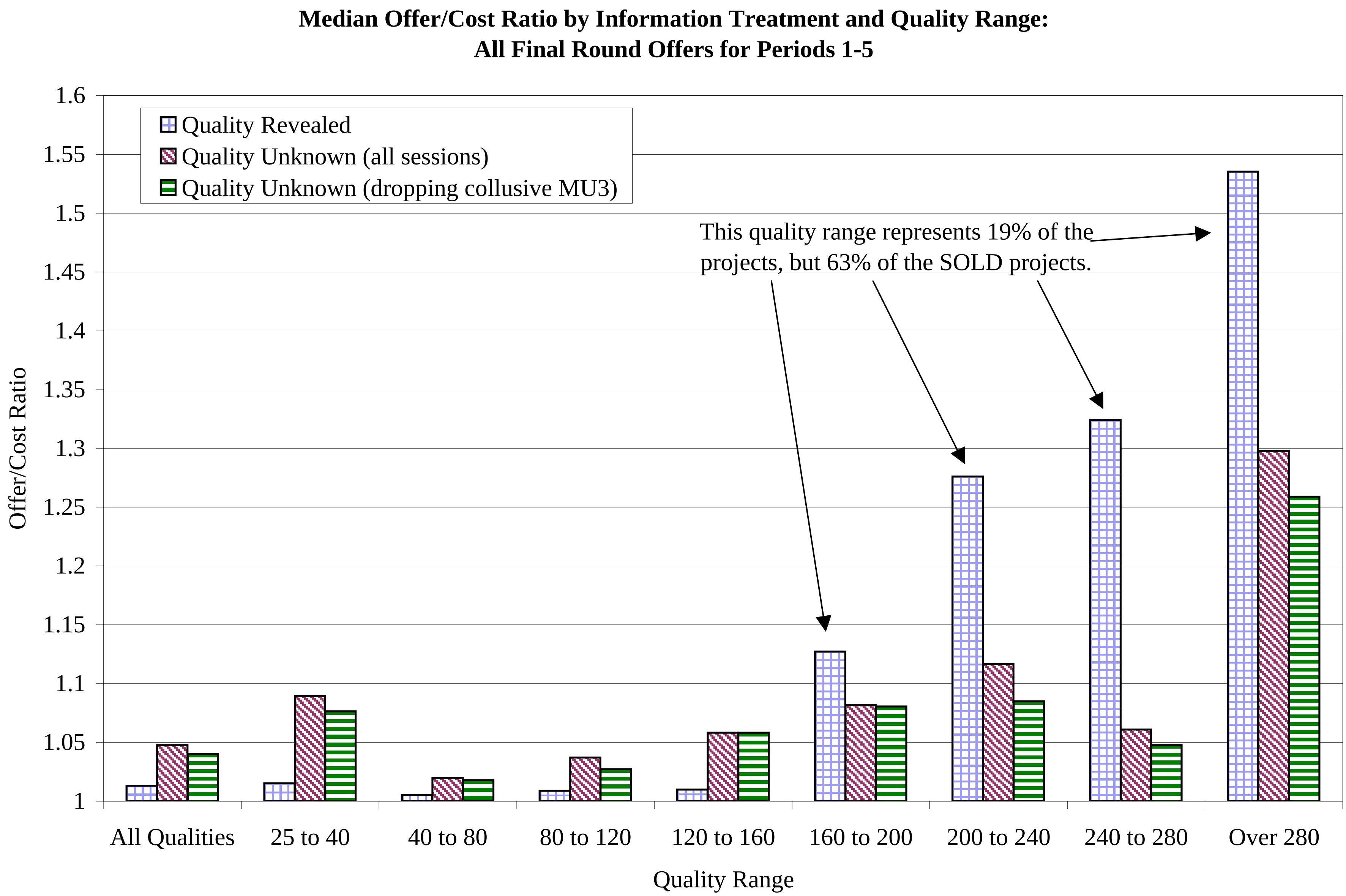
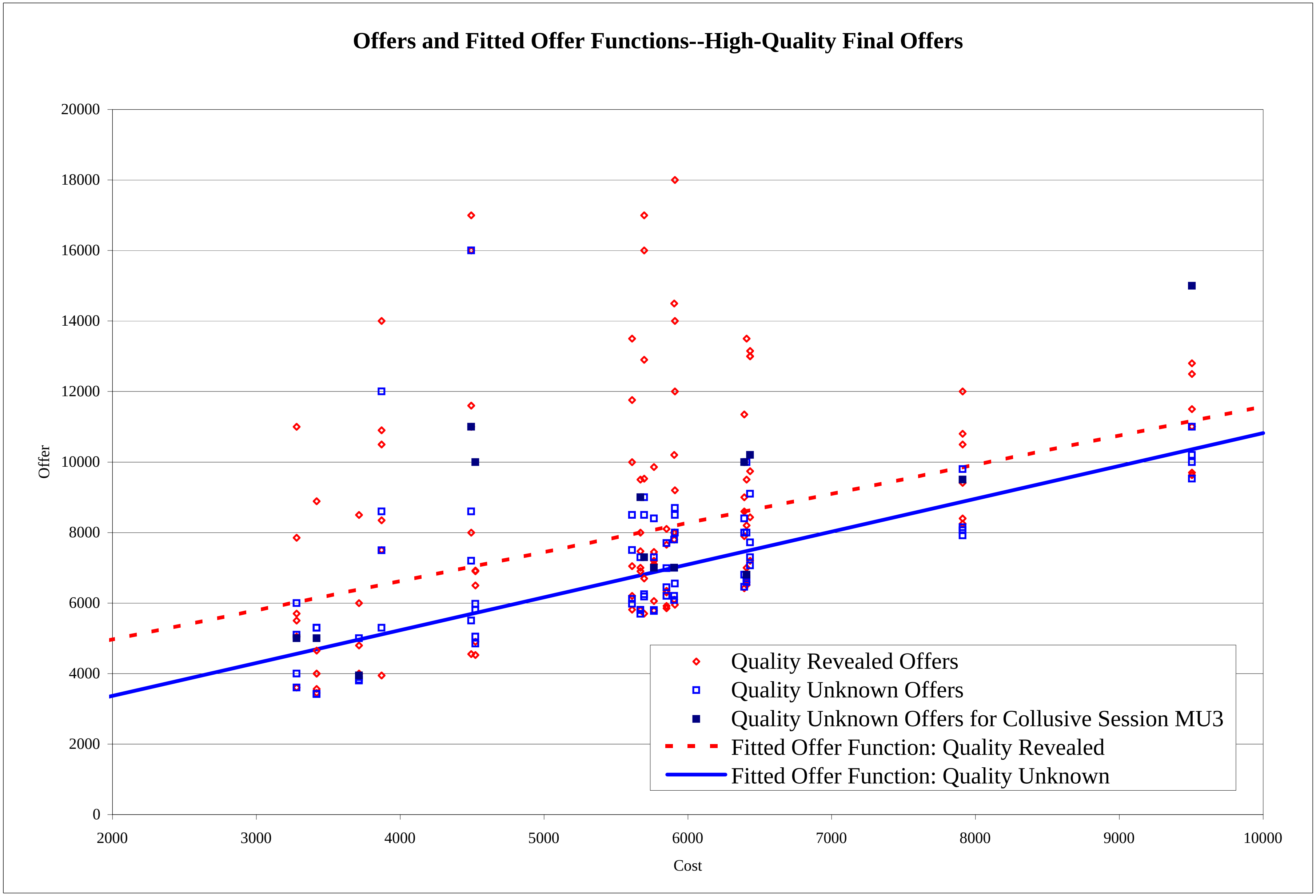

Variance of Offer/Cost Ratio by Information Treatment and Cost Range:
All Final Round Offers for Periods 1-5
Quality Revealed
Quality Unknown (all sessions)
Quality Unknown (dropping collusive MU3)
Variance of Offer/Cost Ratio
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
All Costs
Less than 3K
3K to 4K
4K to 5K
5K to 6K
6K to 7K
7K to 8K
8K to 9K
9K - 10K
Over 10K
Cost Range

Figure 6:



Median Offer/Cost Ratio by Information Treatment and Quality Range:
All Final Round Offers for Periods 1-5
Quality Revealed
Quality Unknown (all sessions)
Quality Unknown (dropping collusive MU3)
This quality range represents 19% of the projects, but 63% of the SOLD projects.
Offer/Cost Ratio
1.6
1.55
1.5
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
All Qualities
25 to 40
40 to 80
80 to 120
120 to 160
160 to 200
200 to 240
240 to 280
Over 280
Quality Range

Figure 7:



Offers and Fitted Offer Functions--High-Quality Final Offers
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Offer
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cost
Quality Revealed Offers
Quality Unknown Offers
Quality Unknown Offers for Collusive Session MU3
Fitted Offer Function: Quality Revealed
Fitted Offer Function: Quality Unknown

Appendix: Experiment Instructions

(Note: the 19 additional words that were shown only on the Quality Revealed treatment are shown in *italics*.)

General

This is an experiment in the economics of decision making. The instructions are simple and if you follow them carefully and make good decisions you will earn money that will be paid to you privately in cash. All earnings on your computer screens are in Experimental Dollars. These Experimental Dollars will be converted to real Dollars at the end of the experiment, at a rate of of ______ Experimental Dollars = 1 real Dollar. Your conversion rate may differ from others' rates. The important thing to remember is that the more experimental dollars you earn, the more real dollars that you take home at the end of the experiment. Everyone also receives an additional ___ real dollars that do not depend on the decisions made in the experiment.

We are going to conduct a set of auctions in which you will be a seller in a sequence of periods. Each period will have multiple offer rounds. On your computer you will find an Excel spreadsheet that will help you calculate your earnings based on the decisions you make. You are not to reveal this information to anyone. It is your own private information.

During each auction period you will sell up to one item. You have up to three types of items to sell, called Blue, Red and Yellow items. These items have different levels of "quality" that are valued differently by the experimenter, who is the buyer. *The quality units associated with each of your items are shown on your computerized record sheet.* Your quality levels may change from period to period, and they may be different from the quality levels of other participants. You can sell only one item per period, and if you sell that item then you must pay that item's cost. If you do not sell any item in a period then your earnings are zero. Notice that you do not pay an item's cost unless you sell that item. Your costs may also change from period to period, and they may be different from the costs of other participants.

Your costs for each of the three types of items are written on your computerized record sheet. The profits from the sales (which are yours to keep) are computed by taking the difference between the sale price of an item and the cost of that item. (How price is determined will be explained shortly.) That is,

[your earnings = (sale price of item) – (cost of item)].

Suppose, for example, that the cost for your Blue item is 110. If you sell your Blue item at a price of 160, your earnings are:

Earnings = 160 – 110 = 50

Notice that if you sell an item for a price that is less than its cost, then you lose money on that sale.

How Your Price is Determined

The price you receive if you sell an item and which (if any) item you sell is determined using a "sealed offer" auction. This auction will be conducted over a sequence of offer rounds. Only the final round will determine the actual sale prices and items sold. In each round you submit an "offer sheet" through your web browser, which lists the amount that you wish to receive for each item. [Do not use a dollar sign when entering your offers on your web browser.] You should also enter these offer prices on your Excel spreadsheet. If you sell an item, you will receive the offer price indicated on your offer sheet. In subsequent rounds, you will have the opportunity to choose different offer prices if you wish. [Those of you who have only two items should enter a very large amount like 99999 in the space for the third (yellow) offer price field, so that you would never sell this item (which you don't have to sell!).]

After everyone submits their offer sheets, the experimenter's computer then ranks the offers on the basis of the offer price and the quality of the items. The experimenter purchases the lowest priced items per unit of quality, spending all of the fixed and constant (and unknown to you) "budget" that is available in the auction. (In the case of a "tie," where two or more items are offered at the same per-quality-unit price but the experimenter cannot purchase them all, the computer randomly determines which unit or units are purchased.) Sometimes you may sell a higher-priced unit when that unit has a higher quality, and sometimes you may not sell any item. Remember, the experimenter will buy no more than one item from each seller.

After each auction round, the experimenter will tell you when to click the "load results" button to display the auction results. Your results page indicates which (if any) item you would sell, if this were the final round of the auction. Enter the color of the one item (if any) that is "provisionally accepted" in column F of your record sheet.

In all but the final offer round, sellers will submit new offer sheets for the next offer round. The final offer round will not be announced until after it is completed, and which round is final may vary from auction period to period. Remember, the experimenter purchases the lowest price items per unit of quality. In each offer round, this determines a set of sellers with "provisionally accepted" items. If this set of sellers with accepted items does not change from one round to the next round, then the auction will be declared final. The auction will also be declared final if a certain number of rounds have been conducted. This maximum number of rounds will not be announced, and it may vary from auction period to period. Once the auction is final, no more rounds will be conducted, and actual purchases and sales will be executed for that period. All auctions will have at least two rounds.

When the auction is final, all sale prices must be recorded in the trading activity section shown on your record sheet for each period. Be careful to enter in the price for the specific item that you sold (either Blue, Red or Yellow). Your record sheet will automatically calculate your profits for the period.

Between Auctions

After each auction period (but not between offer rounds), you are free to discuss all aspects of the market fully for up to two minutes. However, you may not show each other any information on your record sheets.

Summary

- Seller earnings on a sold item = sale price of item – cost of item
- Sellers have three types of items, which can have different costs and quality levels valued differently by the experimenter (who is the buyer). Your costs *and quality units* are shown on your computerized record sheet.
- Sellers submit offer prices for up to three types of items, but the experimenter will buy at most one item from each seller.
- The experimenter purchases the lowest price items per unit of quality, and spends a constant budget in every auction.
- The auction will take place over multiple auction rounds. The final round determines the actual sales and profits for that auction period.
- Sellers are free to discuss all aspects of the auction between periods.

Are there any questions now before we begin the experiment?